

eCos Reference Manual

eCos Reference Manual

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I. The eCos Kernel

Kernel Overview

Name

Kernel — Overview of the eCos Kernel

Description

The kernel is one of the key packages in all of eCos. It provides the core functionality needed for developing multi-threaded applications:

1. The ability to create new threads in the system, either during startup or when the system is already running.
2. Control over the various threads in the system, for example manipulating their priorities.
3. A choice of schedulers, determining which thread should currently be running.
4. A range of synchronization primitives, allowing threads to interact and share data safely.
5. Integration with the system's support for interrupts and exceptions.

In some other operating systems the kernel provides additional functionality. For example the kernel may also provide memory allocation functionality, and device drivers may be part of the kernel as well. This is not the case for eCos. Memory allocation is handled by a separate package. Similarly each device driver will typically be a separate package. Various packages are combined and configured using the eCos configuration technology to meet the requirements of the application.

The eCos kernel package is optional. It is possible to write single-threaded applications which do not use any kernel functionality, for example RedBoot. Typically such applications are based around a central polling loop, continually checking all devices and taking appropriate action when I/O occurs. A small amount of calculation is possible every iteration, at the cost of an increased delay between an I/O event occurring and the polling loop detecting the event. When the requirements are straightforward it may well be easier to develop the application using a polling loop, avoiding the complexities of multiple threads and synchronization between threads. As requirements get more complicated a multi-threaded solution becomes more appropriate, requiring the use of the kernel. In fact some of the more advanced packages in eCos, for example the TCP/IP stack, use multi-threading internally. Therefore if the application uses any of those packages then the kernel becomes a required package, not an optional one.

The kernel functionality can be used in one of two ways. The kernel provides its own C API, with functions like `cyg_thread_create` and `cyg_mutex_lock`. These can be called directly from application code or from other packages. Alternatively there are a number of packages which provide compatibility with existing API's, for example POSIX threads or μ ITRON. These allow application code to call standard functions such as `pthread_create`, and those functions are implemented using the basic functionality provided by the eCos kernel. Using compatibility packages in an eCos application can make it much easier to reuse code developed in other environments, and to share code.

Although the different compatibility packages have similar requirements on the underlying kernel, for example the ability to create a new thread, there are differences in the exact semantics. For example, strict μ ITRON compliance requires that kernel timeslicing is disabled. This is achieved largely through the configuration technology. The kernel provides a number of configuration options that control the exact semantics that are provided, and the various compatibility packages require particular settings for those options. This has two important consequences. First, it is not usually possible to have two different compatibility packages in one eCos configuration because they will have conflicting requirements on the underlying kernel. Second, the semantics of the kernel's own API are only loosely defined because of the many configuration options. For

example `cyg_mutex_lock` will always attempt to lock a mutex, but various configuration options determine the behaviour when the mutex is already locked and there is a possibility of priority inversion.

The optional nature of the kernel package presents some complications for other code, especially device drivers. Wherever possible a device driver should work whether or not the kernel is present. However there are some parts of the system, especially those related to interrupt handling, which should be implemented differently in multi-threaded environments containing the eCos kernel and in single-threaded environments without the kernel. To cope with both scenarios the common HAL package provides a driver API, with functions such as `cyg_drv_interrupt_attach`. When the kernel package is present these driver API functions map directly on to the equivalent kernel functions such as `cyg_interrupt_attach`, using macros to avoid any overheads. When the kernel is absent the common HAL package implements the driver API directly, but this implementation is simpler than the one in the kernel because it can assume a single-threaded environment.

Schedulers

When a system involves multiple threads, a scheduler is needed to determine which thread should currently be running. The eCos kernel can be configured with one of two schedulers, the bitmap scheduler and the multi-level queue (MLQ) scheduler. The bitmap scheduler is somewhat more efficient, but has a number of limitations. Most systems will instead use the MLQ scheduler. Other schedulers may be added in the future, either as extensions to the kernel package or in separate packages.

Both the bitmap and the MLQ scheduler use a simple numerical priority to determine which thread should be running. The number of priority levels is configurable via the option `CYGNUM_KERNEL_SCHED_PRIORITIES`, but a typical system will have up to 32 priority levels. Therefore thread priorities will be in the range 0 to 31, with 0 being the highest priority and 31 the lowest. Usually only the system's idle thread will run at the lowest priority. Thread priorities are absolute, so the kernel will only run a lower-priority thread if all higher-priority threads are currently blocked.

The bitmap scheduler only allows one thread per priority level, so if the system is configured with 32 priority levels then it is limited to only 32 threads — still enough for many applications. A simple bitmap can be used to keep track of which threads are currently runnable. Bitmaps can also be used to keep track of threads waiting on a mutex or other synchronization primitive. Identifying the highest-priority runnable or waiting thread involves a simple operation on the bitmap, and an array index operation can then be used to get hold of the thread data structure itself. This makes the bitmap scheduler fast and totally deterministic.

The MLQ scheduler allows multiple threads to run at the same priority. This means that there is no limit on the number of threads in the system, other than the amount of memory available. However operations such as finding the highest priority runnable thread are a little bit more expensive than for the bitmap scheduler.

Optionally the MLQ scheduler supports timeslicing, where the scheduler automatically switches from one runnable thread to another when some number of clock ticks have occurred. Timeslicing only comes into play when there are two runnable threads at the same priority and no higher priority runnable threads. If timeslicing is disabled then a thread will not be preempted by another thread of the same priority, and will continue running until either it explicitly yields the processor or until it blocks by, for example, waiting on a synchronization primitive. The configuration options `CYGSEM_KERNEL_SCHED_TIMESLICE` and `CYGNUM_KERNEL_SCHED_TIMESLICE_TICKS` control timeslicing. The bitmap scheduler does not provide timeslicing support. It only allows one thread per priority level, so it is not possible to preempt the current thread in favour of another one with the same priority.

Another important configuration option that affects the MLQ scheduler is `CYGIMP_KERNEL_SCHED_SORTED_QUEUES`. This determines what happens when a thread blocks, for example by waiting on a semaphore which has no pending events. The default behaviour of the system is last-in-first-out queuing. For example if several threads are waiting on a semaphore and an event is posted, the thread that gets woken up is the last one that called `cyg_semaphore_wait`. This allows for a simple and fast

implementation of both the queue and dequeue operations. However if there are several queued threads with different priorities, it may not be the highest priority one that gets woken up. In practice this is rarely a problem: usually there will be at most one thread waiting on a queue, or when there are several threads they will be of the same priority. However if the application does require strict priority queueing then the option `CYGIMP_KERNEL_SCHED_SORTED_QUEUES` should be enabled. There are disadvantages: more work is needed whenever a thread is queued, and the scheduler needs to be locked for this operation so the system's dispatch latency is worse. If the bitmap scheduler is used then priority queueing is automatic and does not involve any penalties.

Some kernel functionality is currently only supported with the MLQ scheduler, not the bitmap scheduler. This includes support for SMP systems, and protection against priority inversion using either mutex priority ceilings or priority inheritance.

Synchronization Primitives

The eCos kernel provides a number of different synchronization primitives: [mutexes](#), [condition variables](#), [counting semaphores](#), [mail boxes](#) and [event flags](#).

Mutexes serve a very different purpose from the other primitives. A mutex allows multiple threads to share a resource safely: a thread locks a mutex, manipulates the shared resource, and then unlocks the mutex again. The other primitives are used to communicate information between threads, or alternatively from a DSR associated with an interrupt handler to a thread.

When a thread that has locked a mutex needs to wait for some condition to become true, it should use a condition variable. A condition variable is essentially just a place for a thread to wait, and which another thread, or DSR, can use to wake it up. When a thread waits on a condition variable it releases the mutex before waiting, and when it wakes up it reacquires it before proceeding. These operations are atomic so that synchronization race conditions cannot be introduced.

A counting semaphore is used to indicate that a particular event has occurred. A consumer thread can wait for this event to occur, and a producer thread or a DSR can post the event. There is a count associated with the semaphore so if the event occurs multiple times in quick succession this information is not lost, and the appropriate number of semaphore wait operations will succeed.

Mail boxes are also used to indicate that a particular event has occurred, and allows for one item of data to be exchanged per event. Typically this item of data would be a pointer to some data structure. Because of the need to store this extra data, mail boxes have a finite capacity. If a producer thread generates mail box events faster than they can be consumed then, to avoid overflow, it will be blocked until space is again available in the mail box. This means that mail boxes usually cannot be used by a DSR to wake up a thread. Instead mail boxes are typically only used between threads.

Event flags can be used to wait on some number of different events, and to signal that one or several of these events have occurred. This is achieved by associating bits in a bit mask with the different events. Unlike a counting semaphore no attempt is made to keep track of the number of events that have occurred, only the fact that an event has occurred at least once. Unlike a mail box it is not possible to send additional data with the event, but this does mean that there is no possibility of an overflow and hence event flags can be used between a DSR and a thread as well as between threads.

The eCos common HAL package provides its own device driver API which contains some of the above synchronization primitives. These allow the DSR for an interrupt handler to signal events to higher-level code. If the configuration includes the eCos kernel package then the driver API routines map directly on to the equivalent kernel routines, allowing interrupt handlers to interact with threads. If the kernel package is not included and the application consists of just a single thread running in polled mode then the driver API is implemented entirely within the common HAL, and with no need to worry about multiple threads the implementation can obviously be rather simpler.

Threads and Interrupt Handling

During normal operation the processor will be running one of the threads in the system. This may be an application thread, a system thread running inside say the TCP/IP stack, or the idle thread. From time to time a hardware interrupt will occur, causing control to be transferred briefly to an interrupt handler. When the interrupt has been completed the system's scheduler will decide whether to return control to the interrupted thread or to some other runnable thread.

Threads and interrupt handlers must be able to interact. If a thread is waiting for some I/O operation to complete, the interrupt handler associated with that I/O must be able to inform the thread that the operation has completed. This can be achieved in a number of ways. One very simple approach is for the interrupt handler to set a volatile variable. A thread can then poll continuously until this flag is set, possibly sleeping for a clock tick in between. Polling continuously means that the cpu time is not available for other activities, which may be acceptable for some but not all applications. Polling once every clock tick imposes much less overhead, but means that the thread may not detect that the I/O event has occurred until an entire clock tick has elapsed. In typical systems this could be as long as 10 milliseconds. Such a delay might be acceptable for some applications, but not all.

A better solution would be to use one of the synchronization primitives. The interrupt handler could signal a condition variable, post to a semaphore, or use one of the other primitives. The thread would perform a wait operation on the same primitive. It would not consume any cpu cycles until the I/O event had occurred, and when the event does occur the thread can start running again immediately (subject to any higher priority threads that might also be runnable).

Synchronization primitives constitute shared data, so care must be taken to avoid problems with concurrent access. If the thread that was interrupted was just performing some calculations then the interrupt handler could manipulate the synchronization primitive quite safely. However if the interrupted thread happened to be inside some kernel call then there is a real possibility that some kernel data structure will be corrupted.

One way of avoiding such problems would be for the kernel functions to disable interrupts when executing any critical region. On most architectures this would be simple to implement and very fast, but it would mean that interrupts would be disabled often and for quite a long time. For some applications that might not matter, but many embedded applications require that the interrupt handler run as soon as possible after the hardware interrupt has occurred. If the kernel relied on disabling interrupts then it would not be able to support such applications.

Instead the kernel uses a two-level approach to interrupt handling. Associated with every interrupt vector is an Interrupt Service Routine or ISR, which will run as quickly as possible so that it can service the hardware. However an ISR can make only a small number of kernel calls, mostly related to the interrupt subsystem, and it cannot make any call that would cause a thread to wake up. If an ISR detects that an I/O operation has completed and hence that a thread should be woken up, it can cause the associated Deferred Service Routine or DSR to run. A DSR is allowed to make more kernel calls, for example it can signal a condition variable or post to a semaphore.

Disabling interrupts prevents ISRs from running, but very few parts of the system disable interrupts and then only for short periods of time. The main reason for a thread to disable interrupts is to manipulate some state that is shared with an ISR. For example if a thread needs to add another buffer to a linked list of free buffers and the ISR may remove a buffer from this list at any time, the thread would need to disable interrupts for the few instructions needed to manipulate the list. If the hardware raises an interrupt at this time, it remains pending until interrupts are reenabled.

Analogous to interrupts being disabled or enabled, the kernel has a scheduler lock. The various kernel functions such as `cyg_mutex_lock` and `cyg_semaphore_post` will claim the scheduler lock, manipulate the kernel data structures, and then release the scheduler lock. If an interrupt results in a DSR being requested and the scheduler is currently locked, the DSR remains pending. When the scheduler lock is released any pending DSRs will run. These may post events to synchronization primitives, causing other higher priority threads to be woken up.

For an example, consider the following scenario. The system has a high priority thread A, responsible for processing some data coming from an external device. This device will raise an interrupt when data is available. There are two other threads B and C which spend their time performing calculations and occasionally writing results to a display of some sort. This display is a shared resource so a mutex is used to control access.

At a particular moment in time thread A is likely to be blocked, waiting on a semaphore or another synchronization primitive until data is available. Thread B might be running performing some calculations, and thread C is runnable waiting for its next timeslice. Interrupts are enabled, and the scheduler is unlocked because none of the threads are in the middle of a kernel operation. At this point the device raises an interrupt. The hardware transfers control to a low-level interrupt handler provided by eCos which works out exactly which interrupt occurs, and then the corresponding ISR is run. This ISR manipulates the hardware as appropriate, determines that there is now data available, and wants to wake up thread A by posting to the semaphore. However ISR's are not allowed to call `cyg_semaphore_post` directly, so instead the ISR requests that its associated DSR be run and returns. There are no more interrupts to be processed, so the kernel next checks for DSR's. One DSR is pending and the scheduler is currently unlocked, so the DSR can run immediately and post the semaphore. This will have the effect of making thread A runnable again, so the scheduler's data structures are adjusted accordingly. When the DSR returns thread B is no longer the highest priority runnable thread so it will be suspended, and instead thread A gains control over the cpu.

In the above example no kernel data structures were being manipulated at the exact moment that the interrupt happened. However that cannot be assumed. Suppose that thread B had finished its current set of calculations and wanted to write the results to the display. It would claim the appropriate mutex and manipulate the display. Now suppose that thread B was timesliced in favour of thread C, and that thread C also finished its calculations and wanted to write the results to the display. It would call `cyg_mutex_lock`. This kernel call locks the scheduler, examines the current state of the mutex, discovers that the mutex is already owned by another thread, suspends the current thread, and switches control to another runnable thread. Another interrupt happens in the middle of this `cyg_mutex_lock` call, causing the ISR to run immediately. The ISR decides that thread A should be woken up so it requests that its DSR be run and returns back to the kernel. At this point there is a pending DSR, but the scheduler is still locked by the call to `cyg_mutex_lock` so the DSR cannot run immediately. Instead the call to `cyg_mutex_lock` is allowed to continue, which at some point involves unlocking the scheduler. The pending DSR can now run, safely post the semaphore, and thus wake up thread A.

If the ISR had called `cyg_semaphore_post` directly rather than leaving it to a DSR, it is likely that there would have been some sort of corruption of a kernel data structure. For example the kernel might have completely lost track of one of the threads, and that thread would never have run again. The two-level approach to interrupt handling, ISR's and DSR's, prevents such problems with no need to disable interrupts.

Calling Contexts

eCos defines a number of contexts. Only certain calls are allowed from inside each context, for example most operations on threads or synchronization primitives are not allowed from ISR context. The different contexts are initialization, thread, ISR and DSR.

When eCos starts up it goes through a number of phases, including setting up the hardware and invoking C++ static constructors. During this time interrupts are disabled and the scheduler is locked. When a configuration includes the kernel package the final operation is a call to `cyg_scheduler_start`. At this point interrupts are enabled, the scheduler is unlocked, and control is transferred to the highest priority runnable thread. If the configuration also includes the C library package then usually the C library startup package will have created a thread which will call the application's `main` entry point.

Some application code can also run before the scheduler is started, and this code runs in initialization context. If the application is written partly or completely in C++ then the constructors for any static objects will be run. Alternatively application code can define a function `cyg_user_start` which gets called after any C++ static constructors. This allows applications to be written entirely in C.

```

void
cyg_user_start(void)
{
    /* Perform application-specific initialization here */
}

```

It is not necessary for applications to provide a `cyg_user_start` function since the system will provide a default implementation which does nothing.

Typical operations that are performed from inside static constructors or `cyg_user_start` include creating threads, synchronization primitives, setting up alarms, and registering application-specific interrupt handlers. In fact for many applications all such creation operations happen at this time, using statically allocated data, avoiding any need for dynamic memory allocation or other overheads.

Code running in initialization context runs with interrupts disabled and the scheduler locked. It is not permitted to reenables interrupts or unlock the scheduler because the system is not guaranteed to be in a totally consistent state at this point. A consequence is that initialization code cannot use synchronization primitives such as `cyg_semaphore_wait` to wait for an external event. It is permitted to lock and unlock a mutex: there are no other threads running so it is guaranteed that the mutex is not yet locked, and therefore the lock operation will never block; this is useful when making library calls that may use a mutex internally.

At the end of the startup sequence the system will call `cyg_scheduler_start` and the various threads will start running. In thread context nearly all of the kernel functions are available. There may be some restrictions on interrupt-related operations, depending on the target hardware. For example the hardware may require that interrupts be acknowledged in the ISR or DSR before control returns to thread context, in which case `cyg_interrupt_acknowledge` should not be called by a thread.

At any time the processor may receive an external interrupt, causing control to be transferred from the current thread. Typically a VSR provided by eCos will run and determine exactly which interrupt occurred. Then the VSR will switch to the appropriate ISR, which can be provided by a HAL package, a device driver, or by the application. During this time the system is running at ISR context, and most of the kernel function calls are disallowed. This includes the various synchronization primitives, so for example an ISR is not allowed to post to a semaphore to indicate that an event has happened. Usually the only operations that should be performed from inside an ISR are ones related to the interrupt subsystem itself, for example masking an interrupt or acknowledging that an interrupt has been processed. On SMP systems it is also possible to use spinlocks from ISR context.

When an ISR returns it can request that the corresponding DSR be run as soon as it is safe to do so, and that will run in DSR context. This context is also used for running alarm functions, and threads can switch temporarily to DSR context by locking the scheduler. Only certain kernel functions can be called from DSR context, although more than in ISR context. In particular it is possible to use any synchronization primitives which cannot block. These include `cyg_semaphore_post`, `cyg_cond_signal`, `cyg_cond_broadcast`, `cyg_flag_setbits`, and `cyg_mbox_tryput`. It is not possible to use any primitives that may block such as `cyg_semaphore_wait`, `cyg_mutex_lock`, or `cyg_mbox_put`. Calling such functions from inside a DSR may cause the system to hang. The specific documentation for the various kernel functions gives more details about valid contexts.

Error Handling and Assertions

In many APIs each function is expected to perform some validation of its parameters and possibly of the current state of the system. This is supposed to ensure that each function is used correctly, and that application code is not attempting to perform a semaphore operation on a mutex or anything like that. If an error is detected then a suitable error code is returned, for example the POSIX function `pthread_mutex_lock` can return various

error codes including `EINVAL` and `EDEADLK`. There are a number of problems with this approach, especially in the context of deeply embedded systems:

1. Performing these checks inside the mutex lock and all the other functions requires extra cpu cycles and adds significantly to the code size. Even if the application is written correctly and only makes system function calls with sensible arguments and under the right conditions, these overheads still exist.
2. Returning an error code is only useful if the calling code detects these error codes and takes appropriate action. In practice the calling code will often ignore any errors because the programmer “*knows*” that the function is being used correctly. If the programmer is mistaken then an error condition may be detected and reported, but the application continues running anyway and is likely to fail some time later in mysterious ways.
3. If the calling code does always check for error codes, that adds yet more cpu cycles and code size overhead.
4. Usually there will be no way to recover from certain errors, so if the application code detected an error such as `EINVAL` then all it could do is abort the application somehow.

The approach taken within the eCos kernel is different. Functions such as `cyg_mutex_lock` will not return an error code. Instead they contain various assertions, which can be enabled or disabled. During the development process assertions are normally left enabled, and the various kernel functions will perform parameter checks and other system consistency checks. If a problem is detected then an assertion failure will be reported and the application will be terminated. In a typical debug session a suitable breakpoint will have been installed and the developer can now examine the state of the system and work out exactly what is going on. Towards the end of the development cycle assertions will be disabled by manipulating configuration options within the eCos infrastructure package, and all assertions will be eliminated at compile-time. The assumption is that by this time the application code has been mostly debugged: the initial version of the code might have tried to perform a semaphore operation on a mutex, but any problems like that will have been fixed some time ago. This approach has a number of advantages:

1. In the final application there will be no overheads for checking parameters and other conditions. All that code will have been eliminated at compile-time.
2. Because the final application will not suffer any overheads, it is reasonable for the system to do more work during the development process. In particular the various assertions can test for more error conditions and more complicated errors. When an error is detected it is possible to give a text message describing the error rather than just return an error code.
3. There is no need for application programmers to handle error codes returned by various kernel function calls. This simplifies the application code.
4. If an error is detected then an assertion failure will be reported immediately and the application will be halted. There is no possibility of an error condition being ignored because application code did not check for an error code.

Although none of the kernel functions return an error code, many of them do return a status condition. For example the function `cyg_semaphore_timed_wait` waits until either an event has been posted to a semaphore, or until a certain number of clock ticks have occurred. Usually the calling code will need to know whether the wait operation succeeded or whether a timeout occurred. `cyg_semaphore_timed_wait` returns a boolean: a return value of zero or false indicates a timeout, a non-zero return value indicates that the wait succeeded.

In conventional APIs one common error conditions is lack of memory. For example the POSIX function `pthread_create` usually has to allocate some memory dynamically for the thread stack and other per-thread data. If the target hardware does not have enough memory to meet all demands, or more commonly if the application contains a memory leak, then there may not be enough memory available and the function call would fail. The eCos kernel avoids such problems by never performing any dynamic memory allocation. Instead it is the responsibility of the application code to provide all the memory required for kernel data structures and

other needs. In the case of `cyg_thread_create` this means a `cyg_thread` data structure to hold the thread details, and a char array for the thread stack.

In many applications this approach results in all data structures being allocated statically rather than dynamically. This has several advantages. If the application is in fact too large for the target hardware's memory then there will be an error at link-time rather than at run-time, making the problem much easier to diagnose. Static allocation does not involve any of the usual overheads associated with dynamic allocation, for example there is no need to keep track of the various free blocks in the system, and it may be possible to eliminate `malloc` from the system completely. Problems such as fragmentation and memory leaks cannot occur if all data is allocated statically. However, some applications are sufficiently complicated that dynamic memory allocation is required, and the various kernel functions do not distinguish between statically and dynamically allocated memory. It still remains the responsibility of the calling code to ensure that sufficient memory is available, and passing null pointers to the kernel will result in assertions or system failure.

SMP Support

Name

SMP — Support Symmetric Multiprocessing Systems

Description

eCos contains support for limited Symmetric Multi-Processing (SMP). This is only available on selected architectures and platforms. The implementation has a number of restrictions on the kind of hardware supported. These are described in [the Section called *SMP Support* in Chapter 4](#).

The following sections describe the changes that have been made to the eCos kernel to support SMP operation.

System Startup

The system startup sequence needs to be somewhat different on an SMP system, although this is largely transparent to application code. The main startup takes place on only one CPU, called the primary CPU. All other CPUs, the secondary CPUs, are either placed in suspended state at reset, or are captured by the HAL and put into a spin as they start up. The primary CPU is responsible for copying the DATA segment and zeroing the BSS (if required), calling HAL variant and platform initialization routines and invoking constructors. It then calls `cyg_start` to enter the application. The application may then create extra threads and other objects.

It is only when the application calls `cyg_scheduler_start` that the secondary CPUs are initialized. This routine scans the list of available secondary CPUs and invokes `HAL_SMP_CPU_START` to start each CPU. Finally it calls an internal function `Cyg_Scheduler::start_cpu` to enter the scheduler for the primary CPU.

Each secondary CPU starts in the HAL, where it completes any per-CPU initialization before calling into the kernel at `cyg_kernel_cpu_startup`. Here it claims the scheduler lock and calls `Cyg_Scheduler::start_cpu`.

`Cyg_Scheduler::start_cpu` is common to both the primary and secondary CPUs. The first thing this code does is to install an interrupt object for this CPU's inter-CPU interrupt. From this point on the code is the same as for the single CPU case: an initial thread is chosen and entered.

From this point on the CPUs are all equal, eCos makes no further distinction between the primary and secondary CPUs. However, the hardware may still distinguish between them as far as interrupt delivery is concerned.

Scheduling

To function correctly an operating system kernel must protect its vital data structures, such as the run queues, from concurrent access. In a single CPU system the only concurrent activities to worry about are asynchronous interrupts. The kernel can easily guard its data structures against these by disabling interrupts. However, in a multi-CPU system, this is inadequate since it does not block access by other CPUs.

The eCos kernel protects its vital data structures using the scheduler lock. In single CPU systems this is a simple counter that is atomically incremented to acquire the lock and decremented to release it. If the lock is decremented to zero then the scheduler may be invoked to choose a different thread to run. Because interrupts may continue to be serviced while the scheduler lock is claimed, ISRs are not allowed to access kernel data structures, or call kernel routines that can. Instead all such operations are deferred to an associated DSR routine that is run during the lock release operation, when the data structures are in a consistent state.

By choosing a kernel locking mechanism that does not rely on interrupt manipulation to protect data structures, it is easier to convert eCos to SMP than would otherwise be the case. The principal change needed to make eCos SMP-safe is to convert the scheduler lock into a nestable spin lock. This is done by adding a spinlock and a CPU id to the original counter.

The algorithm for acquiring the scheduler lock is very simple. If the scheduler lock's CPU id matches the current CPU then it can just increment the counter and continue. If it does not match, the CPU must spin on the spinlock, after which it may increment the counter and store its own identity in the CPU id.

To release the lock, the counter is decremented. If it goes to zero the CPU id value must be set to NONE and the spinlock cleared.

To protect these sequences against interrupts, they must be performed with interrupts disabled. However, since these are very short code sequences, they will not have an adverse effect on the interrupt latency.

Beyond converting the scheduler lock, further preparing the kernel for SMP is a relatively minor matter. The main changes are to convert various scalar housekeeping variables into arrays indexed by CPU id. These include the current thread pointer, the need_reschedule flag and the timeslice counter.

At present only the Multi-Level Queue (MLQ) scheduler is capable of supporting SMP configurations. The main change made to this scheduler is to cope with having several threads in execution at the same time. Running threads are marked with the CPU that they are executing on. When scheduling a thread, the scheduler skips past any running threads until it finds a thread that is pending. While not a constant-time algorithm, as in the single CPU case, this is still deterministic, since the worst case time is bounded by the number of CPUs in the system.

A second change to the scheduler is in the code used to decide when the scheduler should be called to choose a new thread. The scheduler attempts to keep the *n* CPUs running the *n* highest priority threads. Since an event or interrupt on one CPU may require a reschedule on another CPU, there must be a mechanism for deciding this. The algorithm currently implemented is very simple. Given a thread that has just been awakened (or had its priority changed), the scheduler scans the CPUs, starting with the one it is currently running on, for a current thread that is of lower priority than the new one. If one is found then a reschedule interrupt is sent to that CPU and the scan continues, but now using the current thread of the rescheduled CPU as the candidate thread. In this way the new thread gets to run as quickly as possible, hopefully on the current CPU, and the remaining CPUs will pick up the remaining highest priority threads as a consequence of processing the reschedule interrupt.

The final change to the scheduler is in the handling of timeslicing. Only one CPU receives timer interrupts, although all CPUs must handle timeslicing. To make this work, the CPU that receives the timer interrupt decrements the timeslice counter for all CPUs, not just its own. If the counter for a CPU reaches zero, then it sends a timeslice interrupt to that CPU. On receiving the interrupt the destination CPU enters the scheduler and looks for another thread at the same priority to run. This is somewhat more efficient than distributing clock ticks to all CPUs, since the interrupt is only needed when a timeslice occurs.

All existing synchronization mechanisms work as before in an SMP system. Additional synchronization mechanisms have been added to provide explicit synchronization for SMP, in the form of [spinlocks](#).

SMP Interrupt Handling

The main area where the SMP nature of a system requires special attention is in device drivers and especially interrupt handling. It is quite possible for the ISR, DSR and thread components of a device driver to execute on different CPUs. For this reason it is much more important that SMP-capable device drivers use the interrupt-related functions correctly. Typically a device driver would use the driver API rather than call the kernel directly, but it is unlikely that anybody would attempt to use a multiprocessor system without the kernel package.

Two new functions have been added to the Kernel API to do [interrupt routing](#): `cyg_interrupt_set_cpu` and `cyg_interrupt_get_cpu`. Although not currently supported, special values for the `cpu` argument may be used in future to indicate that the interrupt is being routed dynamically or is CPU-local. Once a vector has been routed to a new CPU, all other interrupt masking and configuration operations are relative to that CPU, where relevant.

There are more details of how interrupts should be handled in SMP systems in [the Section called *SMP Support* in Chapter 13](#).

Thread creation

Name

`cyg_thread_create` — Create a new thread

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_thread_create(cyg_addrword_t sched_info, cyg_thread_entry_t* entry,
cyg_addrword_t entry_data, char* name, void* stack_base, cyg_ucount32 stack_size,
cyg_handle_t* handle, cyg_thread* thread);
```

Description

The `cyg_thread_create` function allows application code and eCos packages to create new threads. In many applications this only happens during system initialization and all required data is allocated statically. However additional threads can be created at any time, if necessary. A newly created thread is always in suspended state and will not start running until it has been resumed via a call to `cyg_thread_resume`. Also, if threads are created during system initialization then they will not start running until the eCos scheduler has been started.

The *name* argument is used primarily for debugging purposes, making it easier to keep track of which `cyg_thread` structure is associated with which application-level thread. The kernel configuration option `CYGVAR_KERNEL_THREADS_NAME` controls whether or not this name is actually used.

On creation each thread is assigned a unique handle, and this will be stored in the location pointed at by the *handle* argument. Subsequent operations on this thread including the required `cyg_thread_resume` should use this handle to identify the thread.

The kernel requires a small amount of space for each thread, in the form of a `cyg_thread` data structure, to hold information such as the current state of that thread. To avoid any need for dynamic memory allocation within the kernel this space has to be provided by higher-level code, typically in the form of a static variable. The *thread* argument provides this space.

Thread Entry Point

The entry point for a thread takes the form:

```
void
thread_entry_function(cyg_addrword_t data)
{
    ...
}
```

The second argument to `cyg_thread_create` is a pointer to such a function. The third argument *entry_data* is used to pass additional data to the function. Typically this takes the form of a pointer to some static data, or a small integer, or 0 if the thread does not require any additional data.

If the thread entry function ever returns then this is equivalent to the thread calling `cyg_thread_exit`. Even though the thread will no longer run again, it remains registered with the scheduler. If the application needs to re-use the `cyg_thread` data structure then a call to `cyg_thread_delete` is required first.

Thread Priorities

The `sched_info` argument provides additional information to the scheduler. The exact details depend on the scheduler being used. For the bitmap and mlqueue schedulers it is a small integer, typically in the range 0 to 31, with 0 being the highest priority. The lowest priority is normally used only by the system's idle thread. The exact number of priorities is controlled by the kernel configuration option `CYGNUM_KERNEL_SCHED_PRIORITIES`.

It is the responsibility of the application developer to be aware of the various threads in the system, including those created by eCos packages, and to ensure that all threads run at suitable priorities. For threads created by other packages the documentation provided by those packages should indicate any requirements.

The functions `cyg_thread_set_priority`, `cyg_thread_get_priority`, and `cyg_thread_get_current_priority` can be used to manipulate a thread's priority.

Stacks and Stack Sizes

Each thread needs its own stack for local variables and to keep track of function calls and returns. Again it is expected that this stack is provided by the calling code, usually in the form of static data, so that the kernel does not need any dynamic memory allocation facilities. `cyg_thread_create` takes two arguments related to the stack, a pointer to the base of the stack and the total size of this stack. On many processors stacks actually descend from the top down, so the kernel will add the stack size to the base address to determine the starting location.

The exact stack size requirements for any given thread depend on a number of factors. The most important is of course the code that will be executed in the context of this code: if this involves significant nesting of function calls, recursion, or large local arrays, then the stack size needs to be set to a suitably high value. There are some architectural issues, for example the number of cpu registers and the calling conventions will have some effect on stack usage. Also, depending on the configuration, it is possible that some other code such as interrupt handlers will occasionally run on the current thread's stack. This depends in part on configuration options such as `CYGIMP_HAL_COMMON_INTERRUPTS_USE_INTERRUPT_STACK` and `CYGSEM_HAL_COMMON_INTERRUPTS_ALLOW_NESTING`.

Determining an application's actual stack size requirements is the responsibility of the application developer, since the kernel cannot know in advance what code a given thread will run. However, the system does provide some hints about reasonable stack sizes in the form of two constants: `CYGNUM_HAL_STACK_SIZE_MINIMUM` and `CYGNUM_HAL_STACK_SIZE_TYPICAL`. These are defined by the appropriate HAL package. The `MINIMUM` value is appropriate for a thread that just runs a single function and makes very simple system calls. Trying to create a thread with a smaller stack than this is illegal. The `TYPICAL` value is appropriate for applications where application calls are nested no more than half a dozen or so levels, and there are no large arrays on the stack.

If the stack sizes are not estimated correctly and a stack overflow occurs, the probably result is some form of memory corruption. This can be very hard to track down. The kernel does contain some code to help detect stack overflows, controlled by the configuration option `CYGFUN_KERNEL_THREADS_STACK_CHECKING`: a small amount of space is reserved at the stack limit and filled with a special signature: every time a thread context switch occurs this signature is checked, and if invalid that is a good indication (but not absolute proof) that a stack overflow has occurred. This form of stack checking is enabled by default when the system is built with debugging enabled. A related configuration option is `CYGFUN_KERNEL_THREADS_STACK_MEASUREMENT`: enabling this option means that a thread can call the function `cyg_thread_measure_stack_usage` to find out

the maximum stack usage to date. Note that this is not necessarily the true maximum because, for example, it is possible that in the current run no interrupt occurred at the worst possible moment.

Valid contexts

`cyg_thread_create` may be called during initialization and from within thread context. It may not be called from inside a DSR.

Example

A simple example of thread creation is shown below. This involves creating five threads, one producer and four consumers or workers. The threads are created in the system's `cyg_user_start`: depending on the configuration it might be more appropriate to do this elsewhere, for example inside `main`.

```
#include <cyg/hal/hal_arch.h>
#include <cyg/kernel/kapi.h>

// These numbers depend entirely on your application
#define NUMBER_OF_WORKERS    4
#define PRODUCER_PRIORITY    10
#define WORKER_PRIORITY      11
#define PRODUCER_STACKSIZE   CYGNUM_HAL_STACK_SIZE_TYPICAL
#define WORKER_STACKSIZE     (CYGNUM_HAL_STACK_SIZE_MINIMUM + 1024)

static unsigned char producer_stack[PRODUCER_STACKSIZE];
static unsigned char worker_stacks[NUMBER_OF_WORKERS][WORKER_STACKSIZE];
static cyg_handle_t producer_handle, worker_handles[NUMBER_OF_WORKERS];
static cyg_thread  producer_thread, worker_threads[NUMBER_OF_WORKERS];

static void
producer(cyg_addrword_t data)
{
    ...
}

static void
worker(cyg_addrword_t data)
{
    ...
}

void
cyg_user_start(void)
{
    int i;

    cyg_thread_create(PRODUCER_PRIORITY, &producer, 0, "producer",
                      producer_stack, PRODUCER_STACKSIZE,
                      &producer_handle, &producer_thread);
    cyg_thread_resume(producer_handle);
    for (i = 0; i < NUMBER_OF_WORKERS; i++) {
        cyg_thread_create(WORKER_PRIORITY, &worker, i, "worker",
                          worker_stacks[i], WORKER_STACKSIZE,
                          &(worker_handles[i]), &(worker_threads[i]));
        cyg_thread_resume(worker_handles[i]);
    }
}
```

```
    }  
}
```

Thread Entry Points and C++

For code written in C++ the thread entry function must be either a static member function of a class or an ordinary function outside any class. It cannot be a normal member function of a class because such member functions take an implicit additional argument `this`, and the kernel has no way of knowing what value to use for this argument. One way around this problem is to make use of a special static member function, for example:

```
class fred {  
public:  
    void thread_function();  
    static void static_thread_aux(cyg_addrword_t);  
};  
  
void  
fred::static_thread_aux(cyg_addrword_t objptr)  
{  
    fred* object = static_cast<fred*>(objptr);  
    object->thread_function();  
}  
  
static fred instance;  
  
extern "C" void  
cyg_start( void )  
{  
    ...  
    cyg_thread_create( ...,  
                      &fred::static_thread_aux,  
                      reinterpret_cast<cyg_addrword_t>(&instance),  
                      ... );  
    ...  
}
```

Effectively this uses the *entry_data* argument to `cyg_thread_create` to hold the `this` pointer. Unfortunately this approach does require the use of some C++ casts, so some of the type safety that can be achieved when programming in C++ is lost.

Thread information

Name

`cyg_thread_self`, `cyg_thread_idle_thread`, `cyg_thread_get_stack_base`,
`cyg_thread_get_stack_size`, `cyg_thread_measure_stack_usage`,
`cyg_thread_get_next`, `cyg_thread_get_info`, `cyg_thread_get_id`,
`cyg_thread_find` — Get basic thread information

Synopsis

```
#include <cyg/kernel/kapi.h>

cyg_handle_t cyg_thread_self(void);
cyg_handle_t cyg_thread_idle_thread(void);
cyg_addrword_t cyg_thread_get_stack_base(cyg_handle_t thread);
cyg_uint32 cyg_thread_get_stack_size(cyg_handle_t thread);
cyg_uint32 cyg_thread_measure_stack_usage(cyg_handle_t thread);
cyg_bool cyg_thread_get_next(cyg_handle_t *thread, cyg_uint16 *id);
cyg_bool cyg_thread_get_info(cyg_handle_t thread, cyg_uint16 id, cyg_thread_info
*info);
cyg_uint16 cyg_thread_get_id(cyg_handle_t thread);
cyg_handle_t cyg_thread_find(cyg_uint16 id);
```

Description

These functions can be used to obtain some basic information about various threads in the system. Typically they serve little or no purpose in real applications, but they can be useful during debugging.

`cyg_thread_self` returns a handle corresponding to the current thread. It will be the same as the value filled in by `cyg_thread_create` when the current thread was created. This handle can then be passed to other functions such as `cyg_thread_get_priority`.

`cyg_thread_idle_thread` returns the handle corresponding to the idle thread. This thread is created automatically by the kernel, so application-code has no other way of getting hold of this information.

`cyg_thread_get_stack_base` and `cyg_thread_get_stack_size` return information about a specific thread's stack. The values returned will match the values passed to `cyg_thread_create` when this thread was created.

`cyg_thread_measure_stack_usage` is only available if the configuration option `CYGFUN_KERNEL_THREADS_STACK_MEASUREMENT` is enabled. The return value is the maximum number of bytes of stack space used so far by the specified thread. Note that this should not be considered a true upper bound, for example it is possible that in the current test run the specified thread has not yet been interrupted at the deepest point in the function call graph. Never the less the value returned can give some useful indication of the thread's stack requirements.

`cyg_thread_get_next` is used to enumerate all the current threads in the system. It should be called initially with the locations pointed to by `thread` and `id` set to zero. On return these will be set to the handle and ID of the first thread. On subsequent calls, these parameters should be left set to the values returned by the previous call. The handle and ID of the next thread in the system will be installed each time, until a `false` return value indicates the end of the list.

`cyg_thread_get_info` fills in the `cyg_thread_info` structure with information about the thread described by the *thread* and *id* arguments. The information returned includes the thread's handle and id, its state and name, priorities and stack parameters. If the thread does not exist the function returns `false`.

The `cyg_thread_info` structure is defined as follows by `<cyg/kernel/kapi.h>`, but may be extended in future with additional members, and so its size should not be relied upon:

```
typedef struct
{
    cyg_handle_t      handle;
    cyg_uint16        id;
    cyg_uint32        state;
    char              *name;
    cyg_priority_t     set_pri;
    cyg_priority_t     cur_pri;
    cyg_addrword_t     stack_base;
    cyg_uint32         stack_size;
    cyg_uint32         stack_used;
} cyg_thread_info;
```

`cyg_thread_get_id` returns the unique thread ID for the thread identified by *thread*.

`cyg_thread_find` returns a handle for the thread whose ID is *id*. If no such thread exists, a zero handle is returned.

Valid contexts

`cyg_thread_self` may only be called from thread context. `cyg_thread_idle_thread` may be called from thread or DSR context, but only after the system has been initialized. `cyg_thread_get_stack_base`, `cyg_thread_get_stack_size` and `cyg_thread_measure_stack_usage` may be called any time after the specified thread has been created, but measuring stack usage involves looping over at least part of the thread's stack so this should normally only be done from thread context. `cyg_thread_get_id` may be called from any context as long as the caller can guarantee that the supplied thread handle remains valid.

Examples

A simple example of the use of the `cyg_thread_get_next` and `cyg_thread_get_info` follows:

```
#include <cyg/kernel/kapi.h>
#include <stdio.h>

void show_threads(void)
{
    cyg_handle_t thread = 0;
    cyg_uint16 id = 0;

    while( cyg_thread_get_next( &thread, &id ) )
    {
        cyg_thread_info info;

        if( !cyg_thread_get_info( thread, id, &info ) )
            break;

        printf("ID: %04x name: %10s pri: %d\n",
```



```
        info.id, info.name?info.name:"---", info.set_pri );  
    }  
}
```


Thread control

Name

`cyg_thread_yield`, `cyg_thread_delay`, `cyg_thread_suspend`,
`cyg_thread_resume`, `cyg_thread_release` — Control whether or not a thread is running

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_thread_yield(void);
void cyg_thread_delay(cyg_tick_count_t delay);
void cyg_thread_suspend(cyg_handle_t thread);
void cyg_thread_resume(cyg_handle_t thread);
void cyg_thread_release(cyg_handle_t thread);
```

Description

These functions provide some control over whether or not a particular thread can run. Apart from the required use of `cyg_thread_resume` to start a newly-created thread, application code should normally use proper synchronization primitives such as condition variables or mail boxes.

Yield

`cyg_thread_yield` allows a thread to relinquish control of the processor to some other runnable thread which has the same priority. This can have no effect on any higher-priority thread since, if such a thread were runnable, the current thread would have been preempted in its favour. Similarly it can have no effect on any lower-priority thread because the current thread will always be run in preference to those. As a consequence this function is only useful in configurations with a scheduler that allows multiple threads to run at the same priority, for example the mlqueue scheduler. If instead the bitmap scheduler was being used then `cyg_thread_yield()` would serve no purpose.

Even if a suitable scheduler such as the mlqueue scheduler has been configured, `cyg_thread_yield` will still rarely prove useful: instead timeslicing will be used to ensure that all threads of a given priority get a fair slice of the available processor time. However it is possible to disable timeslicing via the configuration option `CYGSEM_KERNEL_SCHED_TIMESLICE`, in which case `cyg_thread_yield` can be used to implement a form of cooperative multitasking.

Delay

`cyg_thread_delay` allows a thread to suspend until the specified number of clock ticks have occurred. For example, if a value of 1 is used and the system clock runs at a frequency of 100Hz then the thread will sleep for up to 10 milliseconds. This functionality depends on the presence of a real-time system clock, as controlled by the configuration option `CYGVAR_KERNEL_COUNTERS_CLOCK`.

If the application requires delays measured in milliseconds or similar units rather than in clock ticks, some calculations are needed to convert between these units as described in [Clocks](#). Usually these calculations can be done by the application developer, or at compile-time. Performing such calculations prior to every call to `cyg_thread_delay` adds unnecessary overhead to the system.

Suspend and Resume

Associated with each thread is a suspend counter. When a thread is first created this counter is initialized to 1. `cyg_thread_suspend` can be used to increment the suspend counter, and `cyg_thread_resume` decrements it. The scheduler will never run a thread with a non-zero suspend counter. Therefore a newly created thread will not run until it has been resumed.

An occasional problem with the use of suspend and resume functionality is that a thread gets suspended more times than it is resumed and hence never becomes runnable again. This can lead to very confusing behaviour. To help with debugging such problems the kernel provides a configuration option `CYGNUM_KERNEL_MAX_SUSPEND_COUNT_ASSERT` which imposes an upper bound on the number of suspend calls without matching resumes, with a reasonable default value. This functionality depends on infrastructure assertions being enabled.

Releasing a Blocked Thread

When a thread is blocked on a synchronization primitive such as a semaphore or a mutex, or when it is waiting for an alarm to trigger, it can be forcibly woken up using `cyg_thread_release`. Typically this will call the affected synchronization primitive to return false, indicating that the operation was not completed successfully. This function has to be used with great care, and in particular it should only be used on threads that have been designed appropriately and check all return codes. If instead it were to be used on, say, an arbitrary thread that is attempting to claim a mutex then that thread might not bother to check the result of the mutex lock operation - usually there would be no reason to do so. Therefore the thread will now continue running in the false belief that it has successfully claimed a mutex lock, and the resulting behaviour is undefined. If the system has been built with assertions enabled then it is possible that an assertion will trigger when the thread tries to release the mutex it does not actually own.

The main use of `cyg_thread_release` is in the POSIX compatibility layer, where it is used in the implementation of per-thread signals and cancellation handlers.

Valid contexts

`cyg_thread_yield` can only be called from thread context, A DSR must always run to completion and cannot yield the processor to some thread. `cyg_thread_suspend`, `cyg_thread_resume`, and `cyg_thread_release` may be called from thread or DSR context.

Thread termination

Name

`cyg_thread_exit`, `cyg_thread_kill`, `cyg_thread_delete` — Allow threads to terminate

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_thread_exit(void);
void cyg_thread_kill(cyg_handle_t thread);
cyg_bool_t cyg_thread_delete(cyg_handle_t thread);
```

Description

In many embedded systems the various threads are allocated statically, created during initialization, and never need to terminate. This avoids any need for dynamic memory allocation or other resource management facilities. However if a given application does have a requirement that some threads be created dynamically, must terminate, and their resources such as the stack be reclaimed, then the kernel provides the functions `cyg_thread_exit`, `cyg_thread_kill`, and `cyg_thread_delete`.

`cyg_thread_exit` allows a thread to terminate itself, thus ensuring that it will not be run again by the scheduler. However the `cyg_thread` data structure passed to `cyg_thread_create` remains in use, and the handle returned by `cyg_thread_create` remains valid. This allows other threads to perform certain operations on the terminated thread, for example to determine its stack usage via `cyg_thread_measure_stack_usage`. When the handle and `cyg_thread` structure are no longer required, `cyg_thread_delete` should be called to release these resources. If the stack was dynamically allocated then this should not be freed until after the call to `cyg_thread_delete`.

Alternatively, one thread may use `cyg_thread_kill` on another. This has much the same effect as the affected thread calling `cyg_thread_exit`. However killing a thread is generally rather dangerous because no attempt is made to unlock any synchronization primitives currently owned by that thread or release any other resources that thread may have claimed. Therefore use of this function should be avoided, and `cyg_thread_exit` is preferred. `cyg_thread_kill` cannot be used by a thread to kill itself.

`cyg_thread_delete` should be used on a thread after it has exited and is no longer required. After this call the thread handle is no longer valid, and both the `cyg_thread` structure and the thread stack can be re-used or freed. If `cyg_thread_delete` is invoked on a thread that is still running then there is an implicit call to `cyg_thread_kill`. This function returns `true` if the delete was successful, and `false` if the delete did not happen. The delete may not happen for example if the thread being destroyed is a lower priority thread than the running thread, and will thus not wake up in order to exit until it is rescheduled.

Valid contexts

`cyg_thread_exit`, `cyg_thread_kill` and `cyg_thread_delete` can only be called from thread context.

Thread priorities

Name

`cyg_thread_get_priority`, `cyg_thread_get_current_priority`,
`cyg_thread_set_priority` — Examine and manipulate thread priorities

Synopsis

```
#include <cyg/kernel/kapi.h>

cyg_priority_t cyg_thread_get_priority(cyg_handle_t thread);
cyg_priority_t cyg_thread_get_current_priority(cyg_handle_t thread);
void cyg_thread_set_priority(cyg_handle_t thread, cyg_priority_t priority);
```

Description

Typical schedulers use the concept of a thread priority to determine which thread should run next. Exactly what this priority consists of will depend on the scheduler, but a typical implementation would be a small integer in the range 0 to 31, with 0 being the highest priority. Usually only the idle thread will run at the lowest priority. The exact number of priority levels available depends on the configuration, typically the option `CYGNUM_KERNEL_SCHED_PRIORITIES`.

`cyg_thread_get_priority` can be used to determine the priority of a thread, or more correctly the value last used in a `cyg_thread_set_priority` call or when the thread was first created. In some circumstances it is possible that the thread is actually running at a higher priority. For example, if it owns a mutex and priority ceilings or inheritance is being used to prevent priority inversion problems, then the thread's priority may have been boosted temporarily. `cyg_thread_get_current_priority` returns the real current priority.

In many applications appropriate thread priorities can be determined and allocated statically. However, if it is necessary for a thread's priority to change at run-time then the `cyg_thread_set_priority` function provides this functionality.

Valid contexts

`cyg_thread_get_priority` and `cyg_thread_get_current_priority` can be called from thread or DSR context, although the latter is rarely useful. `cyg_thread_set_priority` should also only be called from thread context.

Per-thread data

Name

`cyg_thread_new_data_index`, `cyg_thread_free_data_index`,
`cyg_thread_get_data`, `cyg_thread_get_data_ptr`, `cyg_thread_set_data` —
Manipulate per-thread data

Synopsis

```
#include <cyg/kernel/kapi.h>

cyg_ucount32 cyg_thread_new_data_index(void);
void cyg_thread_free_data_index(cyg_ucount32 index);
cyg_addrword_t cyg_thread_get_data(cyg_ucount32 index);
cyg_addrword_t* cyg_thread_get_data_ptr(cyg_ucount32 index);
void cyg_thread_set_data(cyg_ucount32 index, cyg_addrword_t data);
```

Description

In some applications and libraries it is useful to have some data that is specific to each thread. For example, many of the functions in the POSIX compatibility package return -1 to indicate an error and store additional information in what appears to be a global variable `errno`. However, if multiple threads make concurrent calls into the POSIX library and if `errno` were really a global variable then a thread would have no way of knowing whether the current `errno` value really corresponded to the last POSIX call it made, or whether some other thread had run in the meantime and made a different POSIX call which updated the variable. To avoid such confusion `errno` is instead implemented as a per-thread variable, and each thread has its own instance.

The support for per-thread data can be disabled via the configuration option `CYGVAR_KERNEL_THREADS_DATA`. If enabled, each `cyg_thread` data structure holds a small array of words. The size of this array is determined by the configuration option `CYGNUM_KERNEL_THREADS_DATA_MAX`. When a thread is created the array is filled with zeroes.

If an application needs to use per-thread data then it needs an index into this array which has not yet been allocated to other code. This index can be obtained by calling `cyg_thread_new_data_index`, and then used in subsequent calls to `cyg_thread_get_data`. Typically indices are allocated during system initialization and stored in static variables. If for some reason a slot in the array is no longer required and can be re-used then it can be released by calling `cyg_thread_free_data_index`. When a slot index is allocated, then if the `CYGVAR_KERNEL_THREADS_LIST` option is enabled, the corresponding array entry for all threads will be reset back to zero in case that slot had been previously used.

The current per-thread data in a given slot can be obtained using `cyg_thread_get_data`. This implicitly operates on the current thread, and its single argument should be an index as returned by `cyg_thread_new_data_index`. The per-thread data can be updated using `cyg_thread_set_data`. If a particular item of per-thread data is needed repeatedly then `cyg_thread_get_data_ptr` can be used to obtain the address of the data, and indirecting through this pointer allows the data to be examined and updated efficiently.

Some packages, for example the error and POSIX packages, have pre-allocated slots in the array of per-thread data. These slots should not normally be used by application code, and instead slots should be allocated during

initialization by a call to `cyg_thread_new_data_index`. If it is known that, for example, the configuration will never include the POSIX compatibility package then application code may instead decide to re-use the slot allocated to that package, `CYGNUM_KERNEL_THREADS_DATA_POSIX`, but obviously this does involve a risk of strange and subtle bugs if the application's requirements ever change.

Valid contexts

Typically `cyg_thread_new_data_index` is only called during initialization, but may also be called at any time in thread context. `cyg_thread_free_data_index`, if used at all, can also be called during initialization or from thread context. `cyg_thread_get_data`, `cyg_thread_get_data_ptr`, and `cyg_thread_set_data` may only be called from thread context because they implicitly operate on the current thread.

Thread destructors

Name

`cyg_thread_add_destructor`, `cyg_thread_rem_destructor` — Call functions on thread termination

Synopsis

```
#include <cyg/kernel/kapi.h>
typedef void (*cyg_thread_destructor_fn)(cyg_addrword_t);

cyg_bool_t cyg_thread_add_destructor(cyg_thread_destructor_fn fn, cyg_addrword_t data);
cyg_bool_t cyg_thread_rem_destructor(cyg_thread_destructor_fn fn, cyg_addrword_t data);
```

Description

These functions are provided for cases when an application requires a function to be automatically called when a thread exits. This is often useful when, for example, freeing up resources allocated by the thread.

This support must be enabled with the configuration option `CYGPKG_KERNEL_THREADS_DESTRUCTORS`. When enabled, you may register a function of type `cyg_thread_destructor_fn` to be called on thread termination using `cyg_thread_add_destructor`. You may also provide it with a piece of arbitrary information in the `data` argument which will be passed to the destructor function `fn` when the thread terminates. If you no longer wish to call a function previously registered with `cyg_thread_add_destructor`, you may call `cyg_thread_rem_destructor` with the same parameters used to register the destructor function. Both these functions return `true` on success and `false` on failure.

By default, thread destructors are per-thread, which means that registering a destructor function only registers that function for the current thread. In other words, each thread has its own list of destructors. Alternatively you may disable the configuration option `CYGSEM_KERNEL_THREADS_DESTRUCTORS_PER_THREAD` in which case any registered destructors will be run when *any* threads exit. In other words, the thread destructor list is global and all threads have the same destructors.

There is a limit to the number of destructors which may be registered, which can be controlled with the `CYGNUM_KERNEL_THREADS_DESTRUCTORS` configuration option. Increasing this value will very slightly increase the amount of memory in use, and when `CYGSEM_KERNEL_THREADS_DESTRUCTORS_PER_THREAD` is enabled, the amount of memory used per thread will increase. When the limit has been reached, `cyg_thread_add_destructor` will return `false`.

Valid contexts

When `CYGSEM_KERNEL_THREADS_DESTRUCTORS_PER_THREAD` is enabled, these functions must only be called from a thread context as they implicitly operate on the current thread. When `CYGSEM_KERNEL_THREADS_DESTRUCTORS_PER_THREAD` is disabled, these functions may be called from thread or DSR context, or at initialization time.

Exception handling

Name

`cyg_exception_set_handler`, `cyg_exception_clear_handler`,
`cyg_exception_call_handler` — Handle processor exceptions

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_exception_set_handler(cyg_code_t exception_number, cyg_exception_handler_t*
new_handler, cyg_addrword_t new_data, cyg_exception_handler_t** old_handler,
cyg_addrword_t* old_data);
void cyg_exception_clear_handler(cyg_code_t exception_number);
void cyg_exception_call_handler(cyg_handle_t thread, cyg_code_t exception_number,
cyg_addrword_t exception_info);
```

Description

Sometimes code attempts operations that are not legal on the current hardware, for example dividing by zero, or accessing data through a pointer that is not properly aligned. When this happens the hardware will raise an exception. This is very similar to an interrupt, but happens synchronously with code execution rather than asynchronously and hence can be tied to the thread that is currently running.

The exceptions that can be raised depend very much on the hardware, especially the processor. The corresponding documentation should be consulted for more details. Alternatively the architectural HAL header file `hal_intr.h`, or one of the variant or platform header files it includes, will contain appropriate definitions. The details of how to handle exceptions, including whether or not it is possible to recover from them, also depend on the hardware.

Exception handling is optional, and can be disabled through the configuration option `CYGPKG_KERNEL_EXCEPTIONS`. If an application has been exhaustively tested and is trusted never to raise a hardware exception then this option can be disabled and code and data sizes will be reduced somewhat. If exceptions are left enabled then the system will provide default handlers for the various exceptions, but these do nothing. Even the specific type of exception is ignored, so there is no point in attempting to decode this and distinguish between say a divide-by-zero and an unaligned access. If the application installs its own handlers and wants details of the specific exception being raised then the configuration option `CYGSEM_KERNEL_EXCEPTIONS_DECODE` has to be enabled.

An alternative handler can be installed using `cyg_exception_set_handler`. This requires a code for the exception, a function pointer for the new exception handler, and a parameter to be passed to this handler. Details of the previously installed exception handler will be returned via the remaining two arguments, allowing that handler to be reinstated, or null pointers can be used if this information is of no interest. An exception handling function should take the following form:

```
void
my_exception_handler(cyg_addrword_t data, cyg_code_t exception, cyg_addrword_t info)
{
    ...
}
```

The `data` argument corresponds to the `new_data` parameter supplied to `cyg_exception_set_handler`. The exception code is provided as well, in case a single handler is expected to support multiple exceptions. The `info` argument will depend on the hardware and on the specific exception.

`cyg_exception_clear_handler` can be used to restore the default handler, if desired. It is also possible for software to raise an exception and cause the current handler to be invoked, but generally this is useful only for testing.

By default the system maintains a single set of global exception handlers. However, since exceptions occur synchronously it is sometimes useful to handle them on a per-thread basis, and have a different set of handlers for each thread. This behaviour can be obtained by disabling the configuration option `CYGSEM_KERNEL_EXCEPTIONS_GLOBAL`. If per-thread exception handlers are being used then `cyg_exception_set_handler` and `cyg_exception_clear_handler` apply to the current thread. Otherwise they apply to the global set of handlers.

Caution

In the current implementation `cyg_exception_call_handler` can only be used on the current thread. There is no support for delivering an exception to another thread.

Note: Exceptions at the eCos kernel level refer specifically to hardware-related events such as unaligned accesses to memory or division by zero. There is no relation with other concepts that are also known as exceptions, for example the `throw` and `catch` facilities associated with C++.

Valid contexts

If the system is configured with a single set of global exception handlers then `cyg_exception_set_handler` and `cyg_exception_clear_handler` may be called during initialization or from thread context. If instead per-thread exception handlers are being used then it is not possible to install new handlers during initialization because the functions operate implicitly on the current thread, so they can only be called from thread context. `cyg_exception_call_handler` should only be called from thread context.

Counters

Name

`cyg_counter_create`, `cyg_counter_delete`, `cyg_counter_current_value`, `cyg_counter_set_value`, `cyg_counter_tick` — Count event occurrences

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_counter_create(cyg_handle_t* handle, cyg_counter* counter);
void cyg_counter_delete(cyg_handle_t counter);
cyg_tick_count_t cyg_counter_current_value(cyg_handle_t counter);
void cyg_counter_set_value(cyg_handle_t counter, cyg_tick_count_t new_value);
void cyg_counter_tick(cyg_handle_t counter);
```

Description

Kernel counters can be used to keep track of how many times a particular event has occurred. Usually this event is an external signal of some sort. The most common use of counters is in the implementation of clocks, but they can be useful with other event sources as well. Application code can attach [alarms](#) to counters, causing a function to be called when some number of events have occurred.

A new counter is initialized by a call to `cyg_counter_create`. The first argument is used to return a handle to the new counter which can be used for subsequent operations. The second argument allows the application to provide the memory needed for the object, thus eliminating any need for dynamic memory allocation within the kernel. If a counter is no longer required and does not have any alarms attached then `cyg_counter_delete` can be used to release the resources, allowing the `cyg_counter` data structure to be re-used.

Initializing a counter does not automatically attach it to any source of events. Instead some other code needs to call `cyg_counter_tick` whenever a suitable event occurs, which will cause the counter to be incremented and may cause alarms to trigger. The current value associated with the counter can be retrieved using `cyg_counter_current_value` and modified with `cyg_counter_set_value`. Typically the latter function is only used during initialization, for example to set a clock to wallclock time, but it can be used to reset a counter if necessary. However `cyg_counter_set_value` will never trigger any alarms. A newly initialized counter has a starting value of 0.

The kernel provides two different implementations of counters. The default is `CYGIMP_KERNEL_COUNTERS_SINGLE_LIST` which stores all alarms attached to the counter on a single list. This is simple and usually efficient. However when a tick occurs the kernel code has to traverse this list, typically at DSR level, so if there are a significant number of alarms attached to a single counter this will affect the system's dispatch latency. The alternative implementation, `CYGIMP_KERNEL_COUNTERS_MULTI_LIST`, stores each alarm in one of an array of lists such that at most one of the lists needs to be searched per clock tick. This involves extra code and data, but can improve real-time responsiveness in some circumstances. Another configuration option that is relevant here is `CYGIMP_KERNEL_COUNTERS_SORT_LIST`, which is disabled by default. This provides a trade off between doing work whenever a new alarm is added to a counter and doing work whenever a tick occurs. It is application-dependent which of these is more appropriate.

Valid contexts

`cyg_counter_create` is typically called during system initialization but may also be called in thread context. Similarly `cyg_counter_delete` may be called during initialization or in thread context. `cyg_counter_current_value`, `cyg_counter_set_value` and `cyg_counter_tick` may be called during initialization or from thread or DSR context. In fact, `cyg_counter_tick` is usually called from inside a DSR in response to an external event of some sort.

Clocks

Name

`cyg_clock_create`, `cyg_clock_delete`, `cyg_clock_to_counter`,
`cyg_clock_set_resolution`, `cyg_clock_get_resolution`, `cyg_real_time_clock`,
`cyg_current_time` — Provide system clocks

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_clock_create(cyg_resolution_t resolution, cyg_handle_t* handle, cyg_clock*
clock);
void cyg_clock_delete(cyg_handle_t clock);
void cyg_clock_to_counter(cyg_handle_t clock, cyg_handle_t* counter);
void cyg_clock_set_resolution(cyg_handle_t clock, cyg_resolution_t resolution);
cyg_resolution_t cyg_clock_get_resolution(cyg_handle_t clock);
cyg_handle_t cyg_real_time_clock(void);
cyg_tick_count_t cyg_current_time(void);
```

Description

In the eCos kernel clock objects are a special form of [counter](#) objects. They are attached to a specific type of hardware, clocks that generate ticks at very specific time intervals, whereas counters can be used with any event source.

In a default configuration the kernel provides a single clock instance, the real-time clock. This gets used for timeslicing and for operations that involve a timeout, for example `cyg_semaphore_timed_wait`. If this functionality is not required it can be removed from the system using the configuration option `CYGVAR_KERNEL_COUNTERS_CLOCK`. Otherwise the real-time clock can be accessed by a call to `cyg_real_time_clock`, allowing applications to attach alarms, and the current counter value can be obtained using `cyg_current_time`.

Applications can create and destroy additional clocks if desired, using `cyg_clock_create` and `cyg_clock_delete`. The first argument to `cyg_clock_create` specifies the [resolution](#) this clock will run at. The second argument is used to return a handle for this clock object, and the third argument provides the kernel with the memory needed to hold this object. This clock will not actually tick by itself. Instead it is the responsibility of application code to initialize a suitable hardware timer to generate interrupts at the appropriate frequency, install an interrupt handler for this, and call `cyg_counter_tick` from inside the DSR. Associated with each clock is a kernel counter, a handle for which can be obtained using `cyg_clock_to_counter`.

Clock Resolutions and Ticks

At the kernel level all clock-related operations including delays, timeouts and alarms work in units of clock ticks, rather than in units of seconds or milliseconds. If the calling code, whether the application or some other package, needs to operate using units such as milliseconds then it has to convert from these units to clock ticks.

The main reason for this is that it accurately reflects the hardware: calling something like `nanosleep` with a delay of ten nanoseconds will not work as intended on any real hardware because timer interrupts simply will not happen that frequently; instead calling `cyg_thread_delay` with the equivalent delay of 0 ticks gives a much clearer indication that the application is attempting something inappropriate for the target hardware. Similarly, passing a delay of five ticks to `cyg_thread_delay` makes it fairly obvious that the current thread will be suspended for somewhere between four and five clock periods, as opposed to passing 50000000 to `nanosleep` which suggests a granularity that is not actually provided.

A secondary reason is that conversion between clock ticks and units such as milliseconds can be somewhat expensive, and whenever possible should be done at compile-time or by the application developer rather than at run-time. This saves code size and cpu cycles.

The information needed to perform these conversions is the clock resolution. This is a structure with two fields, a dividend and a divisor, and specifies the number of nanoseconds between clock ticks. For example a clock that runs at 100Hz will have 10 milliseconds between clock ticks, or 10000000 nanoseconds. The ratio between the resolution's dividend and divisor will therefore be 10000000 to 1, and typical values for these might be 1000000000 and 100. If the clock runs at a different frequency, say 60Hz, the numbers could be 1000000000 and 60 respectively. Given a delay in nanoseconds, this can be converted to clock ticks by multiplying with the the divisor and then dividing by the dividend. For example a delay of 50 milliseconds corresponds to 50000000 nanoseconds, and with a clock frequency of 100Hz this can be converted to $((50000000 * 100) / 1000000000) = 5$ clock ticks. Given the large numbers involved this arithmetic normally has to be done using 64-bit precision and the long long data type, but allows code to run on hardware with unusual clock frequencies.

The default frequency for the real-time clock on any platform is usually about 100Hz, but platform-specific documentation should be consulted for this information. Usually it is possible to override this default by configuration options, but again this depends on the capabilities of the underlying hardware. The resolution for any clock can be obtained using `cyg_clock_get_resolution`. For clocks created by application code, there is also a function `cyg_clock_set_resolution`. This does not affect the underlying hardware timer in any way, it merely updates the information that will be returned in subsequent calls to `cyg_clock_get_resolution`: changing the actual underlying clock frequency will require appropriate manipulation of the timer hardware.

Valid contexts

`cyg_clock_create` is usually only called during system initialization (if at all), but may also be called from thread context. The same applies to `cyg_clock_delete`. The remaining functions may be called during initialization, from thread context, or from DSR context, although it should be noted that there is no locking between `cyg_clock_get_resolution` and `cyg_clock_set_resolution` so theoretically it is possible that the former returns an inconsistent data structure.

Alarms

Name

`cyg_alarm_create`, `cyg_alarm_delete`, `cyg_alarm_initialize`,
`cyg_alarm_enable`, `cyg_alarm_disable` — Run an alarm function when a number of events have occurred

Synopsis

```
#include <cyg/kernel/kapi.h>
```

```
void cyg_alarm_create(cyg_handle_t counter, cyg_alarm_t* alarmfn, cyg_addrword_t data,  
cyg_handle_t* handle, cyg_alarm* alarm);  
void cyg_alarm_delete(cyg_handle_t alarm);  
void cyg_alarm_initialize(cyg_handle_t alarm, cyg_tick_count_t trigger,  
cyg_tick_count_t interval);  
void cyg_alarm_enable(cyg_handle_t alarm);  
void cyg_alarm_disable(cyg_handle_t alarm);
```

Description

Kernel alarms are used together with counters and allow for action to be taken when a certain number of events have occurred. If the counter is associated with a clock then the alarm action happens when the appropriate number of clock ticks have occurred, in other words after a certain period of time.

Setting up an alarm involves a two-step process. First the alarm must be created with a call to `cyg_alarm_create`. This takes five arguments. The first identifies the counter to which the alarm should be attached. If the alarm should be attached to the system's real-time clock then `cyg_real_time_clock` and `cyg_clock_to_counter` can be used to get hold of the appropriate handle. The next two arguments specify the action to be taken when the alarm is triggered, in the form of a function pointer and some data. This function should take the form:

```
void  
alarm_handler(cyg_handle_t alarm, cyg_addrword_t data)  
{  
    ...  
}
```

The data argument passed to the alarm function corresponds to the third argument passed to `cyg_alarm_create`. The fourth argument to `cyg_alarm_create` is used to return a handle to the newly-created alarm object, and the final argument provides the memory needed for the alarm object and thus avoids any need for dynamic memory allocation within the kernel.

Once an alarm has been created a further call to `cyg_alarm_initialize` is needed to activate it. The first argument specifies the alarm. The second argument indicates the number of events, for example clock ticks, that need to occur before the alarm triggers. If the third argument is 0 then the alarm will only trigger once. A non-zero value specifies that the alarm should trigger repeatedly, with an interval of the specified number of events.

Alarms can be temporarily disabled and reenabled using `cyg_alarm_disable` and `cyg_alarm_enable`. Alternatively another call to `cyg_alarm_initialize` can be used to modify the behaviour of an existing alarm. If an alarm is no longer required then the associated resources can be released using `cyg_alarm_delete`.

The alarm function is invoked when a counter tick occurs, in other words when there is a call to `cyg_counter_tick`, and will happen in the same context. If the alarm is associated with the system's real-time clock then this will be DSR context, following a clock interrupt. If the alarm is associated with some other application-specific counter then the details will depend on how that counter is updated.

If two or more alarms are registered for precisely the same counter tick, the order of execution of the alarm functions is unspecified.

Valid contexts

`cyg_alarm_create` `cyg_alarm_initialize` is typically called during system initialization but may also be called in thread context. The same applies to `cyg_alarm_delete`. `cyg_alarm_initialize`, `cyg_alarm_disable` and `cyg_alarm_enable` may be called during initialization or from thread or DSR context, but `cyg_alarm_enable` and `cyg_alarm_initialize` may be expensive operations and should only be called when necessary.

Mutexes

Name

`cyg_mutex_init`, `cyg_mutex_destroy`, `cyg_mutex_lock`, `cyg_mutex_timed_lock`,
`cyg_mutex_trylock`, `cyg_mutex_unlock`, `cyg_mutex_release`,
`cyg_mutex_set_ceiling`, `cyg_mutex_set_protocol` — Synchronization primitive

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_mutex_init(cyg_mutex_t* mutex);
void cyg_mutex_destroy(cyg_mutex_t* mutex);
cyg_bool_t cyg_mutex_lock(cyg_mutex_t* mutex);
cyg_bool_t cyg_mutex_timed_lock(cyg_mutex_t* mutex, cyg_tick_count_t abstime);
cyg_bool_t cyg_mutex_trylock(cyg_mutex_t* mutex);
void cyg_mutex_unlock(cyg_mutex_t* mutex);
void cyg_mutex_release(cyg_mutex_t* mutex);
void cyg_mutex_set_ceiling(cyg_mutex_t* mutex, cyg_priority_t priority);
void cyg_mutex_set_protocol(cyg_mutex_t* mutex, enum cyg_mutex_protocol protocol);
```

Description

The purpose of mutexes is to let threads share resources safely. If two or more threads attempt to manipulate a data structure with no locking between them then the system may run for quite some time without apparent problems, but sooner or later the data structure will become inconsistent and the application will start behaving strangely and is quite likely to crash. The same can apply even when manipulating a single variable or some other resource. For example, consider:

```
static volatile int counter = 0;

void
process_event(void)
{
    ...

    counter++;
}
```

Assume that after a certain period of time `counter` has a value of 42, and two threads A and B running at the same priority call `process_event`. Typically thread A will read the value of `counter` into a register, increment this register to 43, and write this updated value back to memory. Thread B will do the same, so usually `counter` will end up with a value of 44. However if thread A is timesliced after reading the old value 42 but before writing back 43, thread B will still read back the old value and will also write back 43. The net result is that the counter only gets incremented once, not twice, which depending on the application may prove disastrous.

Sections of code like the above which involve manipulating shared data are generally known as critical regions. Code should claim a lock before entering a critical region and release the lock when leaving. Mutexes provide an appropriate synchronization primitive for this.

```
static volatile int counter = 0;
static cyg_mutex_t lock;

void
process_event(void)
{
    ...

    cyg_mutex_lock(&lock);
    counter++;
    cyg_mutex_unlock(&lock);
}
```

A mutex must be initialized before it can be used, by calling `cyg_mutex_init`. This takes a pointer to a `cyg_mutex_t` data structure which is typically statically allocated, and may be part of a larger data structure. If a mutex is no longer required and there are no threads waiting on it then `cyg_mutex_destroy` can be used.

The main functions for using a mutex are `cyg_mutex_lock` and `cyg_mutex_unlock`. In normal operation `cyg_mutex_lock` will return success after claiming the mutex lock, blocking if another thread currently owns the mutex. However the lock operation may fail if other code calls `cyg_mutex_release` or `cyg_thread_release`, so if these functions may get used then it is important to check the return value. The current owner of a mutex should call `cyg_mutex_unlock` when a lock is no longer required. This operation must be performed by the owner, not by another thread.

The kernel supplies a variant of `cyg_mutex_lock`, `cyg_mutex_timed_wait`, which can be used to wait for the lock or until some number of clock ticks have passed. The number of ticks is specified as an absolute, not relative, tick count and so in order to wait for a relative number of ticks, the return value of the `cyg_current_time()` function should be added to determine the absolute number of ticks. If this function returns `true` then the mutex has been claimed, if it returns `false` then either a timeout has occurred or the thread has been released.

`cyg_mutex_trylock` is a variant of `cyg_mutex_lock` that will always return immediately, returning success or failure as appropriate. This function is rarely useful. Typical code locks a mutex just before entering a critical region, so if the lock cannot be claimed then there may be nothing else for the current thread to do. Use of this function may also cause a form of priority inversion if the owner runs at a lower priority, because the priority inheritance code will not be triggered. Instead the current thread continues running, preventing the owner from getting any cpu time, completing the critical region, and releasing the mutex.

`cyg_mutex_release` can be used to wake up all threads that are currently blocked inside a call to `cyg_mutex_lock` for a specific mutex. These lock calls will return failure. The current mutex owner is not affected.

Priority Inversion

The use of mutexes gives rise to a problem known as priority inversion. In a typical scenario this requires three threads A, B, and C, running at high, medium and low priority respectively. Thread A and thread B are temporarily blocked waiting for some event, so thread C gets a chance to run, needs to enter a critical region, and locks a mutex. At this point threads A and B are woken up - the exact order does not matter. Thread A needs to claim the same mutex but has to wait until C has left the critical region and can release the mutex. Meanwhile thread B works on something completely different and can continue running without problems. Because thread C is running a lower priority than B it will not get a chance to run until B blocks for some reason, and hence thread A cannot run either. The overall effect is that a high-priority thread A cannot proceed because of a lower priority thread B, and priority inversion has occurred.

In simple applications it may be possible to arrange the code such that priority inversion cannot occur, for example by ensuring that a given mutex is never shared by threads running at different priority levels. However this may not always be possible even at the application level. In addition mutexes may be used internally by underlying code, for example the memory allocation package, so careful analysis of the whole system would be needed to be sure that priority inversion cannot occur. Instead it is common practice to use one of two techniques: priority ceilings and priority inheritance.

Priority ceilings involve associating a priority with each mutex. Usually this will match the highest priority thread that will ever lock the mutex. When a thread running at a lower priority makes a successful call to `cyg_mutex_lock` or `cyg_mutex_trylock` its priority will be boosted to that of the mutex. For example, given the previous example the priority associated with the mutex would be that of thread A, so for as long as it owns the mutex thread C will run in preference to thread B. When C releases the mutex its priority drops to the normal value again, allowing A to run and claim the mutex. Setting the priority for a mutex involves a call to `cyg_mutex_set_ceiling`, which is typically called during initialization. It is possible to change the ceiling dynamically but this will only affect subsequent lock operations, not the current owner of the mutex.

Priority ceilings are very suitable for simple applications, where for every thread in the system it is possible to work out which mutexes will be accessed. For more complicated applications this may prove difficult, especially if thread priorities change at run-time. An additional problem occurs for any mutexes outside the application, for example used internally within eCos packages. A typical eCos package will be unaware of the details of the various threads in the system, so it will have no way of setting suitable ceilings for its internal mutexes. If those mutexes are not exported to application code then using priority ceilings may not be viable. The kernel does provide a configuration option `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_PRIORITY` that can be used to set the default priority ceiling for all mutexes, which may prove sufficient.

The alternative approach is to use priority inheritance: if a thread calls `cyg_mutex_lock` for a mutex that it currently owned by a lower-priority thread, then the owner will have its priority raised to that of the current thread. Often this is more efficient than priority ceilings because priority boosting only happens when necessary, not for every lock operation, and the required priority is determined at run-time rather than by static analysis. However there are complications when multiple threads running at different priorities try to lock a single mutex, or when the current owner of a mutex then tries to lock additional mutexes, and this makes the implementation significantly more complicated than priority ceilings.

There are a number of configuration options associated with priority inversion. First, if after careful analysis it is known that priority inversion cannot arise then the component `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL` can be disabled. More commonly this component will be enabled, and one of either `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_INHERIT` or `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_CEILING` will be selected, so that one of the two protocols is available for all mutexes. It is possible to select multiple protocols, so that some mutexes can have priority ceilings while others use priority inheritance or no priority inversion protection at all. Obviously this flexibility will add to the code size and to the cost of mutex operations. The default for all mutexes will be controlled by `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT`, and can be changed at run-time using `cyg_mutex_set_protocol`.

Priority inversion problems can also occur with other synchronization primitives such as semaphores. For example there could be a situation where a high-priority thread A is waiting on a semaphore, a low-priority thread C needs to do just a little bit more work before posting the semaphore, but a medium priority thread B is running and preventing C from making progress. However a semaphore does not have the concept of an owner, so there is no way for the system to know that it is thread C which would next post to the semaphore. Hence there is no way for the system to boost the priority of C automatically and prevent the priority inversion. Instead situations like this have to be detected by application developers and appropriate precautions have to be taken, for example making sure that all the threads run at suitable priorities at all times.

Warning

The current implementation of priority inheritance within the eCos kernel does not handle certain exceptional circumstances completely correctly. Problems will only arise if a thread owns one mutex, then attempts to claim another mutex, and there are other threads attempting to lock these same mutexes. Although the system will continue running, the current owners of the various mutexes involved may not run at the priority they should. This situation never arises in typical code because a mutex will only be locked for a small critical region, and there is no need to manipulate other shared resources inside this region. A more complicated implementation of priority inheritance is possible but would add significant overhead and certain operations would no longer be deterministic.

Warning

Support for priority ceilings and priority inheritance is not implemented for all schedulers. In particular neither priority ceilings nor priority inheritance are currently available for the bitmap scheduler.

Alternatives

In nearly all circumstances, if two or more threads need to share some data then protecting this data with a mutex is the correct thing to do. Mutexes are the only primitive that combine a locking mechanism and protection against priority inversion problems. However this functionality is achieved at a cost, and in exceptional circumstances such as an application's most critical inner loop it may be desirable to use some other means of locking.

When a critical region is very very small it is possible to lock the scheduler, thus ensuring that no other thread can run until the scheduler is unlocked again. This is achieved with calls to `cyg_scheduler_lock` and `cyg_scheduler_unlock`. If the critical region is sufficiently small then this can actually improve both performance and dispatch latency because `cyg_mutex_lock` also locks the scheduler for a brief period of time. This approach will not work on SMP systems because another thread may already be running on a different processor and accessing the critical region.

Another way of avoiding the use of mutexes is to make sure that all threads that access a particular critical region run at the same priority and configure the system with timeslicing disabled (`CYGSEM_KERNEL_SCHED_TIMESLICE`). Without timeslicing a thread can only be preempted by a higher-priority one, or if it performs some operation that can block. This approach requires that none of the operations in the critical region can block, so for example it is not legal to call `cyg_semaphore_wait`. It is also vulnerable to any changes in the configuration or to the various thread priorities: any such changes may now have unexpected side effects. It will not work on SMP systems.

Recursive Mutexes

The implementation of mutexes within the eCos kernel does not support recursive locks. If a thread has locked a mutex and then attempts to lock the mutex again, typically as a result of some recursive call in a complicated call graph, then either an assertion failure will be reported or the thread will deadlock. This behaviour is deliberate. When a thread has just locked a mutex associated with some data structure, it can assume that that data structure is in a consistent state. Before unlocking the mutex again it must ensure that the data structure is again in a consistent state. Recursive mutexes allow a thread to make arbitrary changes to a data structure, then in a recursive call lock the mutex again while the data structure is still inconsistent. The net result is that

code can no longer make any assumptions about data structure consistency, which defeats the purpose of using mutexes.

Valid contexts

`cyg_mutex_init`, `cyg_mutex_set_ceiling` and `cyg_mutex_set_protocol` are normally called during initialization but may also be called from thread context. The remaining functions should only be called from thread context. Mutexes serve as a mutual exclusion mechanism between threads, and cannot be used to synchronize between threads and the interrupt handling subsystem. If a critical region is shared between a thread and a DSR then it must be protected using `cyg_scheduler_lock` and `cyg_scheduler_unlock`. If a critical region is shared between a thread and an ISR, it must be protected by disabling or masking interrupts. Obviously these operations must be used with care because they can affect dispatch and interrupt latencies.

Condition Variables

Name

`cyg_cond_init`, `cyg_cond_destroy`, `cyg_cond_wait`, `cyg_cond_timed_wait`,
`cyg_cond_signal`, `cyg_cond_broadcast` — Synchronization primitive

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_cond_init(cyg_cond_t* cond, cyg_mutex_t* mutex);
void cyg_cond_destroy(cyg_cond_t* cond);
cyg_bool_t cyg_cond_wait(cyg_cond_t* cond);
cyg_bool_t cyg_cond_timed_wait(cyg_cond_t* cond, cyg_tick_count_t abstime);
void cyg_cond_signal(cyg_cond_t* cond);
void cyg_cond_broadcast(cyg_cond_t* cond);
```

Description

Condition variables are used in conjunction with mutexes to implement long-term waits for some condition to become true. For example consider a set of functions that control access to a pool of resources:

```
cyg_mutex_t res_lock;
res_t res_pool[RES_MAX];
int res_count = RES_MAX;

void res_init(void)
{
    cyg_mutex_init(&res_lock);
    <fill pool with resources>
}

res_t res_allocate(void)
{
    res_t res;

    cyg_mutex_lock(&res_lock);           // lock the mutex

    if( res_count == 0 )                 // check for free resource
        res = RES_NONE;                 // return RES_NONE if none
    else
    {
        res_count--;                    // allocate a resources
        res = res_pool[res_count];
    }

    cyg_mutex_unlock(&res_lock);         // unlock the mutex

    return res;
}
```

```

void res_free(res_t res)
{
    cyg_mutex_lock(&res_lock);                // lock the mutex

    res_pool[res_count] = res;                // free the resource
    res_count++;

    cyg_mutex_unlock(&res_lock);              // unlock the mutex
}

```

These routines use the variable `res_count` to keep track of the resources available. If there are none then `res_allocate` returns `RES_NONE`, which the caller must check for and take appropriate error handling actions.

Now suppose that we do not want to return `RES_NONE` when there are no resources, but want to wait for one to become available. This is where a condition variable can be used:

```

cyg_mutex_t res_lock;
cyg_cond_t res_wait;
res_t res_pool[RES_MAX];
int res_count = RES_MAX;

void res_init(void)
{
    cyg_mutex_init(&res_lock);
    cyg_cond_init(&res_wait, &res_lock);
    <fill pool with resources>
}

res_t res_allocate(void)
{
    res_t res;

    cyg_mutex_lock(&res_lock);                // lock the mutex

    while( res_count == 0 )                  // wait for a resources
        cyg_cond_wait(&res_wait);

    res_count--;                             // allocate a resource
    res = res_pool[res_count];

    cyg_mutex_unlock(&res_lock);              // unlock the mutex

    return res;
}

void res_free(res_t res)
{
    cyg_mutex_lock(&res_lock);                // lock the mutex

    res_pool[res_count] = res;                // free the resource
    res_count++;

    cyg_cond_signal(&res_wait);               // wake up any waiting allocators

    cyg_mutex_unlock(&res_lock);              // unlock the mutex
}

```

In this version of the code, when `res_allocate` detects that there are no resources it calls `cyg_cond_wait`. This does two things: it unlocks the mutex, and puts the calling thread to sleep on the condition variable. When `res_free` is eventually called, it puts a resource back into the pool and calls `cyg_cond_signal` to wake up any thread waiting on the condition variable. When the waiting thread eventually gets to run again, it will re-lock the mutex before returning from `cyg_cond_wait`.

There are two important things to note about the way in which this code works. The first is that the mutex unlock and wait in `cyg_cond_wait` are atomic: no other thread can run between the unlock and the wait. If this were not the case then a call to `res_free` by that thread would release the resource but the call to `cyg_cond_signal` would be lost, and the first thread would end up waiting when there were resources available.

The second feature is that the call to `cyg_cond_wait` is in a `while` loop and not a simple `if` statement. This is because of the need to re-lock the mutex in `cyg_cond_wait` when the signalled thread reawakens. If there are other threads already queued to claim the lock then this thread must wait. Depending on the scheduler and the queue order, many other threads may have entered the critical section before this one gets to run. So the condition that it was waiting for may have been rendered false. Using a loop around all condition variable wait operations is the only way to guarantee that the condition being waited for is still true after waiting.

Before a condition variable can be used it must be initialized with a call to `cyg_cond_init`. This requires two arguments, memory for the data structure and a pointer to an existing mutex. This mutex will not be initialized by `cyg_cond_init`, instead a separate call to `cyg_mutex_init` is required. If a condition variable is no longer required and there are no threads waiting on it then `cyg_cond_destroy` can be used.

When a thread needs to wait for a condition to be satisfied it can call `cyg_cond_wait`. The thread must have already locked the mutex that was specified in the `cyg_cond_init` call. This mutex will be unlocked and the current thread will be suspended in an atomic operation. When some other thread performs a signal or broadcast operation the current thread will be woken up and automatically reclaim ownership of the mutex again, allowing it to examine global state and determine whether or not the condition is now satisfied.

The kernel supplies a variant of this function, `cyg_cond_timed_wait`, which can be used to wait on the condition variable or until some number of clock ticks have occurred. The number of ticks is specified as an absolute, not relative tick count, and so in order to wait for a relative number of ticks, the return value of the `cyg_current_time()` function should be added to determine the absolute number of ticks. The mutex will always be reclaimed before `cyg_cond_timed_wait` returns, regardless of whether it was a result of a signal operation or a timeout.

There is no `cyg_cond_trywait` function because this would not serve any purpose. If a thread has locked the mutex and determined that the condition is satisfied, it can just release the mutex and return. There is no need to perform any operation on the condition variable.

When a thread changes shared state that may affect some other thread blocked on a condition variable, it should call either `cyg_cond_signal` or `cyg_cond_broadcast`. These calls do not require ownership of the mutex, but usually the mutex will have been claimed before updating the shared state. A signal operation only wakes up the first thread that is waiting on the condition variable, while a broadcast wakes up all the threads. If there are no threads waiting on the condition variable at the time, then the signal or broadcast will have no effect: past signals are not counted up or remembered in any way. Typically a signal should be used when all threads will check the same condition and at most one thread can continue running. A broadcast should be used if threads check slightly different conditions, or if the change to the global state might allow multiple threads to proceed.

Valid contexts

`cyg_cond_init` is typically called during system initialization but may also be called in thread context. The same applies to `cyg_cond_delete`. `cyg_cond_wait` and `cyg_cond_timedwait` may only be called from thread context since they may block. `cyg_cond_signal` and `cyg_cond_broadcast` may be called from thread or DSR context.

Semaphores

Name

`cyg_semaphore_init`, `cyg_semaphore_destroy`, `cyg_semaphore_wait`,
`cyg_semaphore_timed_wait`, `cyg_semaphore_post`, `cyg_semaphore_peek` —
Synchronization primitive

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_semaphore_init(cyg_sem_t* sem, cyg_count32 val);
void cyg_semaphore_destroy(cyg_sem_t* sem);
cyg_bool_t cyg_semaphore_wait(cyg_sem_t* sem);
cyg_bool_t cyg_semaphore_timed_wait(cyg_sem_t* sem, cyg_tick_count_t abstime);
cyg_bool_t cyg_semaphore_trywait(cyg_sem_t* sem);
void cyg_semaphore_post(cyg_sem_t* sem);
void cyg_semaphore_peek(cyg_sem_t* sem, cyg_count32* val);
```

Description

Counting semaphores are a [synchronization primitive](#) that allow threads to wait until an event has occurred. The event may be generated by a producer thread, or by a DSR in response to a hardware interrupt. Associated with each semaphore is an integer counter that keeps track of the number of events that have not yet been processed. If this counter is zero, an attempt by a consumer thread to wait on the semaphore will block until some other thread or a DSR posts a new event to the semaphore. If the counter is greater than zero then an attempt to wait on the semaphore will consume one event, in other words decrement the counter, and return immediately. Posting to a semaphore will wake up the first thread that is currently waiting, which will then resume inside the semaphore wait operation and decrement the counter again.

Another use of semaphores is for certain forms of resource management. The counter would correspond to how many of a certain type of resource are currently available, with threads waiting on the semaphore to claim a resource and posting to release the resource again. In practice [condition variables](#) are usually much better suited for operations like this.

`cyg_semaphore_init` is used to initialize a semaphore. It takes two arguments, a pointer to a `cyg_sem_t` structure and an initial value for the counter. Note that semaphore operations, unlike some other parts of the kernel API, use pointers to data structures rather than handles. This makes it easier to embed semaphores in a larger data structure. The initial counter value can be any number, zero, positive or negative, but typically a value of zero is used to indicate that no events have occurred yet.

`cyg_semaphore_wait` is used by a consumer thread to wait for an event. If the current counter is greater than 0, in other words if the event has already occurred in the past, then the counter will be decremented and the call will return immediately. Otherwise the current thread will be blocked until there is a `cyg_semaphore_post` call.

`cyg_semaphore_post` is called when an event has occurs. This increments the counter and wakes up the first thread waiting on the semaphore (if any). Usually that thread will then continue running inside `cyg_semaphore_wait` and decrement the counter again. However other scenarios are possible. For example the thread calling `cyg_semaphore_post` may be running at high priority, some other thread running at

medium priority may be about to call `cyg_semaphore_wait` when it next gets a chance to run, and a low priority thread may be waiting on the semaphore. What will happen is that the current high priority thread continues running until it is descheduled for some reason, then the medium priority thread runs and its call to `cyg_semaphore_wait` succeeds immediately, and later on the low priority thread runs again, discovers a counter value of 0, and blocks until another event is posted. If there are multiple threads blocked on a semaphore then the configuration option `CYGIMP_KERNEL_SCHED_SORTED_QUEUES` determines which one will be woken up by a post operation.

`cyg_semaphore_wait` returns a boolean. Normally it will block until it has successfully decremented the counter, retrying as necessary, and return success. However the wait operation may be aborted by a call to `cyg_thread_release`, and `cyg_semaphore_wait` will then return false.

`cyg_semaphore_timed_wait` is a variant of `cyg_semaphore_wait`. It can be used to wait until either an event has occurred or a number of clock ticks have happened. The number of ticks is specified as an absolute, not relative tick count, and so in order to wait for a relative number of ticks, the return value of the `cyg_current_time()` function should be added to determine the absolute number of ticks. The function returns success if the semaphore wait operation succeeded, or false if the operation timed out or was aborted by `cyg_thread_release`. If support for the real-time clock has been removed from the current configuration then this function will not be available. `cyg_semaphore_trywait` is another variant which will always return immediately rather than block, again returning success or failure. If `cyg_semaphore_timedwait` is given a timeout in the past, it operates like `cyg_semaphore_trywait`.

`cyg_semaphore_peek` can be used to get hold of the current counter value. This function is rarely useful except for debugging purposes since the counter value may change at any time if some other thread or a DSR performs a semaphore operation.

Valid contexts

`cyg_semaphore_init` is normally called during initialization but may also be called from thread context. `cyg_semaphore_wait` and `cyg_semaphore_timed_wait` may only be called from thread context because these operations may block. `cyg_semaphore_trywait`, `cyg_semaphore_post` and `cyg_semaphore_peek` may be called from thread or DSR context.

Mail boxes

Name

`cyg_mbox_create`, `cyg_mbox_delete`, `cyg_mbox_get`, `cyg_mbox_timed_get`,
`cyg_mbox_tryget`, `cyg_mbox_peek_item`, `cyg_mbox_put`, `cyg_mbox_timed_put`,
`cyg_mbox_tryput`, `cyg_mbox_peek`, `cyg_mbox_waiting_to_get`,
`cyg_mbox_waiting_to_put` — Synchronization primitive

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_mbox_create(cyg_handle_t* handle, cyg_mbox* mbox);
void cyg_mbox_delete(cyg_handle_t mbox);
void* cyg_mbox_get(cyg_handle_t mbox);
void* cyg_mbox_timed_get(cyg_handle_t mbox, cyg_tick_count_t abstime);
void* cyg_mbox_tryget(cyg_handle_t mbox);
cyg_count32 cyg_mbox_peek(cyg_handle_t mbox);
void* cyg_mbox_peek_item(cyg_handle_t mbox);
cyg_bool_t cyg_mbox_put(cyg_handle_t mbox, void* item);
cyg_bool_t cyg_mbox_timed_put(cyg_handle_t mbox, void* item, cyg_tick_count_t abstime);
cyg_bool_t cyg_mbox_tryput(cyg_handle_t mbox, void* item);
cyg_bool_t cyg_mbox_waiting_to_get(cyg_handle_t mbox);
cyg_bool_t cyg_mbox_waiting_to_put(cyg_handle_t mbox);
```

Description

Mail boxes are a synchronization primitive. Like semaphores they can be used by a consumer thread to wait until a certain event has occurred, but the producer also has the ability to transmit some data along with each event. This data, the message, is normally a pointer to some data structure. It is stored in the mail box itself, so the producer thread that generates the event and provides the data usually does not have to block until some consumer thread is ready to receive the event. However a mail box will only have a finite capacity, typically ten slots. Even if the system is balanced and events are typically consumed at least as fast as they are generated, a burst of events can cause the mail box to fill up and the generating thread will block until space is available again. This behaviour is very different from semaphores, where it is only necessary to maintain a counter and hence an overflow is unlikely.

Before a mail box can be used it must be created with a call to `cyg_mbox_create`. Each mail box has a unique handle which will be returned via the first argument and which should be used for subsequent operations. `cyg_mbox_create` also requires an area of memory for the kernel structure, which is provided by the `cyg_mbox` second argument. If a mail box is no longer required then `cyg_mbox_delete` can be used. This will simply discard any messages that remain posted.

The main function for waiting on a mail box is `cyg_mbox_get`. If there is a pending message because of a call to `cyg_mbox_put` then `cyg_mbox_get` will return immediately with the message that was put into the mail box. Otherwise this function will block until there is a put operation. Exceptionally the thread can instead be unblocked by a call to `cyg_thread_release`, in which case `cyg_mbox_get` will return a null pointer. It is assumed that there will never be a call to `cyg_mbox_put` with a null pointer, because it would not be possible

to distinguish between that and a release operation. Messages are always retrieved in the order in which they were put into the mail box, and there is no support for messages with different priorities.

There are two variants of `cyg_mbox_get`. The first, `cyg_mbox_timed_get` will wait until either a message is available or until a number of clock ticks have occurred. The number of ticks is specified as an absolute, not relative tick count, and so in order to wait for a relative number of ticks, the return value of the `cyg_current_time()` function should be added to determine the absolute number of ticks. If no message is posted within the timeout then a null pointer will be returned. `cyg_mbox_tryget` is a non-blocking operation which will either return a message if one is available or a null pointer.

New messages are placed in the mail box by calling `cyg_mbox_put` or one of its variants. The main put function takes two arguments, a handle to the mail box and a pointer for the message itself. If there is a spare slot in the mail box then the new message can be placed there immediately, and if there is a waiting thread it will be woken up so that it can receive the message. If the mail box is currently full then `cyg_mbox_put` will block until there has been a get operation and a slot is available. The `cyg_mbox_timed_put` variant imposes a time limit on the put operation, returning false if the operation cannot be completed within the specified number of clock ticks and as for `cyg_mbox_timed_get` this is an absolute tick count. The `cyg_mbox_tryput` variant is non-blocking, returning false if there are no free slots available and the message cannot be posted without blocking.

There are a further four functions available for examining the current state of a mailbox. The results of these functions must be used with care because usually the state can change at any time as a result of activity within other threads, but they may prove occasionally useful during debugging or in special situations. `cyg_mbox_peek` returns a count of the number of messages currently stored in the mail box. `cyg_mbox_peek_item` retrieves the first message, but it remains in the mail box until a get operation is performed. `cyg_mbox_waiting_to_get` and `cyg_mbox_waiting_to_put` indicate whether or not there are currently threads blocked in a get or a put operation on a given mail box.

The number of slots in each mail box is controlled by a configuration option `CYGNUM_KERNEL_SYNCH_MBOX_QUEUE_SIZE`, with a default value of 10. All mail boxes are the same size.

Valid contexts

`cyg_mbox_create` is typically called during system initialization but may also be called in thread context. The remaining functions are normally called only during thread context. Of special note is `cyg_mbox_put` which can be a blocking operation when the mail box is full, and which therefore must never be called from DSR context. It is permitted to call `cyg_mbox_tryput`, `cyg_mbox_tryget`, and the information functions from DSR context but this is rarely useful.

Event Flags

Name

`cyg_flag_init`, `cyg_flag_destroy`, `cyg_flag_setbits`, `cyg_flag_maskbits`,
`cyg_flag_wait`, `cyg_flag_timed_wait`, `cyg_flag_poll`, `cyg_flag_peek`,
`cyg_flag_waiting` — Synchronization primitive

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_flag_init(cyg_flag_t* flag);
void cyg_flag_destroy(cyg_flag_t* flag);
void cyg_flag_setbits(cyg_flag_t* flag, cyg_flag_value_t value);
void cyg_flag_maskbits(cyg_flag_t* flag, cyg_flag_value_t value);
cyg_flag_value_t cyg_flag_wait(cyg_flag_t* flag, cyg_flag_value_t pattern,
cyg_flag_mode_t mode);
cyg_flag_value_t cyg_flag_timed_wait(cyg_flag_t* flag, cyg_flag_value_t pattern,
cyg_flag_mode_t mode, cyg_tick_count_t abstime);
cyg_flag_value_t cyg_flag_poll(cyg_flag_t* flag, cyg_flag_value_t pattern,
cyg_flag_mode_t mode);
cyg_flag_value_t cyg_flag_peek(cyg_flag_t* flag);
cyg_bool_t cyg_flag_waiting(cyg_flag_t* flag);
```

Description

Event flags allow a consumer thread to wait for one of several different types of event to occur. Alternatively it is possible to wait for some combination of events. The implementation is relatively straightforward. Each event flag contains a 32-bit integer. Application code associates these bits with specific events, so for example bit 0 could indicate that an I/O operation has completed and data is available, while bit 1 could indicate that the user has pressed a start button. A producer thread or a DSR can cause one or more of the bits to be set, and a consumer thread currently waiting for these bits will be woken up.

Unlike semaphores no attempt is made to keep track of event counts. It does not matter whether a given event occurs once or multiple times before being consumed, the corresponding bit in the event flag will change only once. However semaphores cannot easily be used to handle multiple event sources. Event flags can often be used as an alternative to condition variables, although they cannot be used for completely arbitrary conditions and they only support the equivalent of condition variable broadcasts, not signals.

Before an event flag can be used it must be initialized by a call to `cyg_flag_init`. This takes a pointer to a `cyg_flag_t` data structure, which can be part of a larger structure. All 32 bits in the event flag will be set to 0, indicating that no events have yet occurred. If an event flag is no longer required it can be cleaned up with a call to `cyg_flag_destroy`, allowing the memory for the `cyg_flag_t` structure to be re-used.

A consumer thread can wait for one or more events by calling `cyg_flag_wait`. This takes three arguments. The first identifies a particular event flag. The second is some combination of bits, indicating which events are of interest. The final argument should be one of the following:

`CYG_FLAG_WAITMODE_AND`

The call to `cyg_flag_wait` will block until all the specified event bits are set. The event flag is not cleared when the wait succeeds, in other words all the bits remain set.

`CYG_FLAG_WAITMODE_OR`

The call will block until at least one of the specified event bits is set. The event flag is not cleared on return.

`CYG_FLAG_WAITMODE_AND` | `CYG_FLAG_WAITMODE_CLR`

The call will block until all the specified event bits are set, and the entire event flag is cleared when the call succeeds. Note that if this mode of operation is used then a single event flag cannot be used to store disjoint sets of events, even though enough bits might be available. Instead each disjoint set of events requires its own event flag.

`CYG_FLAG_WAITMODE_OR` | `CYG_FLAG_WAITMODE_CLR`

The call will block until at least one of the specified event bits is set, and the entire flag is cleared when the call succeeds.

A call to `cyg_flag_wait` normally blocks until the required condition is satisfied. It will return the value of the event flag at the point that the operation succeeded, which may be a superset of the requested events. If `cyg_thread_release` is used to unblock a thread that is currently in a wait operation, the `cyg_flag_wait` call will instead return 0.

`cyg_flag_timed_wait` is a variant of `cyg_flag_wait` which adds a timeout: the wait operation must succeed within the specified number of ticks, or it will fail with a return value of 0. The number of ticks is specified as an absolute, not relative tick count, and so in order to wait for a relative number of ticks, the return value of the `cyg_current_time()` function should be added to determine the absolute number of ticks. `cyg_flag_poll` is a non-blocking variant: if the wait operation can succeed immediately it acts like `cyg_flag_wait`, otherwise it returns immediately with a value of 0.

`cyg_flag_setbits` is called by a producer thread or from inside a DSR when an event occurs. The specified bits are or'd into the current event flag value. This may cause one or more waiting threads to be woken up, if their conditions are now satisfied. How many threads are awoken depends on the use of `CYG_FLAG_WAITMODE_CLR`. The queue of threads waiting on the flag is walked to find threads which now have their wake condition fulfilled. If the awoken thread has passed `CYG_FLAG_WAITMODE_CLR` the walking of the queue is terminated, otherwise the walk continues. Thus if no threads have passed `CYG_FLAG_WAITMODE_CLR` all threads with fulfilled conditions will be awoken. If `CYG_FLAG_WAITMODE_CLR` is passed by threads with fulfilled conditions, the number of awoken threads will depend on the order the threads are in the queue.

`cyg_flag_maskbits` can be used to clear one or more bits in the event flag. This can be called from a producer when a particular condition is no longer satisfied, for example when the user is no longer pressing a particular button. It can also be used by a consumer thread if `CYG_FLAG_WAITMODE_CLR` was not used as part of the wait operation, to indicate that some but not all of the active events have been consumed. If there are multiple consumer threads performing wait operations without using `CYG_FLAG_WAITMODE_CLR` then typically some additional synchronization such as a mutex is needed to prevent multiple threads consuming the same event.

Two additional functions are provided to query the current state of an event flag. `cyg_flag_peek` returns the current value of the event flag, and `cyg_flag_waiting` can be used to find out whether or not there are any threads currently blocked on the event flag. Both of these functions must be used with care because other threads may be operating on the event flag.

Valid contexts

`cyg_flag_init` is typically called during system initialization but may also be called in thread context. The same applies to `cyg_flag_destroy`. `cyg_flag_wait` and `cyg_flag_timed_wait` may only be called from thread context. The remaining functions may be called from thread or DSR context.

Spinlocks

Name

`cyg_spinlock_create`, `cyg_spinlock_destroy`, `cyg_spinlock_spin`,
`cyg_spinlock_clear`, `cyg_spinlock_test`, `cyg_spinlock_spin_intsave`,
`cyg_spinlock_clear_intsave` — Low-level Synchronization Primitive

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_spinlock_init(cyg_spinlock_t* lock, cyg_bool_t locked);
void cyg_spinlock_destroy(cyg_spinlock_t* lock);
void cyg_spinlock_spin(cyg_spinlock_t* lock);
void cyg_spinlock_clear(cyg_spinlock_t* lock);
cyg_bool_t cyg_spinlock_try(cyg_spinlock_t* lock);
cyg_bool_t cyg_spinlock_test(cyg_spinlock_t* lock);
void cyg_spinlock_spin_intsave(cyg_spinlock_t* lock, cyg_addrword_t* istate);
void cyg_spinlock_clear_intsave(cyg_spinlock_t* lock, cyg_addrword_t istate);
```

Description

Spinlocks provide an additional synchronization primitive for applications running on SMP systems. They operate at a lower level than the other primitives such as mutexes, and for most purposes the higher-level primitives should be preferred. However there are some circumstances where a spinlock is appropriate, especially when interrupt handlers and threads need to share access to hardware, and on SMP systems the kernel implementation itself depends on spinlocks.

Essentially a spinlock is just a simple flag. When code tries to claim a spinlock it checks whether or not the flag is already set. If not then the flag is set and the operation succeeds immediately. The exact implementation of this is hardware-specific, for example it may use a test-and-set instruction to guarantee the desired behaviour even if several processors try to access the spinlock at the exact same time. If it is not possible to claim a spinlock then the current thread spins in a tight loop, repeatedly checking the flag until it is clear. This behaviour is very different from other synchronization primitives such as mutexes, where contention would cause a thread to be suspended. The assumption is that a spinlock will only be held for a very short time. If claiming a spinlock could cause the current thread to be suspended then spinlocks could not be used inside interrupt handlers, which is not acceptable.

This does impose a constraint on any code which uses spinlocks. Specifically it is important that spinlocks are held only for a short period of time, typically just some dozens of instructions. Otherwise another processor could be blocked on the spinlock for a long time, unable to do any useful work. It is also important that a thread which owns a spinlock does not get preempted because that might cause another processor to spin for a whole timeslice period, or longer. One way of achieving this is to disable interrupts on the current processor, and the function `cyg_spinlock_spin_intsave` is provided to facilitate this.

Spinlocks should not be used on single-processor systems. Consider a high priority thread which attempts to claim a spinlock already held by a lower priority thread: it will just loop forever and the lower priority thread will never get another chance to run and release the spinlock. Even if the two threads were running at the same priority, the one attempting to claim the spinlock would spin until it was timesliced and a lot of cpu time would

be wasted. If an interrupt handler tried to claim a spinlock owned by a thread, the interrupt handler would loop forever. Therefore spinlocks are only appropriate for SMP systems where the current owner of a spinlock can continue running on a different processor.

Before a spinlock can be used it must be initialized by a call to `cyg_spinlock_init`. This takes two arguments, a pointer to a `cyg_spinlock_t` data structure, and a flag to specify whether the spinlock starts off locked or unlocked. If a spinlock is no longer required then it can be destroyed by a call to `cyg_spinlock_destroy`.

There are two routines for claiming a spinlock: `cyg_spinlock_spin` and `cyg_spinlock_spin_intsave`. The former can be used when it is known the current code will not be preempted, for example because it is running in an interrupt handler or because interrupts are disabled. The latter will disable interrupts in addition to claiming the spinlock, so is safe to use in all circumstances. The previous interrupt state is returned via the second argument, and should be used in a subsequent call to `cyg_spinlock_clear_intsave`.

Similarly there are two routines for releasing a spinlock: `cyg_spinlock_clear` and `cyg_spinlock_clear_intsave`. Typically the former will be used if the spinlock was claimed by a call to `cyg_spinlock_spin`, and the latter when `cyg_spinlock_intsave` was used.

There are two additional routines. `cyg_spinlock_try` is a non-blocking version of `cyg_spinlock_spin`: if possible the lock will be claimed and the function will return `true`; otherwise the function will return immediately with failure. `cyg_spinlock_test` can be used to find out whether or not the spinlock is currently locked. This function must be used with care because, especially on a multiprocessor system, the state of the spinlock can change at any time.

Spinlocks should only be held for a short period of time, and attempting to claim a spinlock will never cause a thread to be suspended. This means that there is no need to worry about priority inversion problems, and concepts such as priority ceilings and inheritance do not apply.

Valid contexts

All of the spinlock functions can be called from any context, including ISR and DSR context. Typically `cyg_spinlock_init` is only called during system initialization.

Scheduler Control

Name

`cyg_scheduler_start`, `cyg_scheduler_lock`, `cyg_scheduler_unlock`,
`cyg_scheduler_safe_lock`, `cyg_scheduler_read_lock` — Control the state of the scheduler

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_scheduler_start(void);
void cyg_scheduler_lock(void);
void cyg_scheduler_unlock(void);
cyg_ucount32 cyg_scheduler_read_lock(void);
```

Description

`cyg_scheduler_start` should only be called once, to mark the end of system initialization. In typical configurations it is called automatically by the system startup, but some applications may bypass the standard startup in which case `cyg_scheduler_start` will have to be called explicitly. The call will enable system interrupts, allowing I/O operations to commence. Then the scheduler will be invoked and control will be transferred to the highest priority runnable thread. The call will never return.

The various data structures inside the eCos kernel must be protected against concurrent updates. Consider a call to `cyg_semaphore_post` which causes a thread to be woken up: the semaphore data structure must be updated to remove the thread from its queue; the scheduler data structure must also be updated to mark the thread as runnable; it is possible that the newly runnable thread has a higher priority than the current one, in which case preemption is required. If in the middle of the semaphore post call an interrupt occurred and the interrupt handler tried to manipulate the same data structures, for example by making another thread runnable, then it is likely that the structures will be left in an inconsistent state and the system will fail.

To prevent such problems the kernel contains a special lock known as the scheduler lock. A typical kernel function such as `cyg_semaphore_post` will claim the scheduler lock, do all its manipulation of kernel data structures, and then release the scheduler lock. The current thread cannot be preempted while it holds the scheduler lock. If an interrupt occurs and a DSR is supposed to run to signal that some event has occurred, that DSR is postponed until the scheduler unlock operation. This prevents concurrent updates of kernel data structures.

The kernel exports three routines for manipulating the scheduler lock. `cyg_scheduler_lock` can be called to claim the lock. On return it is guaranteed that the current thread will not be preempted, and that no other code is manipulating any kernel data structures. `cyg_scheduler_unlock` can be used to release the lock, which may cause the current thread to be preempted. `cyg_scheduler_read_lock` can be used to query the current state of the scheduler lock. This function should never be needed because well-written code should always know whether or not the scheduler is currently locked, but may prove useful during debugging.

The implementation of the scheduler lock involves a simple counter. Code can call `cyg_scheduler_lock` multiple times, causing the counter to be incremented each time, as long as `cyg_scheduler_unlock` is called the same number of times. This behaviour is different from mutexes where an attempt by a thread to lock a mutex multiple times will result in deadlock or an assertion failure.

Typical application code should not use the scheduler lock. Instead other synchronization primitives such as mutexes and semaphores should be used. While the scheduler is locked the current thread cannot be preempted, so any higher priority threads will not be able to run. Also no DSRs can run, so device drivers may not be able to service I/O requests. However there is one situation where locking the scheduler is appropriate: if some data structure needs to be shared between an application thread and a DSR associated with some interrupt source, the thread can use the scheduler lock to prevent concurrent invocations of the DSR and then safely manipulate the structure. It is desirable that the scheduler lock is held for only a short period of time, typically some tens of instructions. In exceptional cases there may also be some performance-critical code where it is more appropriate to use the scheduler lock rather than a mutex, because the former is more efficient.

Valid contexts

`cyg_scheduler_start` can only be called during system initialization, since it marks the end of that phase. The remaining functions may be called from thread or DSR context. Locking the scheduler from inside the DSR has no practical effect because the lock is claimed automatically by the interrupt subsystem before running DSRs, but allows functions to be shared between normal thread code and DSRs.

Interrupt Handling

Name

`cyg_interrupt_create`, `cyg_interrupt_delete`, `cyg_interrupt_attach`,
`cyg_interrupt_detach`, `cyg_interrupt_configure`, `cyg_interrupt_acknowledge`,
`cyg_interrupt_enable`, `cyg_interrupt_disable`, `cyg_interrupt_mask`,
`cyg_interrupt_mask_intunsafe`, `cyg_interrupt_unmask`,
`cyg_interrupt_unmask_intunsafe`, `cyg_interrupt_set_cpu`,
`cyg_interrupt_get_cpu`, `cyg_interrupt_get_vsr`, `cyg_interrupt_set_vsr` —
Manage interrupt handlers

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_interrupt_create(cyg_vector_t vector, cyg_priority_t priority, cyg_addrword_t
data, cyg_ISR_t* isr, cyg_DSR_t* dsr, cyg_handle_t* handle, cyg_interrupt* intr);
void cyg_interrupt_delete(cyg_handle_t interrupt);
void cyg_interrupt_attach(cyg_handle_t interrupt);
void cyg_interrupt_detach(cyg_handle_t interrupt);
void cyg_interrupt_configure(cyg_vector_t vector, cyg_bool_t level, cyg_bool_t up);
void cyg_interrupt_acknowledge(cyg_vector_t vector);
void cyg_interrupt_disable(void);
void cyg_interrupt_enable(void);
void cyg_interrupt_mask(cyg_vector_t vector);
void cyg_interrupt_mask_intunsafe(cyg_vector_t vector);
void cyg_interrupt_unmask(cyg_vector_t vector);
void cyg_interrupt_unmask_intunsafe(cyg_vector_t vector);
void cyg_interrupt_set_cpu(cyg_vector_t vector, cyg_cpu_t cpu);
cyg_cpu_t cyg_interrupt_get_cpu(cyg_vector_t vector);
void cyg_interrupt_get_vsr(cyg_vector_t vector, cyg_VSR_t** vsr);
void cyg_interrupt_set_vsr(cyg_vector_t vector, cyg_VSR_t* vsr);
```

Description

The kernel provides an interface for installing interrupt handlers and controlling when interrupts occur. This functionality is used primarily by eCos device drivers and by any application code that interacts directly with hardware. However in most cases it is better to avoid using this kernel functionality directly, and instead the device driver API provided by the common HAL package should be used. Use of the kernel package is optional, and some applications such as RedBoot work with no need for multiple threads or synchronization primitives. Any code which calls the kernel directly rather than the device driver API will not function in such a configuration. When the kernel package is present the device driver API is implemented as `#define`'s to the equivalent kernel calls, otherwise it is implemented inside the common HAL package. The latter implementation can be simpler than the kernel one because there is no need to consider thread preemption and similar issues.

The exact details of interrupt handling vary widely between architectures. The functionality provided by the kernel abstracts away from many of the details of the underlying hardware, thus simplifying application development. However this is not always successful. For example, if some hardware does not provide any support at all for masking specific interrupts then calling `cyg_interrupt_mask` may not behave as intended: instead

of masking just the one interrupt source it might disable all interrupts, because that is as close to the desired behaviour as is possible given the hardware restrictions. Another possibility is that masking a given interrupt source also affects all lower-priority interrupts, but still allows higher-priority ones. The documentation for the appropriate HAL packages should be consulted for more information about exactly how interrupts are handled on any given hardware. The HAL header files will also contain useful information.

Interrupt Handlers

Interrupt handlers are created by a call to `cyg_interrupt_create`. This takes the following arguments:

`cyg_vector_t vector`

The interrupt vector, a small integer, identifies the specific interrupt source. The appropriate hardware documentation or HAL header files should be consulted for details of which vector corresponds to which device.

`cyg_priority_t priority`

Some hardware may support interrupt priorities, where a low priority interrupt handler can in turn be interrupted by a higher priority one. Again hardware-specific documentation should be consulted for details about what the valid interrupt priority levels are.

`cyg_addrword_t data`

When an interrupt occurs eCos will first call the associated interrupt service routine or ISR, then optionally a deferred service routine or DSR. The *data* argument to `cyg_interrupt_create` will be passed to both these functions. Typically it will be a pointer to some data structure.

`cyg_ISR_t isr`

When an interrupt occurs the hardware will transfer control to the appropriate vector service routine or VSR, which is usually provided by eCos. This performs any appropriate processing, for example to work out exactly which interrupt occurred, and then as quickly as possible transfers control the installed ISR. An ISR is a C function which takes the following form:

```
cyg_uint32
isr_function(cyg_vector_t vector, cyg_addrword_t data)
{
    cyg_bool_t dsr_required = 0;

    ...

    return dsr_required ?
        (CYG_ISR_CALL_DSR | CYG_ISR_HANDLED) :
        CYG_ISR_HANDLED;
}
```

The first argument identifies the particular interrupt source, especially useful if there multiple instances of a given device and a single ISR can be used for several different interrupt vectors. The second argument is the *data* field passed to `cyg_interrupt_create`, usually a pointer to some data structure. The exact conditions under which an ISR runs will depend partly on the hardware and partly on configuration options. Interrupts may currently be disabled globally, especially if the hardware does not support interrupt priorities. Alternatively interrupts may be enabled such that higher priority interrupts are allowed through. The ISR may be running on a separate interrupt stack, or on the stack of whichever thread was running at the time the interrupt happened.

A typical ISR will do as little work as possible, just enough to meet the needs of the hardware and then acknowledge the interrupt by calling `cyg_interrupt_acknowledge`. This ensures that interrupts will be quickly reenabled, so higher priority devices can be serviced. For some applications there may be one device which is especially important and whose ISR can take much longer than normal. However eCos device drivers usually will not assume that they are especially important, so their ISRs will be as short as possible.

The return value of an ISR is normally a bit mask containing zero, one or both of the following bits: `CYG_ISR_CALL_DSR` or `CYG_ISR_HANDLED`. The former indicates that further processing is required at DSR level, and the interrupt handler's DSR will be run as soon as possible. The latter indicates that the interrupt was handled by this ISR so there is no need to call other interrupt handlers which might be chained on this interrupt vector. If this ISR did not handle the interrupt it should not set the `CYG_ISR_HANDLED` bit so that other chained interrupt handlers may handle the interrupt.

An ISR is allowed to make very few kernel calls. It can manipulate the interrupt mask, and on SMP systems it can use spinlocks. However an ISR must not make higher-level kernel calls such as posting to a semaphore, instead any such calls must be made from the DSR. This avoids having to disable interrupts throughout the kernel and thus improves interrupt latency.

`cyg_DSR_t dsr`

If an interrupt has occurred and the ISR has returned a value with `CYG_ISR_CALL_DSR` bit being set, the system will call the DSR associated with this interrupt handler. If the scheduler is not currently locked then the DSR will run immediately. However if the interrupted thread was in the middle of a kernel call and had locked the scheduler, then the DSR will be deferred until the scheduler is again unlocked. This allows the DSR to make certain kernel calls safely, for example posting to a semaphore or signalling a condition variable. A DSR is a C function which takes the following form:

```
void
dsr_function(cyg_vector_t vector,
             cyg_ucount32 count,
             cyg_addrword_t data)
{
}
```

The first argument identifies the specific interrupt that has caused the DSR to run. The second argument indicates the number of these interrupts that have occurred and for which the ISR requested a DSR. Usually this will be 1, unless the system is suffering from a very heavy load. The third argument is the *data* field passed to `cyg_interrupt_create`.

`cyg_handle_t* handle`

The kernel will return a handle to the newly created interrupt handler via this argument. Subsequent operations on the interrupt handler such as attaching it to the interrupt source will use this handle.

`cyg_interrupt* intr`

This provides the kernel with an area of memory for holding this interrupt handler and associated data.

The call to `cyg_interrupt_create` simply fills in a kernel data structure. A typical next step is to call `cyg_interrupt_attach` using the handle returned by the create operation. This makes it possible to have several different interrupt handlers for a given vector, attaching whichever one is currently appropriate. Replacing an interrupt handler requires a call to `cyg_interrupt_detach`, followed by another call to `cyg_interrupt_attach` for the replacement handler. `cyg_interrupt_delete` can be used if an interrupt handler is no longer required.

Some hardware may allow for further control over specific interrupts, for example whether an interrupt is level or edge triggered. Any such hardware functionality can be accessed using `cyg_interrupt_configure`: the `level` argument selects between level versus edge triggered; the `up` argument selects between high and low level, or between rising and falling edges.

Usually interrupt handlers are created, attached and configured during system initialization, while global interrupts are still disabled. On most hardware it will also be necessary to call `cyg_interrupt_unmask`, since the sensible default for interrupt masking is to ignore any interrupts for which no handler is installed.

Controlling Interrupts

eCos provides two ways of controlling whether or not interrupts happen. It is possible to disable and reenble all interrupts globally, using `cyg_interrupt_disable` and `cyg_interrupt_enable`. Typically this works by manipulating state inside the cpu itself, for example setting a flag in a status register or executing special instructions. Alternatively it may be possible to mask a specific interrupt source by writing to one or to several interrupt mask registers. Hardware-specific documentation should be consulted for the exact details of how interrupt masking works, because a full implementation is not possible on all hardware.

The primary use for these functions is to allow data to be shared between ISRs and other code such as DSRs or threads. If both a thread and an ISR need to manipulate either a data structure or the hardware itself, there is a possible conflict if an interrupt happens just when the thread is doing such manipulation. Problems can be avoided by the thread either disabling or masking interrupts during the critical region. If this critical region requires only a few instructions then usually it is more efficient to disable interrupts. For larger critical regions it may be more appropriate to use interrupt masking, allowing other interrupts to occur. There are other uses for interrupt masking. For example if a device is not currently being used by the application then it may be desirable to mask all interrupts generated by that device.

There are two functions for masking a specific interrupt source, `cyg_interrupt_mask` and `cyg_interrupt_mask_intunsafe`. On typical hardware masking an interrupt is not an atomic operation, so if two threads were to perform interrupt masking operations at the same time there could be problems. `cyg_interrupt_mask` disables all interrupts while it manipulates the interrupt mask. In situations where interrupts are already known to be disabled, `cyg_interrupt_mask_intunsafe` can be used instead. There are matching functions `cyg_interrupt_unmask` and `cyg_interrupt_unmask_intsafe`.

SMP Support

On SMP systems the kernel provides an additional two functions related to interrupt handling. `cyg_interrupt_set_cpu` specifies that a particular hardware interrupt should always be handled on one specific processor in the system. In other words when the interrupt triggers it is only that processor which detects it, and it is only on that processor that the VSR and ISR will run. If a DSR is requested then it will also run on the same CPU. The function `cyg_interrupt_get_cpu` can be used to find out which interrupts are handled on which processor.

VSR Support

When an interrupt occurs the hardware will transfer control to a piece of code known as the VSR, or Vector Service Routine. By default this code is provided by eCos. Usually it is written in assembler, but on some architectures it may be possible to implement VSRs in C by specifying an interrupt attribute. Compiler documentation should be consulted for more information on this. The default eCos VSR will work out which ISR function should process the interrupt, and set up a C environment suitable for this ISR.

For some applications it may be desirable to replace the default eCos VSR and handle some interrupts directly. This minimizes interrupt latency, but it requires application developers to program at a lower level. Usually the best way to write a custom VSR is to copy the existing one supplied by eCos and then make appropriate modifications. The function `cyg_interrupt_get_vsr` can be used to get hold of the current VSR for a given interrupt vector, allowing it to be restored if the custom VSR is no longer required. `cyg_interrupt_set_vsr` can be used to install a replacement VSR. Usually the *vsr* argument will correspond to an exported label in an assembler source file.

Note: On some eCos platforms, possibly only in certain configurations, the table of VSRs resides in read-only memory and `cyg_interrupt_set_vsr` will not be available. Portable code can test for this condition by including the header file `cyg/hal/hal_intr.h` and testing for the macro `HAL_VSR_SET`.

Valid contexts

In a typical configuration interrupt handlers are created and attached during system initialization, and never detached or deleted. However it is possible to perform these operations at thread level, if desired. Similarly `cyg_interrupt_configure`, `cyg_interrupt_set_vsr`, and `cyg_interrupt_set_cpu` are usually called only during system initialization, but on typical hardware may be called at any time. `cyg_interrupt_get_vsr` and `cyg_interrupt_get_cpu` may be called at any time.

The functions for enabling, disabling, masking and unmasking interrupts can be called in any context, when appropriate. It is the responsibility of application developers to determine when the use of these functions is appropriate.

Kernel Real-time Characterization

Name

`tm_basic` — Measure the performance of the eCos kernel

Description

When building a real-time system, care must be taken to ensure that the system will be able to perform properly within the constraints of that system. One of these constraints may be how fast certain operations can be performed. Another might be how deterministic the overall behavior of the system is. Lastly the memory footprint (size) and unit cost may be important.

One of the major problems encountered while evaluating a system will be how to compare it with possible alternatives. Most manufacturers of real-time systems publish performance numbers, ostensibly so that users can compare the different offerings. However, what these numbers mean and how they were gathered is often not clear. The values are typically measured on a particular piece of hardware, so in order to truly compare, one must obtain measurements for exactly the same set of hardware that were gathered in a similar fashion.

Two major items need to be present in any given set of measurements. First, the raw values for the various operations; these are typically quite easy to measure and will be available for most systems. Second, the determinacy of the numbers; in other words how much the value might change depending on other factors within the system. This value is affected by a number of factors: how long interrupts might be masked, whether or not the function can be interrupted, even very hardware-specific effects such as cache locality and pipeline usage. It is very difficult to measure the determinacy of any given operation, but that determinacy is fundamentally important to proper overall characterization of a system.

In the discussion and numbers that follow, three key measurements are provided. The first measurement is an estimate of the interrupt latency: this is the length of time from when a hardware interrupt occurs until its Interrupt Service Routine (ISR) is called. The second measurement is an estimate of overall interrupt overhead: this is the length of time average interrupt processing takes, as measured by the real-time clock interrupt (other interrupt sources will certainly take a different amount of time, but this data cannot be easily gathered). The third measurement consists of the timings for the various kernel primitives.

Methodology

Key operations in the kernel were measured by using a simple test program which exercises the various kernel primitive operations. A hardware timer, normally the one used to drive the real-time clock, was used for these measurements. In most cases this timer can be read with quite high resolution, typically in the range of a few microseconds. For each measurement, the operation was repeated a number of times. Time stamps were obtained directly before and after the operation was performed. The data gathered for the entire set of operations was then analyzed, generating average (mean), maximum and minimum values. The sample variance (a measure of how close most samples are to the mean) was also calculated. The cost of obtaining the real-time clock timer values was also measured, and was subtracted from all other times.

Most kernel functions can be measured separately. In each case, a reasonable number of iterations are performed. Where the test case involves a kernel object, for example creating a task, each iteration is performed on a different object. There is also a set of tests which measures the interactions between multiple tasks and certain kernel primitives. Most functions are tested in such a way as to determine the variations introduced by varying numbers of objects in the system. For example, the mailbox tests measure the cost of a 'peek' operation when the mailbox is empty, has a single item, and has multiple items present. In this way, any effects of the state of the object or how many items it contains can be determined.

There are a few things to consider about these measurements. Firstly, they are quite micro in scale and only measure the operation in question. These measurements do not adequately describe how the timings would be perturbed in a real system with multiple interrupting sources. Secondly, the possible aberration incurred by the real-time clock (system heartbeat tick) is explicitly avoided. Virtually all kernel functions have been designed to be interruptible. Thus the times presented are typical, but best case, since any particular function may be interrupted by the clock tick processing. This number is explicitly calculated so that the value may be included in any deadline calculations required by the end user. Lastly, the reported measurements were obtained from a system built with all options at their default values. Kernel instrumentation and asserts are also disabled for these measurements. Any number of configuration options can change the measured results, sometimes quite dramatically. For example, mutexes are using priority inheritance in these measurements. The numbers will change if the system is built with priority inheritance on mutex variables turned off.

The final value that is measured is an estimate of interrupt latency. This particular value is not explicitly calculated in the test program used, but rather by instrumenting the kernel itself. The raw number of timer ticks that elapse between the time the timer generates an interrupt and the start of the timer ISR is kept in the kernel. These values are printed by the test program after all other operations have been tested. Thus this should be a reasonable estimate of the interrupt latency over time.

Using these Measurements

These measurements can be used in a number of ways. The most typical use will be to compare different real-time kernel offerings on similar hardware, another will be to estimate the cost of implementing a task using eCos (applications can be examined to see what effect the kernel operations will have on the total execution time). Another use would be to observe how the tuning of the kernel affects overall operation.

Influences on Performance

A number of factors can affect real-time performance in a system. One of the most common factors, yet most difficult to characterize, is the effect of device drivers and interrupts on system timings. Different device drivers will have differing requirements as to how long interrupts are suppressed, for example. The eCos system has been designed with this in mind, by separating the management of interrupts (ISR handlers) and the processing required by the interrupt (DSR—Deferred Service Routine— handlers). However, since there is so much variability here, and indeed most device drivers will come from the end users themselves, these effects cannot be reliably measured. Attempts have been made to measure the overhead of the single interrupt that eCos relies on, the real-time clock timer. This should give you a reasonable idea of the cost of executing interrupt handling for devices.

Measured Items

This section describes the various tests and the numbers presented. All tests use the C kernel API (available by way of `cyg/kernel/kapi.h`). There is a single main thread in the system that performs the various tests. Additional threads may be created as part of the testing, but these are short lived and are destroyed between tests unless otherwise noted. The terminology “lower priority” means a priority that is less important, not necessarily lower in numerical value. A higher priority thread will run in preference to a lower priority thread even though the priority value of the higher priority thread may be numerically less than that of the lower priority thread.

Thread Primitives

Create thread

This test measures the `cyg_thread_create()` call. Each call creates a totally new thread. The set of threads created by this test will be reused in the subsequent thread primitive tests.

Yield thread

This test measures the `cyg_thread_yield()` call. For this test, there are no other runnable threads, thus the test should just measure the overhead of trying to give up the CPU.

Suspend [suspended] thread

This test measures the `cyg_thread_suspend()` call. A thread may be suspended multiple times; each thread is already suspended from its initial creation, and is suspended again.

Resume thread

This test measures the `cyg_thread_resume()` call. All of the threads have a suspend count of 2, thus this call does not make them runnable. This test just measures the overhead of resuming a thread.

Set priority

This test measures the `cyg_thread_set_priority()` call. Each thread, currently suspended, has its priority set to a new value.

Get priority

This test measures the `cyg_thread_get_priority()` call.

Kill [suspended] thread

This test measures the `cyg_thread_kill()` call. Each thread in the set is killed. All threads are known to be suspended before being killed.

Yield [no other] thread

This test measures the `cyg_thread_yield()` call again. This is to demonstrate that the `cyg_thread_yield()` call has a fixed overhead, regardless of whether there are other threads in the system.

Resume [suspended low priority] thread

This test measures the `cyg_thread_resume()` call again. In this case, the thread being resumed is lower priority than the main thread, thus it will simply become ready to run but not be granted the CPU. This test measures the cost of making a thread ready to run.

Resume [runnable low priority] thread

This test measures the `cyg_thread_resume()` call again. In this case, the thread being resumed is lower priority than the main thread and has already been made runnable, so in fact the resume call has no effect.

Suspend [runnable] thread

This test measures the `cyg_thread_suspend()` call again. In this case, each thread has already been made runnable (by previous tests).

Yield [only low priority] thread

This test measures the `cyg_thread_yield()` call. In this case, there are many other runnable threads, but they are all lower priority than the main thread, thus no thread switches will take place.

Suspend [runnable->not runnable] thread

This test measures the `cyg_thread_suspend()` call again. The thread being suspended will become non-runnable by this action.

Kill [runnable] thread

This test measures the `cyg_thread_kill()` call again. In this case, the thread being killed is currently runnable, but lower priority than the main thread.

Resume [high priority] thread

This test measures the `cyg_thread_resume()` call. The thread being resumed is higher priority than the main thread, thus a thread switch will take place on each call. In fact there will be two thread switches; one to the new higher priority thread and a second back to the test thread. The test thread exits immediately.

Thread switch

This test attempts to measure the cost of switching from one thread to another. Two equal priority threads are started and they will each yield to the other for a number of iterations. A time stamp is gathered in one thread before the `cyg_thread_yield()` call and after the call in the other thread.

Scheduler Primitives

Scheduler lock

This test measures the `cyg_scheduler_lock()` call.

Scheduler unlock [0 threads]

This test measures the `cyg_scheduler_unlock()` call. There are no other threads in the system and the unlock happens immediately after a lock so there will be no pending DSR's to run.

Scheduler unlock [1 suspended thread]

This test measures the `cyg_scheduler_unlock()` call. There is one other thread in the system which is currently suspended.

Scheduler unlock [many suspended threads]

This test measures the `cyg_scheduler_unlock()` call. There are many other threads in the system which are currently suspended. The purpose of this test is to determine the cost of having additional threads in the system when the scheduler is activated by way of `cyg_scheduler_unlock()`.

Scheduler unlock [many low priority threads]

This test measures the `cyg_scheduler_unlock()` call. There are many other threads in the system which are runnable but are lower priority than the main thread. The purpose of this test is to determine the cost of having additional threads in the system when the scheduler is activated by way of `cyg_scheduler_unlock()`.

Mutex Primitives

Init mutex

This test measures the `cyg_mutex_init()` call. A number of separate mutex variables are created. The purpose of this test is to measure the cost of creating a new mutex and introducing it to the system.

Lock [unlocked] mutex

This test measures the `cyg_mutex_lock()` call. The purpose of this test is to measure the cost of locking a mutex which is currently unlocked. There are no other threads executing in the system while this test runs.

Unlock [locked] mutex

This test measures the `cyg_mutex_unlock()` call. The purpose of this test is to measure the cost of unlocking a mutex which is currently locked. There are no other threads executing in the system while this test runs.

Trylock [unlocked] mutex

This test measures the `cyg_mutex_trylock()` call. The purpose of this test is to measure the cost of locking a mutex which is currently unlocked. There are no other threads executing in the system while this test runs.

Trylock [locked] mutex

This test measures the `cyg_mutex_trylock()` call. The purpose of this test is to measure the cost of locking a mutex which is currently locked. There are no other threads executing in the system while this test runs.

Destroy mutex

This test measures the `cyg_mutex_destroy()` call. The purpose of this test is to measure the cost of deleting a mutex from the system. There are no other threads executing in the system while this test runs.

Unlock/Lock mutex

This test attempts to measure the cost of unlocking a mutex for which there is another higher priority thread waiting. When the mutex is unlocked, the higher priority waiting thread will immediately take the lock. The time from when the unlock is issued until after the lock succeeds in the second thread is measured, thus giving the round-trip or circuit time for this type of synchronizer.

Mailbox Primitives

Create mbox

This test measures the `cyg_mbox_create()` call. A number of separate mailboxes is created. The purpose of this test is to measure the cost of creating a new mailbox and introducing it to the system.

Peek [empty] mbox

This test measures the `cyg_mbox_peek()` call. An attempt is made to peek the value in each mailbox, which is currently empty. The purpose of this test is to measure the cost of checking a mailbox for a value without blocking.

Put [first] mbox

This test measures the `cyg_mbox_put()` call. One item is added to a currently empty mailbox. The purpose of this test is to measure the cost of adding an item to a mailbox. There are no other threads currently waiting for mailbox items to arrive.

Peek [1 msg] mbox

This test measures the `cyg_mbox_peek()` call. An attempt is made to peek the value in each mailbox, which contains a single item. The purpose of this test is to measure the cost of checking a mailbox which has data to deliver.

Put [second] mbox

This test measures the `cyg_mbox_put()` call. A second item is added to a mailbox. The purpose of this test is to measure the cost of adding an additional item to a mailbox. There are no other threads currently waiting for mailbox items to arrive.

Peek [2 msgs] mbox

This test measures the `cyg_mbox_peek()` call. An attempt is made to peek the value in each mailbox, which contains two items. The purpose of this test is to measure the cost of checking a mailbox which has data to deliver.

Get [first] mbox

This test measures the `cyg_mbox_get()` call. The first item is removed from a mailbox that currently contains two items. The purpose of this test is to measure the cost of obtaining an item from a mailbox without blocking.

Get [second] mbox

This test measures the `cyg_mbox_get()` call. The last item is removed from a mailbox that currently contains one item. The purpose of this test is to measure the cost of obtaining an item from a mailbox without blocking.

Tryput [first] mbox

This test measures the `cyg_mbox_tryput()` call. A single item is added to a currently empty mailbox. The purpose of this test is to measure the cost of adding an item to a mailbox.

Peek item [non-empty] mbox

This test measures the `cyg_mbox_peek_item()` call. A single item is fetched from a mailbox that contains a single item. The purpose of this test is to measure the cost of obtaining an item without disturbing the mailbox.

Tryget [non-empty] mbox

This test measures the `cyg_mbox_tryget()` call. A single item is removed from a mailbox that contains exactly one item. The purpose of this test is to measure the cost of obtaining one item from a non-empty mailbox.

Peek item [empty] mbox

This test measures the `cyg_mbox_peek_item()` call. An attempt is made to fetch an item from a mailbox that is empty. The purpose of this test is to measure the cost of trying to obtain an item when the mailbox is empty.

Tryget [empty] mbox

This test measures the `cyg_mbox_tryget()` call. An attempt is made to fetch an item from a mailbox that is empty. The purpose of this test is to measure the cost of trying to obtain an item when the mailbox is empty.

Waiting to get mbox

This test measures the `cyg_mbox_waiting_to_get()` call. The purpose of this test is to measure the cost of determining how many threads are waiting to obtain a message from this mailbox.

Waiting to put mbox

This test measures the `cyg_mbox_waiting_to_put()` call. The purpose of this test is to measure the cost of determining how many threads are waiting to put a message into this mailbox.

Delete mbox

This test measures the `cyg_mbox_delete()` call. The purpose of this test is to measure the cost of destroying a mailbox and removing it from the system.

Put/Get mbox

In this round-trip test, one thread is sending data to a mailbox that is being consumed by another thread. The time from when the data is put into the mailbox until it has been delivered to the waiting thread is measured. Note that this time will contain a thread switch.

Semaphore Primitives

Init semaphore

This test measures the `cyg_semaphore_init()` call. A number of separate semaphore objects are created and introduced to the system. The purpose of this test is to measure the cost of creating a new semaphore.

Post [0] semaphore

This test measures the `cyg_semaphore_post()` call. Each semaphore currently has a value of 0 and there are no other threads in the system. The purpose of this test is to measure the overhead cost of posting to a semaphore. This cost will differ if there is a thread waiting for the semaphore.

Wait [1] semaphore

This test measures the `cyg_semaphore_wait()` call. The semaphore has a current value of 1 so the call is non-blocking. The purpose of the test is to measure the overhead of “taking” a semaphore.

Trywait [0] semaphore

This test measures the `cyg_semaphore_trywait()` call. The semaphore has a value of 0 when the call is made. The purpose of this test is to measure the cost of seeing if a semaphore can be “taken” without blocking. In this case, the answer would be no.

Trywait [1] semaphore

This test measures the `cyg_semaphore_trywait()` call. The semaphore has a value of 1 when the call is made. The purpose of this test is to measure the cost of seeing if a semaphore can be “taken” without blocking. In this case, the answer would be yes.

Peek semaphore

This test measures the `cyg_semaphore_peek()` call. The purpose of this test is to measure the cost of obtaining the current semaphore count value.

Destroy semaphore

This test measures the `cyg_semaphore_destroy()` call. The purpose of this test is to measure the cost of deleting a semaphore from the system.

Post/Wait semaphore

In this round-trip test, two threads are passing control back and forth by using a semaphore. The time from when one thread calls `cyg_semaphore_post()` until the other thread completes its `cyg_semaphore_wait()` is measured. Note that each iteration of this test will involve a thread switch.

Counters

Create counter

This test measures the `cyg_counter_create()` call. A number of separate counters are created. The purpose of this test is to measure the cost of creating a new counter and introducing it to the system.

Get counter value

This test measures the `cyg_counter_current_value()` call. The current value of each counter is obtained.

Set counter value

This test measures the `cyg_counter_set_value()` call. Each counter is set to a new value.

Tick counter

This test measures the `cyg_counter_tick()` call. Each counter is “ticked” once.

Delete counter

This test measures the `cyg_counter_delete()` call. Each counter is deleted from the system. The purpose of this test is to measure the cost of deleting a counter object.

Alarms

Create alarm

This test measures the `cyg_alarm_create()` call. A number of separate alarms are created, all attached to the same counter object. The purpose of this test is to measure the cost of creating a new counter and introducing it to the system.

Initialize alarm

This test measures the `cyg_alarm_initialize()` call. Each alarm is initialized to a small value.

Disable alarm

This test measures the `cyg_alarm_disable()` call. Each alarm is explicitly disabled.

Enable alarm

This test measures the `cyg_alarm_enable()` call. Each alarm is explicitly enabled.

Delete alarm

This test measures the `cyg_alarm_delete()` call. Each alarm is destroyed. The purpose of this test is to measure the cost of deleting an alarm and removing it from the system.

Tick counter [1 alarm]

This test measures the `cyg_counter_tick()` call. A counter is created that has a single alarm attached to it. The purpose of this test is to measure the cost of “ticking” a counter when it has a single attached alarm. In this test, the alarm is not activated (fired).

Tick counter [many alarms]

This test measures the `cyg_counter_tick()` call. A counter is created that has multiple alarms attached to it. The purpose of this test is to measure the cost of “ticking” a counter when it has many attached alarms. In this test, the alarms are not activated (fired).

Tick & fire counter [1 alarm]

This test measures the `cyg_counter_tick()` call. A counter is created that has a single alarm attached to it. The purpose of this test is to measure the cost of “ticking” a counter when it has a single attached alarm. In this test, the alarm is activated (fired). Thus the measured time will include the overhead of calling the alarm callback function.

Tick & fire counter [many alarms]

This test measures the `cyg_counter_tick()` call. A counter is created that has multiple alarms attached to it. The purpose of this test is to measure the cost of “ticking” a counter when it has many attached alarms. In this test, the alarms are activated (fired). Thus the measured time will include the overhead of calling the alarm callback function.

Alarm latency [0 threads]

This test attempts to measure the latency in calling an alarm callback function. The time from the clock interrupt until the alarm function is called is measured. In this test, there are no threads that can be run, other than the system idle thread, when the clock interrupt occurs (all threads are suspended).

Alarm latency [2 threads]

This test attempts to measure the latency in calling an alarm callback function. The time from the clock interrupt until the alarm function is called is measured. In this test, there are exactly two threads which are running when the clock interrupt occurs. They are simply passing back and forth by way of the `cyg_thread_yield()` call. The purpose of this test is to measure the variations in the latency when there are executing threads.

Alarm latency [many threads]

This test attempts to measure the latency in calling an alarm callback function. The time from the clock interrupt until the alarm function is called is measured. In this test, there are a number of threads which are running when the clock interrupt occurs. They are simply passing back and forth by way of the `cyg_thread_yield()` call. The purpose of this test is to measure the variations in the latency when there are many executing threads.

II. The eCos Hardware Abstraction Layer (HAL)

Chapter 1. Introduction

This is an initial specification of the *eCos* Hardware Abstraction Layer (HAL). The HAL abstracts the underlying hardware of a processor architecture and/or the platform to a level sufficient for the eCos kernel to be ported onto that platform.

Caveat: This document is an informal description of the HAL capabilities and is not intended to be full documentation, although it may be used as a source for such. It also describes the HAL as it is currently implemented for the architectures targeted in this release. It most closely describes the HALs for the MIPS, I386 and PowerPC HALs. Other architectures are similar but may not be organized precisely as described here.

Chapter 2. Architecture, Variant and Platform

We have identified three levels at which the HAL must operate.

- The *architecture HAL* abstracts the basic CPU architecture and includes things like interrupt delivery, context switching, CPU startup etc.
- The *variant HAL* encapsulates features of the CPU variant such as caches, MMU and FPU features. It also deals with any on-chip peripherals such as memory and interrupt controllers. For architectural variations, the actual implementation of the variation is often in the architectural HAL, and the variant HAL simply provides the correct configuration definitions.
- The *platform HAL* abstracts the properties of the current platform and includes things like platform startup, timer devices, I/O register access and interrupt controllers.

The boundaries between these three HAL levels are necessarily blurred since functionality shifts between levels on a target-by-target basis. For example caches and MMU may be either an architecture feature or a variant feature. Similarly, memory and interrupt controllers may be on-chip and in the variant HAL, or off-chip and in the platform HAL.

Generally there is a separate package for each of the architecture, variant and package HALs for a target. For some of the older targets, or where it would be essentially empty, the variant HAL is omitted.

Chapter 3. General principles

The HAL has been implemented according to the following general principles:

1. The HAL is implemented in C and assembler, although the eCos kernel is largely implemented in C++. This is to permit the HAL the widest possible applicability.
2. All interfaces to the HAL are implemented by CPP macros. This allows them to be implemented as inline C code, inline assembler or function calls to external C or assembler code. This allows the most efficient implementation to be selected without affecting the interface. It also allows them to be redefined if the platform or variant HAL needs to replace or enhance a definition from the architecture HAL.
3. The HAL provides simple, portable mechanisms for dealing with the hardware of a wide range of architectures and platforms. It is always possible to bypass the HAL and program the hardware directly, but this may lead to a loss of portability.

Chapter 4. HAL Interfaces

This section describes the main HAL interfaces.

Base Definitions

These are definitions that characterize the properties of the base architecture that are used to compile the portable parts of the kernel. They are concerned with such things as portable type definitions, endianness, and labeling.

These definitions are supplied by the `cyg/hal/basetype.h` header file which is supplied by the architecture HAL. It is included automatically by `cyg/infra/cyg_type.h`.

Byte order

`CYG_BYTEORDER`

This defines the byte order of the target and must be set to either `CYG_LSBFIRST` or `CYG_MSBFIRST`.

Label Translation

`CYG_LABEL_NAME(name)`

This is a wrapper used in some C and C++ files which use labels defined in assembly code or the linker script. It need only be defined if the default implementation in `cyg/infra/cyg_type.h`, which passes the name argument unaltered, is inadequate. It should be paired with `CYG_LABEL_DEFN()`.

`CYG_LABEL_DEFN(name)`

This is a wrapper used in assembler sources and linker scripts which define labels. It need only be defined if the default implementation in `cyg/infra/cyg_type.h`, which passes the name argument unaltered, is inadequate. The most usual alternative definition of this macro prepends an underscore to the label name.

Base types

```
cyg_halint8
cyg_halint16
cyg_halint32
cyg_halint64
cyg_halcount8
cyg_halcount16
cyg_halcount32
cyg_halcount64
cyg_halbool
```

These macros define the C base types that should be used to define variables of the given size. They only need to be defined if the default types specified in `cyg/infra/cyg_type.h` cannot be used. Note that these are only the base types, they will be composed with `signed` and `unsigned` to form full type specifications.

Atomic types

```
cyg_halatomic CYG_ATOMIC
```

These types are guaranteed to be read or written in a single uninterruptible operation. It is architecture defined what size this type is, but it will be at least a byte.

Architecture Characterization

These are definition that are related to the basic architecture of the CPU. These include the CPU context save format, context switching, bit twiddling, breakpoints, stack sizes and address translation.

Most of these definition are found in `cyg/hal/hal_arch.h`. This file is supplied by the architecture HAL. If there are variant or platform specific definitions then these will be found in `cyg/hal/var_arch.h` or `cyg/hal/plf_arch.h`. These files are include automatically by this header, so need not be included explicitly.

Register Save Format

```
typedef struct HAL_SavedRegisters
{
    /* architecture-dependent list of registers to be saved */
} HAL_SavedRegisters;
```

This structure describes the layout of a saved machine state on the stack. Such states are saved during thread context switches, interrupts and exceptions. Different quantities of state may be saved during each of these, but usually a thread context state is a subset of the interrupt state which is itself a subset of an exception state. For debugging purposes, the same structure is used for all three purposes, but where these states are significantly different, this structure may contain a union of the three states.

Thread Context Initialization

```
HAL_THREAD_INIT_CONTEXT( sp, arg, entry, id )
```

This macro initializes a thread's context so that it may be switched to by `HAL_THREAD_SWITCH_CONTEXT()`. The arguments are:

`sp`

A location containing the current value of the thread's stack pointer. This should be a variable or a structure field. The SP value will be read out of here and an adjusted value written back.

`arg`

A value that is passed as the first argument to the entry point function.

entry

The address of an entry point function. This will be called according the C calling conventions, and the value of *arg* will be passed as the first argument. This function should have the following type signature `void entry(CYG_ADDRWORD arg)`.

id

A thread id value. This is only used for debugging purposes, it is ORed into the initialization pattern for unused registers and may be used to help identify the thread from its register dump. The least significant 16 bits of this value should be zero to allow space for a register identifier.

Thread Context Switching

```
HAL_THREAD_LOAD_CONTEXT( to )
HAL_THREAD_SWITCH_CONTEXT( from, to )
```

These macros implement the thread switch code. The arguments are:

from

A pointer to a location where the stack pointer of the current thread will be stored.

to

A pointer to a location from where the stack pointer of the next thread will be read.

For `HAL_THREAD_LOAD_CONTEXT()` the current CPU state is discarded and the state of the destination thread is loaded. This is only used once, to load the first thread when the scheduler is started.

For `HAL_THREAD_SWITCH_CONTEXT()` the state of the current thread is saved onto its stack, using the current value of the stack pointer, and the address of the saved state placed in **from*. The value in **to* is then read and the state of the new thread is loaded from it.

While these two operations may be implemented with inline assembler, they are normally implemented as calls to assembly code functions in the HAL. There are two advantages to doing it this way. First, the return link of the call provides a convenient PC value to be used in the saved context. Second, the calling conventions mean that the compiler will have already saved the caller-saved registers before the call, so the HAL need only save the callee-saved registers.

The implementation of `HAL_THREAD_SWITCH_CONTEXT()` saves the current CPU state on the stack, including the current interrupt state (or at least the register that contains it). For debugging purposes it is useful to save the entire register set, but for performance only the ABI-defined callee-saved registers need be saved. If it is implemented, the option `CYGDBG_HAL_COMMON_CONTEXT_SAVE_MINIMUM` controls how many registers are saved.

The implementation of `HAL_THREAD_LOAD_CONTEXT()` loads a thread context, destroying the current context. With a little care this can be implemented by sharing code with `HAL_THREAD_SWITCH_CONTEXT()`. To load a thread context simply requires the saved registers to be restored from the stack and a jump or return made back to the saved PC.

Note that interrupts are not disabled during this process, any interrupts that occur will be delivered onto the stack to which the current CPU stack pointer points. Hence the stack pointer should never be invalid, or loaded with a value that might cause the saved state to become corrupted by an interrupt. However, the current interrupt state is saved and restored as part of the thread context. If a thread disables interrupts and does something to cause a context switch, interrupts may be re-enabled on switching to another thread. Interrupts will be disabled again when the original thread regains control.

Bit indexing

```
HAL_LSBIT_INDEX( index, mask )
HAL_MSBIT_INDEX( index, mask )
```

These macros place in *index* the bit index of the least significant bit in *mask*. Some architectures have instruction level support for one or other of these operations. If no architectural support is available, then these macros may call C functions to do the job.

Idle thread activity

```
HAL_IDLE_THREAD_ACTION( count )
```

It may be necessary under some circumstances for the HAL to execute code in the kernel idle thread's loop. An example might be to execute a processor halt instruction. This macro provides a portable way of doing this. The argument is a copy of the idle thread's loop counter, and may be used to trigger actions at longer intervals than every loop.

Reorder barrier

```
HAL_REORDER_BARRIER( )
```

When optimizing the compiler can reorder code. In some parts of multi-threaded systems, where the order of actions is vital, this can sometimes cause problems. This macro may be inserted into places where reordering should not happen and prevents code being migrated across it by the compiler optimizer. It should be placed between statements that must be executed in the order written in the code.

Breakpoint support

```
HAL_BREAKPOINT( label )
HAL_BREAKINST
HAL_BREAKINST_SIZE
```

These macros provide support for breakpoints.

`HAL_BREAKPOINT()` executes a breakpoint instruction. The label is defined at the breakpoint instruction so that exception code can detect which breakpoint was executed.

`HAL_BREAKINST` contains the breakpoint instruction code as an integer value. `HAL_BREAKINST_SIZE` is the size of that breakpoint instruction in bytes. Together these may be used to place a breakpoint in any code.

GDB support

```
HAL_THREAD_GET_SAVED_REGISTERS( sp, regs )
HAL_GET_GDB_REGISTERS( regval, regs )
HAL_SET_GDB_REGISTERS( regs, regval )
```

These macros provide support for interfacing GDB to the HAL.

`HAL_THREAD_GET_SAVED_REGISTERS()` extracts a pointer to a `HAL_SavedRegisters` structure from a stack pointer value. The stack pointer passed in should be the value saved by the thread context macros. The macro will assign a pointer to the `HAL_SavedRegisters` structure to the variable passed as the second argument.

`HAL_GET_GDB_REGISTERS()` translates a register state as saved by the HAL and into a register dump in the format expected by GDB. It takes a pointer to a `HAL_SavedRegisters` structure in the *regs* argument and a pointer to the memory to contain the GDB register dump in the *regval* argument.

`HAL_SET_GDB_REGISTERS()` translates a GDB format register dump into a the format expected by the HAL. It takes a pointer to the memory containing the GDB register dump in the *regval* argument and a pointer to a `HAL_SavedRegisters` structure in the *regs* argument.

Setjmp and longjmp support

```
CYGARC_JMP_BUF_SIZE
hal_jmp_buf[CYGARC_JMP_BUF_SIZE]
hal_setjmp( hal_jmp_buf env )
hal_longjmp( hal_jmp_buf env, int val )
```

These functions provide support for the C `setjmp()` and `longjmp()` functions. Refer to the C library for further information.

Stack Sizes

```
CYGNUM_HAL_STACK_SIZE_MINIMUM
CYGNUM_HAL_STACK_SIZE_TYPICAL
```

The values of these macros define the minimum and typical sizes of thread stacks.

`CYGNUM_HAL_STACK_SIZE_MINIMUM` defines the minimum size of a thread stack. This is enough for the thread to function correctly within eCos and allows it to take interrupts and context switches. There should also be enough space for a simple thread entry function to execute and call basic kernel operations on objects like mutexes and semaphores. However there will not be enough room for much more than this. When creating stacks for their own threads, applications should determine the stack usage needed for application purposes and then add `CYGNUM_HAL_STACK_SIZE_MINIMUM`.

`CYGNUM_HAL_STACK_SIZE_TYPICAL` is a reasonable increment over `CYGNUM_HAL_STACK_SIZE_MINIMUM`, usually about 1kB. This should be adequate for most modest thread needs. Only threads that need to define significant amounts of local data, or have very deep call trees should need to use a larger stack size.

Address Translation

```
CYGARC_CACHED_ADDRESS(addr)
CYGARC_UNCACHED_ADDRESS(addr)
CYGARC_PHYSICAL_ADDRESS(addr)
```

These macros provide address translation between different views of memory. In many architectures a given memory location may be visible at different addresses in both cached and uncached forms. It is also possible that the MMU or some other address translation unit in the CPU presents memory to the program at a different virtual address to its physical address on the bus.

`CYGARC_CACHED_ADDRESS()` translates the given address to its location in cached memory. This is typically where the application will access the memory.

`CYGARC_UNCACHED_ADDRESS()` translates the given address to its location in uncached memory. This is typically where device drivers will access the memory to avoid cache problems. It may additionally be necessary for the cache to be flushed before the contents of this location is fully valid.

`CYGARC_PHYSICAL_ADDRESS()` translates the given address to its location in the physical address space. This is typically the address that needs to be passed to device hardware such as a DMA engine, ethernet device or PCI bus bridge. The physical address may not be directly accessible to the program, it may be re-mapped by address translation.

Global Pointer

```
CYGARC_HAL_SAVE_GP( )  
CYGARC_HAL_RESTORE_GP( )
```

These macros insert code to save and restore any global data pointer that the ABI uses. These are necessary when switching context between two eCos instances - for example between an eCos application and RedBoot.

Interrupt Handling

These interfaces contain definitions related to interrupt handling. They include definitions of exception and interrupt numbers, interrupt enabling and masking.

These definitions are normally found in `cyg/hal/hal_intr.h`. This file is supplied by the architecture HAL. Any variant or platform specific definitions will be found in `cyg/hal/var_intr.h`, `cyg/hal/plf_intr.h` or `cyg/hal/hal_platform_ints.h` in the variant or platform HAL, depending on the exact target. These files are included automatically by this header, so need not be included explicitly.

Vector numbers

```
CYGNUM_HAL_VECTOR_XXXX  
CYGNUM_HAL_VSR_MIN  
CYGNUM_HAL_VSR_MAX  
CYGNUM_HAL_VSR_COUNT  
  
CYGNUM_HAL_INTERRUPT_XXXX  
CYGNUM_HAL_ISR_MIN  
CYGNUM_HAL_ISR_MAX  
CYGNUM_HAL_ISR_COUNT  
  
CYGNUM_HAL_EXCEPTION_XXXX  
CYGNUM_HAL_EXCEPTION_MIN  
CYGNUM_HAL_EXCEPTION_MAX  
CYGNUM_HAL_EXCEPTION_COUNT
```

All possible VSR, interrupt and exception vectors are specified here, together with maximum and minimum values for range checking. While the VSR and exception numbers will be defined in this file, the interrupt numbers will normally be defined in the variant or platform HAL file that is included by this header.

There are two ranges of numbers, those for the vector service routines and those for the interrupt service routines. The relationship between these two ranges is undefined, and no equivalence should be assumed if vectors from the two ranges coincide.

The VSR vectors correspond to the set of exception vectors that can be delivered by the CPU architecture, many of these will be internal exception traps. The ISR vectors correspond to the set of external interrupts that can be delivered and are usually determined by extra decoding of the interrupt controller by the interrupt VSR.

Where a CPU supports synchronous exceptions, the range of such exceptions allowed are defined by `CYGNUM_HAL_EXCEPTION_MIN` and `CYGNUM_HAL_EXCEPTION_MAX`. The `CYGNUM_HAL_EXCEPTION_XXXX` definitions are standard names used by target independent code to test for the presence of particular exceptions in the architecture. The actual exception numbers will normally correspond to the VSR exception range. In future other exceptions generated by the system software (such as stack overflow) may be added.

`CYGNUM_HAL_ISR_COUNT`, `CYGNUM_HAL_VSR_COUNT` and `CYGNUM_HAL_EXCEPTION_COUNT` define the number of ISRs, VSRs and EXCEPTIONs respectively for the purposes of defining arrays etc. There might be a translation from the supplied vector numbers into array offsets. Hence `CYGNUM_HAL_XXX_COUNT` may not simply be `CYGNUM_HAL_XXX_MAX - CYGNUM_HAL_XXX_MIN` or `CYGNUM_HAL_XXX_MAX+1`.

Interrupt state control

```
CYG_INTERRUPT_STATE
HAL_DISABLE_INTERRUPTS( old )
HAL_RESTORE_INTERRUPTS( old )
HAL_ENABLE_INTERRUPTS()
HAL_QUERY_INTERRUPTS( state )
```

These macros provide control over the state of the CPUs interrupt mask mechanism. They should normally manipulate a CPU status register to enable and disable interrupt delivery. They should not access an interrupt controller.

`CYG_INTERRUPT_STATE` is a data type that should be used to store the interrupt state returned by `HAL_DISABLE_INTERRUPTS()` and `HAL_QUERY_INTERRUPTS()` and passed to `HAL_RESTORE_INTERRUPTS()`.

`HAL_DISABLE_INTERRUPTS()` disables the delivery of interrupts and stores the original state of the interrupt mask in the variable passed in the `old` argument.

`HAL_RESTORE_INTERRUPTS()` restores the state of the interrupt mask to that recorded in `old`.

`HAL_ENABLE_INTERRUPTS()` simply enables interrupts regardless of the current state of the mask.

`HAL_QUERY_INTERRUPTS()` stores the state of the interrupt mask in the variable passed in the `state` argument. The state stored here should also be capable of being passed to `HAL_RESTORE_INTERRUPTS()` at a later point.

It is at the HAL implementer's discretion exactly which interrupts are masked by this mechanism. Where a CPU has more than one interrupt type that may be masked separately (e.g. the ARM's IRQ and FIQ) only those that can raise DSRs need to be masked here. A separate architecture specific mechanism may then be used to control the other interrupt types.

ISR and VSR management

```
HAL_INTERRUPT_IN_USE( vector, state )
HAL_INTERRUPT_ATTACH( vector, isr, data, object )
HAL_INTERRUPT_DETACH( vector, isr )
HAL_VSR_SET( vector, vsr, poldvsr )
HAL_VSR_GET( vector, pvsr )
HAL_VSR_SET_TO_ECOS_HANDLER( vector, poldvsr )
```

These macros manage the attachment of interrupt and vector service routines to interrupt and exception vectors respectively.

`HAL_INTERRUPT_IN_USE()` tests the state of the supplied interrupt vector and sets the value of the state parameter to either 1 or 0 depending on whether there is already an ISR attached to the vector. The HAL

will only allow one ISR to be attached to each vector, so it is a good idea to use this function before using `HAL_INTERRUPT_ATTACH()`.

`HAL_INTERRUPT_ATTACH()` attaches the ISR, data pointer and object pointer to the given *vector*. When an interrupt occurs on this vector the ISR is called using the C calling convention and the vector number and data pointer are passed to it as the first and second arguments respectively.

`HAL_INTERRUPT_DETACH()` detaches the ISR from the vector.

`HAL_VSR_SET()` replaces the VSR attached to the *vector* with the replacement supplied in *vsr*. The old VSR is returned in the location pointed to by *pvsr*. On some platforms, possibly only in certain configurations, the table of VSRs will be in read-only memory. If so then this macro should be left undefined.

`HAL_VSR_GET()` assigns a copy of the VSR to the location pointed to by *pvsr*.

`HAL_VSR_SET_TO_ECOS_HANDLER()` ensures that the VSR for a specific exception is pointing at the eCos exception VSR and not one for RedBoot or some other ROM monitor. The default when running under RedBoot is for exceptions to be handled by RedBoot and passed to GDB. This macro diverts the exception to eCos so that it may be handled by application code. The arguments are the VSR vector to be replaces, and a location in which to store the old VSR pointer, so that it may be replaced at a later point. On some platforms, possibly only in certain configurations, the table of VSRs will be in read-only memory. If so then this macro should be left undefined.

Interrupt controller management

```
HAL_INTERRUPT_MASK( vector )
HAL_INTERRUPT_UNMASK( vector )
HAL_INTERRUPT_ACKNOWLEDGE( vector )
HAL_INTERRUPT_CONFIGURE( vector, level, up )
HAL_INTERRUPT_SET_LEVEL( vector, level )
```

These macros exert control over any prioritized interrupt controller that is present. If no priority controller exists, then these macros should be empty.

Note: These macros may not be reentrant, so care should be taken to prevent them being called while interrupts are enabled. This means that they can be safely used in initialization code before interrupts are enabled, and in ISRs. In DSRs, ASRs and thread code, however, interrupts must be disabled before these macros are called. Here is an example for use in a DSR where the interrupt source is unmasked after data processing:

```
...
HAL_DISABLE_INTERRUPTS(old);
HAL_INTERRUPT_UNMASK(CYGNUM_HAL_INTERRUPT_ETH);
HAL_RESTORE_INTERRUPTS(old);
...
```

`HAL_INTERRUPT_MASK()` causes the interrupt associated with the given vector to be blocked.

`HAL_INTERRUPT_UNMASK()` causes the interrupt associated with the given vector to be unblocked.

`HAL_INTERRUPT_ACKNOWLEDGE()` acknowledges the current interrupt from the given vector. This is usually executed from the ISR for this vector when it is prepared to allow further interrupts. Most interrupt controllers need some form of acknowledge action before the next interrupt is allowed through. Executing this macro may cause another interrupt to be delivered. Whether this interrupts the current code depends on the state of the CPU interrupt mask.

`HAL_INTERRUPT_CONFIGURE()` provides control over how an interrupt signal is detected. The arguments are:

vector

The interrupt vector to be configured.

level

Set to `true` if the interrupt is detected by level, and `false` if it is edge triggered.

up

If the interrupt is set to level detect, then if this is `true` it is detected by a high signal level, and if `false` by a low signal level. If the interrupt is set to edge triggered, then if this is `true` it is triggered by a rising edge and if `false` by a falling edge.

`HAL_INTERRUPT_SET_LEVEL()` provides control over the hardware priority of the interrupt. The arguments are:

vector

The interrupt whose level is to be set.

level

The priority level to which the interrupt is to set. In some architectures the masking of an interrupt is achieved by changing its priority level. Hence this function, `HAL_INTERRUPT_MASK()` and `HAL_INTERRUPT_UNMASK()` may interfere with each other.

Clocks and Timers

These interfaces contain definitions related to clock and timer handling. They include interfaces to initialize and read a clock for generating regular interrupts, definitions for setting the frequency of the clock, and support for short timed delays.

Clock Control

```
HAL_CLOCK_INITIALIZE( period )
HAL_CLOCK_RESET( vector, period )
HAL_CLOCK_READ( pvalue )
```

These macros provide control over a clock or timer device that may be used by the kernel to provide time-out, delay and scheduling services. The clock is assumed to be implemented by some form of counter that is incremented or decremented by some external source and which raises an interrupt when it reaches a predetermined value.

`HAL_CLOCK_INITIALIZE()` initializes the timer device to interrupt at the given period. The period is essentially the value used to initialize the timer counter and must be calculated from the timer frequency and the desired interrupt rate. The timer device should generate an interrupt every `period` cycles.

`HAL_CLOCK_RESET()` re-initializes the timer to provoke the next interrupt. This macro is only really necessary when the timer device needs to be reset in some way after each interrupt.

`HAL_CLOCK_READ()` reads the current value of the timer counter and puts the value in the location pointed to by `pvalue`. The value stored will always be the number of timer cycles since the last interrupt, and hence ranges between zero and the initial period value. If this is a count-down cyclic timer, some arithmetic may be necessary to generate this value.

Microsecond Delay

`HAL_DELAY_US(us)`

This macro provides a busy loop delay for the given number of microseconds. It is intended mainly for controlling hardware that needs short delays between operations. Code which needs longer delays, of the order of milliseconds, should instead use higher-level functions such as `cyg_thread_delay`. The macro implementation should be thread-safe. It can also be used in ISRs or DSRs, although such usage is undesirable because of the impact on interrupt and dispatch latency.

The macro should never delay for less than the specified amount of time. It may delay for somewhat longer, although since the macro uses a busy loop this is a waste of cpu cycles. Of course the code invoking `HAL_DELAY_US` may get interrupted or timesliced, in which case the delay may be much longer than intended. If this is unacceptable then the calling code must take preventative action such as disabling interrupts or locking the scheduler.

There are three main ways of implementing the macro:

1. a counting loop, typically written in inline assembler, using an outer loop for the microseconds and an inner loop that consumes approximately 1us. This implementation is automatically thread-safe and does not impose any dependencies on the rest of the system, for example it does not depend on the system clock having been started. However it assumes that the cpu clock speed is known at compile-time or can be easily determined at run-time.
2. monitor one of the hardware clocks, usually the system clock. Usually this clock ticks at a rate independent of the cpu so calibration is easier. However the implementation relies on the system clock having been started, and assumes that no other code is manipulating the clock hardware. There can also be complications when the system clock wraps around.
3. a combination of the previous two. The system clock is used during system initialization to determine the cpu clock speed, and the result is then used to calibrate a counting loop. This has the disadvantage of significantly increasing the system startup time, which may be unacceptable to some applications. There are also complications if the system startup code normally runs with the cache disabled because the instruction cache will greatly affect any calibration loop.

Clock Frequency Definition

`CYGNUM_HAL_RTC_NUMERATOR`
`CYGNUM_HAL_RTC_DENOMINATOR`
`CYGNUM_HAL_RTC_PERIOD`

These macros are defined in the CDL for each platform and supply the necessary parameters to specify the frequency at which the clock interrupts. These parameters are usually found in the CDL definitions for the target platform, or in some cases the CPU variant.

`CYGNUM_HAL_RTC_NUMERATOR` and `CYGNUM_HAL_RTC_DENOMINATOR` specify the resolution of the clock interrupt. This resolution involves two separate values, the numerator and the denominator. The result of dividing the numerator by the denominator should correspond to the number of nanoseconds between clock interrupts. For example a numerator of 1000000000 and a denominator of 100 means that there are 10000000 nanoseconds (or 10 milliseconds) between clock interrupts. Expressing the resolution as a fraction minimizes clock drift even for frequencies that cannot be expressed as a simple integer. For example a frequency of 60Hz corresponds to a clock resolution of 16666666.66... nanoseconds. This can be expressed accurately as 1000000000 over 60.

CYGNUM_HAL_RTC_PERIOD specifies the exact value used to initialize the clock hardware, it is the value passed as a parameter to HAL_CLOCK_INITIALIZE() and HAL_CLOCK_RESET(). The exact meaning of the value and the range of legal values therefore depends on the target hardware, and the hardware documentation should be consulted for further details.

The default values for these macros in all HALs are calculated to give a clock interrupt frequency of 100Hz, or 10ms between interrupts. To change the clock frequency, the period needs to be changed, and the resolution needs to be adjusted accordingly. As an example consider the i386 PC target. The default values for these macros are:

```
CYGNUM_HAL_RTC_NUMERATOR      1000000000
CYGNUM_HAL_RTC_DENOMINATOR    100
CYGNUM_HAL_RTC_PERIOD         11932
```

To change to, say, a 200Hz clock the period needs to be halved to 5966, and to compensate the denominator needs to be doubled to 200. To change to a 1KHz interrupt rate change the period to 1193 and the denominator to 1000.

Some HALs make this process a little easier by deriving the period arithmetically from the denominator. This calculation may also involve the CPU clock frequency and possibly other factors. For example in the ARM AT91 variant HAL the period is defined by the following expression:

```
((CYGNUM_HAL_ARM_AT91_CLOCK_SPEED/32) / CYGNUM_HAL_RTC_DENOMINATOR)
```

In this case it is not necessary to change the period at all, just change the denominator to select the desired clock frequency. However, note that for certain choices of frequency, rounding errors in this calculation may result in a small clock drift over time. This is usually negligible, but if perfect accuracy is required, it may be necessary to adjust the frequency or period by hand.

HAL I/O

This section contains definitions for supporting access to device control registers in an architecture neutral fashion.

These definitions are normally found in the header file `cyg/hal/hal_io.h`. This file itself contains macros that are generic to the architecture. If there are variant or platform specific IO access macros then these will be found in `cyg/hal/var_io.h` and `cyg/hal/plf_io.h` in the variant or platform HALs respectively. These files are include automatically by this header, so need not be included explicitly.

This header (or more likely `cyg/hal/plf_io.h`) also defines the PCI access macros. For more information on these see the eCos PCI library reference documentation.

Register address

```
HAL_IO_REGISTER
```

This type is used to store the address of an I/O register. It will normally be a memory address, an integer port address or an offset into an I/O space. More complex architectures may need to code an address space plus offset pair into a single word, or may represent it as a structure.

Values of variables and constants of this type will usually be supplied by configuration mechanisms or in target specific headers.

Register read

```
HAL_READ_XXX( register, value )  
HAL_READ_XXX_VECTOR( register, buffer, count, stride )
```

These macros support the reading of I/O registers in various sizes. The *XXX* component of the name may be `UINT8`, `UINT16`, `UINT32`.

`HAL_READ_XXX()` reads the appropriately sized value from the register and stores it in the variable passed as the second argument.

`HAL_READ_XXX_VECTOR()` reads *count* values of the appropriate size into *buffer*. The *stride* controls how the pointer advances through the register space. A stride of zero will read the same register repeatedly, and a stride of one will read adjacent registers of the given size. Greater strides will step by larger amounts, to allow for sparsely mapped registers for example.

Register write

```
HAL_WRITE_XXX( register, value )  
HAL_WRITE_XXX_VECTOR( register, buffer, count, stride )
```

These macros support the writing of I/O registers in various sizes. The *XXX* component of the name may be `UINT8`, `UINT16`, `UINT32`.

`HAL_WRITE_XXX()` writes the appropriately sized value from the variable passed as the second argument stored it in the register.

`HAL_WRITE_XXX_VECTOR()` writes *count* values of the appropriate size from *buffer*. The *stride* controls how the pointer advances through the register space. A stride of zero will write the same register repeatedly, and a stride of one will write adjacent registers of the given size. Greater strides will step by larger amounts, to allow for sparsely mapped registers for example.

Cache Control

This section contains definitions for supporting control of the caches on the CPU.

These definitions are usually found in the header file `cyg/hal/hal_cache.h`. This file may be defined in the architecture, variant or platform HAL, depending on where the caches are implemented for the target. Often there will be a generic implementation of the cache control macros in the architecture HAL with the ability to override or undefine them in the variant or platform HAL. Even when the implementation of the cache macros is in the architecture HAL, the cache dimensions will be defined in the variant or platform HAL. As with other files, the variant or platform specific definitions are usually found in `cyg/hal/var_cache.h` and `cyg/hal/plf_cache.h` respectively. These files are included automatically by this header, so need not be included explicitly.

There are versions of the macros defined here for both the Data and Instruction caches. these are distinguished by the use of either `DCACHE` or `ICACHE` in the macro names. Some architectures have a unified cache, where both data and instruction share the same cache. In these cases the control macros use `UCACHE` and the `DCACHE` and `ICACHE` macros will just be calls to the `UCACHE` version. In the following descriptions, `XCACHE` is used to stand for any of these. Where there are issues specific to a particular cache, this will be explained in the text.

There might be target specific restrictions on the use of some of the macros which it is the user's responsibility to comply with. Such restrictions are documented in the header file with the macro definition.

Note that destructive cache macros should be used with caution. Preceding a cache invalidation with a cache synchronization is not safe in itself since an interrupt may happen after the synchronization but before the invalidation. This might cause the state of dirty data lines created during the interrupt to be lost.

Depending on the architecture's capabilities, it may be possible to temporarily disable the cache while doing the synchronization and invalidation which solves the problem (no new data would be cached during an interrupt). Otherwise it is necessary to disable interrupts while manipulating the cache which may take a long time.

Some platform HALs now support a pair of cache state query macros: `HAL_ICACHE_IS_ENABLED(x)` and `HAL_DCACHE_IS_ENABLED(x)` which set the argument to true if the instruction or data cache is enabled, respectively. Like most cache control macros, these are optional, because the capabilities of different targets and boards can vary considerably. Code which uses them, if it is to be considered portable, should test for their existence first by means of `#ifdef`. Be sure to include `<cyg/hal/hal_cache.h>` in order to do this test and (maybe) use the macros.

Cache Dimensions

```
HAL_XCACHE_SIZE
HAL_XCACHE_LINE_SIZE
HAL_XCACHE_WAYS
HAL_XCACHE_SETS
```

These macros define the size and dimensions of the Instruction and Data caches.

HAL_XCACHE_SIZE

Defines the total size of the cache in bytes.

HAL_XCACHE_LINE_SIZE

Defines the cache line size in bytes.

HAL_XCACHE_WAYS

Defines the number of ways in each set and defines its level of associativity. This would be 1 for a direct mapped cache, 2 for a 2-way cache, 4 for 4-way and so on.

HAL_XCACHE_SETS

Defines the number of sets in the cache, and is calculated from the previous values.

Global Cache Control

```
HAL_XCACHE_ENABLE( )
HAL_XCACHE_DISABLE( )
HAL_XCACHE_INVALIDATE_ALL( )
HAL_XCACHE_SYNC( )
HAL_XCACHE_BURST_SIZE( size )
HAL_DCACHE_WRITE_MODE( mode )
HAL_XCACHE_LOCK( base, size )
HAL_XCACHE_UNLOCK( base, size )
HAL_XCACHE_UNLOCK_ALL( )
```

These macros affect the state of the entire cache, or a large part of it.

HAL_XCACHE_ENABLE() and HAL_XCACHE_DISABLE()

Enable and disable the cache.

HAL_XCACHE_INVALIDATE_ALL()

Causes the entire contents of the cache to be invalidated. Depending on the hardware, this may require the cache to be disabled during the invalidation process. If so, the implementation must use `HAL_XCACHE_IS_ENABLED()` to save and restore the previous state.

Note: If this macro is called after `HAL_XCACHE_SYNC()` with the intention of clearing the cache (invalidating the cache after writing dirty data back to memory), you must prevent interrupts from happening between the two calls:

```
...
HAL_DISABLE_INTERRUPTS(old);
HAL_XCACHE_SYNC();
HAL_XCACHE_INVALIDATE_ALL();
HAL_RESTORE_INTERRUPTS(old);
...
```

Since the operation may take a very long time, real-time responsiveness could be affected, so only do this when it is absolutely required and you know the delay will not interfere with the operation of drivers or the application.

HAL_XCACHE_SYNC()

Causes the contents of the cache to be brought into synchronization with the contents of memory. In some implementations this may be equivalent to `HAL_XCACHE_INVALIDATE_ALL()`.

HAL_XCACHE_BURST_SIZE()

Allows the size of cache to/from memory bursts to be controlled. This macro will only be defined if this functionality is available.

HAL_DCACHE_WRITE_MODE()

Controls the way in which data cache lines are written back to memory. There will be definitions for the possible modes. Typical definitions are `HAL_DCACHE_WRITEBACK_MODE` and `HAL_DCACHE_WRITETHRU_MODE`. This macro will only be defined if this functionality is available.

HAL_XCACHE_LOCK()

Causes data to be locked into the cache. The base and size arguments define the memory region that will be locked into the cache. It is architecture dependent whether more than one locked region is allowed at any one time, and whether this operation causes the cache to cease acting as a cache for addresses outside the region during the duration of the lock. This macro will only be defined if this functionality is available.

HAL_XCACHE_UNLOCK()

Cancels the locking of the memory region given. This should normally correspond to a region supplied in a matching lock call. This macro will only be defined if this functionality is available.

HAL_XCACHE_UNLOCK_ALL()

Cancels all existing locked memory regions. This may be required as part of the cache initialization on some architectures. This macro will only be defined if this functionality is available.

Cache Line Control

```

HAL_DCACHE_ALLOCATE( base , size )
HAL_DCACHE_FLUSH( base , size )
HAL_XCACHE_INVALIDATE( base , size )
HAL_DCACHE_STORE( base , size )
HAL_DCACHE_READ_HINT( base , size )
HAL_DCACHE_WRITE_HINT( base , size )
HAL_DCACHE_ZERO( base , size )

```

All of these macros apply a cache operation to all cache lines that match the memory address region defined by the base and size arguments. These macros will only be defined if the described functionality is available. Also, it is not guaranteed that the cache function will only be applied to just the described regions, in some architectures it may be applied to the whole cache.

HAL_DCACHE_ALLOCATE()

Allocates lines in the cache for the given region without reading their contents from memory, hence the contents of the lines is undefined. This is useful for preallocating lines which are to be completely overwritten, for example in a block copy operation.

HAL_DCACHE_FLUSH()

Invalidates all cache lines in the region after writing any dirty lines to memory.

HAL_XCACHE_INVALIDATE()

Invalidates all cache lines in the region. Any dirty lines are invalidated without being written to memory.

HAL_DCACHE_STORE()

Writes all dirty lines in the region to memory, but does not invalidate any lines.

HAL_DCACHE_READ_HINT()

Hints to the cache that the region is going to be read from in the near future. This may cause the region to be speculatively read into the cache.

HAL_DCACHE_WRITE_HINT()

Hints to the cache that the region is going to be written to in the near future. This may have the identical behavior to HAL_DCACHE_READ_HINT().

HAL_DCACHE_ZERO()

Allocates and zeroes lines in the cache for the given region without reading memory. This is useful if a large area of memory is to be cleared.

Linker Scripts

When an eCos application is linked it must be done under the control of a linker script. This script defines the memory areas, addresses and sized, into which the code and data are to be put, and allocates the various sections generated by the compiler to these.

The linker script actually used is in `lib/target.ld` in the install directory. This is actually manufactured out of two other files: a base linker script and an `.ldi` file that was generated by the memory layout tool.

The base linker script is usually supplied either by the architecture HAL or the variant HAL. It consists of a set of linker script fragments, in the form of C preprocessor macros, that define the major output sections to be generated by the link operation. The `.ldi` file, which is `#include'd` by the base linker script, uses these macro definitions to assign the output sections to the required memory areas and link addresses.

The `.ldi` file is supplied by the platform HAL, and contains knowledge of the memory layout of the target platform. These files generally conform to a standard naming convention, each file being of the form:

```
pkgconf/mlt_<architecture>_<variant>_<platform>_<startup>.ldi
```

where `<architecture>`, `<variant>` and `<platform>` are the respective HAL package names and `<startup>` is the startup type which is usually one of ROM, RAM or ROMRAM.

In addition to the `.ldi` file, there is also a congruously name `.h` file. This may be used by the application to access information defined in the `.ldi` file. Specifically it contains the memory layout defined there, together with any additional section names defined by the user. Examples of the latter are heap areas or PCI bus memory access windows.

The `.ldi` is manufactured by the Memory Layout Tool (MLT). The MLT saves the memory configuration into a file named

```
include/pkgconf/mlt_<architecture>_<variant>_<platform>_<startup>.mlt
```

in the platform HAL. This file is used by the MLT to manufacture both the `.ldi` and `.h` files. Users should beware that direct edits to either of these files may be overwritten if the MLT is run and regenerates them from the `.mlt` file.

The names of the `.ldi` and `.h` files are defined by macro definitions in `pkgconf/system.h`. These are `CYGHWR_MEMORY_LAYOUT_LDI` and `CYGHWR_MEMORY_LAYOUT_H` respectively. While there will be little need for the application to refer to the `.ldi` file directly, it may include the `.h` file as follows:

```
#include CYGHWR_MEMORY_LAYOUT_H
```

Diagnostic Support

The HAL provides support for low level diagnostic IO. This is particularly useful during early development as an aid to bringing up a new platform. Usually this diagnostic channel is a UART or some other serial IO device, but it may equally be a memory buffer, a simulator supported output channel, a ROM emulator virtual UART, and LCD panel, a memory mapped video buffer or any other output device.

`HAL_DIAG_INIT()` performs any initialization required on the device being used to generate diagnostic output. This may include, for a UART, setting baud rate, and stop, parity and character bits. For other devices it may include initializing a controller or establishing contact with a remote device.

`HAL_DIAG_WRITE_CHAR(c)` writes the character supplied to the diagnostic output device.

`HAL_DIAG_READ_CHAR(c)` reads a character from the diagnostic device into the supplied variable. This is not supported for all diagnostic devices.

These macros are defined in the header file `cyg/hal/hal_diag.h`. This file is usually supplied by the variant or platform HAL, depending on where the IO device being used is located. For example for on-chip UARTs it would be in the variant HAL, but for a board-level LCD panel it would be in the platform HAL.

SMP Support

eCos contains support for limited Symmetric Multi-Processing (SMP). This is only available on selected architectures and platforms.

Target Hardware Limitations

To allow a reasonable implementation of SMP, and to reduce the disruption to the existing source base, a number of assumptions have been made about the features of the target hardware.

- Modest multiprocessing. The typical number of CPUs supported is two to four, with an upper limit around eight. While there are no inherent limits in the code, hardware and algorithmic limitations will probably become significant beyond this point.
- SMP synchronization support. The hardware must supply a mechanism to allow software on two CPUs to synchronize. This is normally provided as part of the instruction set in the form of test-and-set, compare-and-swap or load-link/store-conditional instructions. An alternative approach is the provision of hardware semaphore registers which can be used to serialize implementations of these operations. Whatever hardware facilities are available, they are used in eCos to implement spinlocks.
- Coherent caches. It is assumed that no extra effort will be required to access shared memory from any processor. This means that either there are no caches, they are shared by all processors, or are maintained in a coherent state by the hardware. It would be too disruptive to the eCos sources if every memory access had to be bracketed by cache load/flush operations. Any hardware that requires this is not supported.
- Uniform addressing. It is assumed that all memory that is shared between CPUs is addressed at the same location from all CPUs. Like non-coherent caches, dealing with CPU-specific address translation is considered too disruptive to the eCos source base. This does not, however, preclude systems with non-uniform access costs for different CPUs.
- Uniform device addressing. As with access to memory, it is assumed that all devices are equally accessible to all CPUs. Since device access is often made from thread contexts, it is not possible to restrict access to device control registers to certain CPUs, since there is currently no support for binding or migrating threads to CPUs.
- Interrupt routing. The target hardware must have an interrupt controller that can route interrupts to specific CPUs. It is acceptable for all interrupts to be delivered to just one CPU, or for some interrupts to be bound to specific CPUs, or for some interrupts to be local to each CPU. At present dynamic routing, where a different CPU may be chosen each time an interrupt is delivered, is not supported. eCos cannot support hardware where all interrupts are delivered to all CPUs simultaneously with the expectation that software will resolve any conflicts.
- Inter-CPU interrupts. A mechanism to allow one CPU to interrupt another is needed. This is necessary so that events on one CPU can cause rescheduling on other CPUs.
- CPU Identifiers. Code running on a CPU must be able to determine which CPU it is running on. The CPU Id is usually provided either in a CPU status register, or in a register associated with the inter-CPU interrupt delivery subsystem. eCos expects CPU Ids to be small positive integers, although alternative representations, such as bitmaps, can be converted relatively easily. Complex mechanisms for getting the CPU Id cannot be supported. Getting the CPU Id must be a cheap operation, since it is done often, and in performance critical places such as interrupt handlers and the scheduler.

HAL Support

SMP support in any platform depends on the HAL supplying the appropriate operations. All HAL SMP support is defined in the `cyg/hal/hal_smp.h` header. Variant and platform specific definitions will be in `cyg/hal/var_smp.h` and `cyg/hal/plf_smp.h` respectively. These files are include automatically by this header, so need not be included explicitly.

SMP support falls into a number of functional groups.

CPU Control

This group consists of descriptive and control macros for managing the CPUs in an SMP system.

`HAL_SMP_CPU_TYPE`

A type that can contain a CPU id. A CPU id is usually a small integer that is used to index arrays of variables that are managed on an per-CPU basis.

`HAL_SMP_CPU_MAX`

The maximum number of CPUs that can be supported. This is used to provide the size of any arrays that have an element per CPU.

`HAL_SMP_CPU_COUNT()`

Returns the number of CPUs currently operational. This may differ from `HAL_SMP_CPU_MAX` depending on the runtime environment.

`HAL_SMP_CPU_THIS()`

Returns the CPU id of the current CPU.

`HAL_SMP_CPU_NONE`

A value that does not match any real CPU id. This is uses where a CPU type variable must be set to a null value.

`HAL_SMP_CPU_START(cpu)`

Starts the given CPU executing at a defined HAL entry point. After performing any HAL level initialization, the CPU calls up into the kernel at `cyg_kernel_cpu_startup()`.

`HAL_SMP_CPU_RESCHEDULE_INTERRUPT(cpu, wait)`

Sends the CPU a reschedule interrupt, and if *wait* is non-zero, waits for an acknowledgment. The interrupted CPU should call `cyg_scheduler_set_need_reschedule()` in its DSR to cause the reschedule to occur.

`HAL_SMP_CPU_TIMESLICE_INTERRUPT(cpu, wait)`

Sends the CPU a timeslice interrupt, and if *wait* is non-zero, waits for an acknowledgment. The interrupted CPU should call `cyg_scheduler_timeslice_cpu()` to cause the timeslice event to be processed.

Test-and-set Support

Test-and-set is the foundation of the SMP synchronization mechanisms.

`HAL_TAS_TYPE`

The type for all test-and-set variables. The test-and-set macros only support operations on a single bit (usually the least significant bit) of this location. This allows for maximum flexibility in the implementation.

`HAL_TAS_SET(tas, oldb)`

Performs a test and set operation on the location *tas*. *oldb* will contain `true` if the location was already set, and `false` if it was clear.

`HAL_TAS_CLEAR(tas, oldb)`

Performs a test and clear operation on the location *tas*. *oldb* will contain `true` if the location was already set, and `false` if it was clear.

Spinlocks

Spinlocks provide inter-CPU locking. Normally they will be implemented on top of the test-and-set mechanism above, but may also be implemented by other means if, for example, the hardware has more direct support for spinlocks.

`HAL_SPINLOCK_TYPE`

The type for all spinlock variables.

`HAL_SPINLOCK_INIT_CLEAR`

A value that may be assigned to a spinlock variable to initialize it to clear.

`HAL_SPINLOCK_INIT_SET`

A value that may be assigned to a spinlock variable to initialize it to set.

`HAL_SPINLOCK_SPIN(lock)`

The caller spins in a busy loop waiting for the lock to become clear. It then sets it and continues. This is all handled atomically, so that there are no race conditions between CPUs.

`HAL_SPINLOCK_CLEAR(lock)`

The caller clears the lock. One of any waiting spinners will then be able to proceed.

`HAL_SPINLOCK_TRY(lock, val)`

Attempts to set the lock. The value put in *val* will be `true` if the lock was claimed successfully, and `false` if it was not.

`HAL_SPINLOCK_TEST(lock, val)`

Tests the current value of the lock. The value put in *val* will be `true` if the lock is claimed and `false` if it is clear.

Scheduler Lock

The scheduler lock is the main protection for all kernel data structures. By default the kernel implements the scheduler lock itself using a spinlock. However, if spinlocks cannot be supported by the hardware, or there is a more efficient implementation available, the HAL may provide macros to implement the scheduler lock.

HAL_SMP_SCHEDLOCK_DATA_TYPE

A data type, possibly a structure, that contains any data items needed by the scheduler lock implementation. A variable of this type will be instantiated as a static member of the `Cyg_Scheduler_SchedLock` class and passed to all the following macros.

HAL_SMP_SCHEDLOCK_INIT(*lock*, *data*)

Initialize the scheduler lock. The *lock* argument is the scheduler lock counter and the *data* argument is a variable of `HAL_SMP_SCHEDLOCK_DATA_TYPE` type.

HAL_SMP_SCHEDLOCK_INC(*lock*, *data*)

Increment the scheduler lock. The first increment of the lock from zero to one for any CPU may cause it to wait until the lock is zeroed by another CPU. Subsequent increments should be less expensive since this CPU already holds the lock.

HAL_SMP_SCHEDLOCK_ZERO(*lock*, *data*)

Zero the scheduler lock. This operation will also clear the lock so that other CPUs may claim it.

HAL_SMP_SCHEDLOCK_SET(*lock*, *data*, *new*)

Set the lock to a different value, in *new*. This is only called when the lock is already known to be owned by the current CPU. It is never called to zero the lock, or to increment it from zero.

Interrupt Routing

The routing of interrupts to different CPUs is supported by two new interfaces in `hal_intr.h`.

Once an interrupt has been routed to a new CPU, the existing vector masking and configuration operations should take account of the CPU routing. For example, if the operation is not invoked on the destination CPU itself, then the HAL may need to arrange to transfer the operation to the destination CPU for correct application.

HAL_INTERRUPT_SET_CPU(*vector*, *cpu*)

Route the interrupt for the given *vector* to the given *cpu*.

HAL_INTERRUPT_GET_CPU(*vector*, *cpu*)

Set *cpu* to the id of the CPU to which this vector is routed.

Chapter 5. Exception Handling

Most of the HAL consists of simple macros or functions that are called via the interfaces described in the previous section. These just perform whatever operation is required by accessing the hardware and then return. The exception to this is the handling of exceptions: either synchronous hardware traps or asynchronous device interrupts. Here control is passed first to the HAL, which then passed it on to eCos or the application. After eCos has finished with it, control is then passed back to the HAL for it to tidy up the CPU state and resume processing from the point at which the exception occurred.

The HAL exceptions handling code is usually found in the file `vectors.S` in the architecture HAL. Since the reset entry point is usually implemented as one of these it also deals with system startup.

The exact implementation of this code is under the control of the HAL implementer. So long as it interacts correctly with the interfaces defined previously it may take any form. However, all current implementation follow the same pattern, and there should be a very good reason to break with this. The rest of this section describes these operate.

Exception handling normally deals with the following broad areas of functionality:

- Startup and initialization.
- Hardware exception delivery.
- Default handling of synchronous exceptions.
- Default handling of asynchronous interrupts.

HAL Startup

Execution normally begins at the reset vector with the machine in a minimal startup state. From here the HAL needs to get the machine running, set up the execution environment for the application, and finally invoke its entry point.

The following is a list of the jobs that need to be done in approximately the order in which they should be accomplished. Many of these will not be needed in some configurations.

- Initialize the hardware. This may involve initializing several subsystems in both the architecture, variant and platform HALs. These include:
 - Initialize various CPU status registers. Most importantly, the CPU interrupt mask should be set to disable interrupts.
 - Initialize the MMU, if it is used. On many platforms it is only possible to control the cacheability of address ranges via the MMU. Also, it may be necessary to remap RAM and device registers to locations other than their defaults. However, for simplicity, the mapping should be kept as close to one-to-one physical-to-virtual as possible.
 - Set up the memory controller to access RAM, ROM and I/O devices correctly. Until this is done it may not be possible to access RAM. If this is a ROMRAM startup then the program code can now be copied to its RAM address and control transferred to it.
 - Set up any bus bridges and support chips. Often access to device registers needs to go through various bus bridges and other intermediary devices. In many systems these are combined with the memory controller,

- so it makes sense to set these up together. This is particularly important if early diagnostic output needs to go through one of these devices.
- Set up diagnostic mechanisms. If the platform includes an LED or LCD output device, it often makes sense to output progress indications on this during startup. This helps with diagnosing hardware and software errors.
- Initialize floating point and other extensions such as SIMD and multimedia engines. It is usually necessary to enable these and maybe initialize control and exception registers for these extensions.
- Initialize interrupt controller. At the very least, it should be configured to mask all interrupts. It may also be necessary to set up the mapping from the interrupt controller's vector number space to the CPU's exception number space. Similar mappings may need to be set up between primary and secondary interrupt controllers.
- Disable and initialize the caches. The caches should not normally be enabled at this point, but it may be necessary to clear or initialize them so that they can be enabled later. Some architectures require that the caches be explicitly reinitialized after a power-on reset.
- Initialize the timer, clock etc. While the timer used for RTC interrupts will be initialized later, it may be necessary to set up the clocks that drive it here.

The exact order in which these initializations is done is architecture or variant specific. It is also often not necessary to do anything at all for some of these options. These fragments of code should concentrate on getting the target up and running so that C function calls can be made and code can be run. More complex initializations that cannot be done in assembly code may be postponed until calls to `hal_variant_init()` or `hal_platform_init()` are made.

Not all of these initializations need to be done for all startup types. In particular, RAM startups can reasonably assume that the ROM monitor or loader has already done most of this work.

- Set up the stack pointer, this allows subsequent initialization code to make proper procedure calls. Usually the interrupt stack is used for this purpose since it is available, large enough, and will be reused for other purposes later.
- Initialize any global pointer register needed for access to globally defined variables. This allows subsequent initialization code to access global variables.
- If the system is starting from ROM, copy the ROM template of the `.data` section out to its correct position in RAM. (the Section called *Linker Scripts* in Chapter 4).
- Zero the `.bss` section.
- Create a suitable C call stack frame. This may involve making stack space for call frames, and arguments, and initializing the back pointers to halt a GDB backtrace operation.
- Call `hal_variant_init()` and `hal_platform_init()`. These will perform any additional initialization needed by the variant and platform. This typically includes further initialization of the interrupt controller, PCI bus bridges, basic IO devices and enabling the caches.
- Call `cyg_hal_invoke_constructors()` to run any static constructors.
- Call `cyg_start()`. If `cyg_start()` returns, drop into an infinite loop.

Vectors and VSRs

The CPU delivers all exceptions, whether synchronous faults or asynchronous interrupts, to a set of hardware defined vectors. Depending on the architecture, these may be implemented in a number of different ways.

Examples of existing mechanisms are:

PowerPC

Exceptions are vectored to locations 256 bytes apart starting at either zero or 0xFFF00000. There are 16 such vectors defined by the basic architecture and extra vectors may be defined by specific variants. One of the base vectors is for all external interrupts, and another is for the architecture defined timer.

MIPS

Most exceptions and all interrupts are vectored to a single address at either 0x80000000 or 0xBFC00180. Software is responsible for reading the exception code from the CPU `cause` register to discover its true source. Some TLB and debug exceptions are delivered to different vector addresses, but these are not used currently by eCos. One of the exception codes in the `cause` register indicates an external interrupt. Additional bits in the `cause` register provide a first-level decode for the interrupt source, one of which represents an architecture defined timer.

IA32

Exceptions are delivered via an Interrupt Descriptor Table (IDT) which is essentially an indirection table indexed by exception number. The IDT may be placed anywhere in memory. In PC hardware the standard interrupt controller can be programmed to deliver the external interrupts to a block of 16 vectors at any offset in the IDT. There is no hardware supplied mechanism for determining the vector taken, other than from the address jumped to.

ARM

All exceptions, including the FIQ and IRQ interrupts, are vectored to locations four bytes apart starting at zero. There is only room for one instruction here, which must immediately jump out to handling code higher in memory. Interrupt sources have to be decoded entirely from the interrupt controller.

With such a wide variety of hardware approaches, it is not possible to provide a generic mechanism for the substitution of exception vectors directly. Therefore, eCos translates all of these mechanisms in to a common approach that can be used by portable code on all platforms.

The mechanism implemented is to attach to each hardware vector a short piece of trampoline code that makes an indirect jump via a table to the actual handler for the exception. This handler is called the Vector Service Routine (VSR) and the table is called the VSR table.

The trampoline code performs the absolute minimum processing necessary to identify the exception source, and jump to the VSR. The VSR is then responsible for saving the CPU state and taking the necessary actions to handle the exception or interrupt. The entry conditions for the VSR are as close to the raw hardware exception entry state as possible - although on some platforms the trampoline will have had to move or reorganize some registers to do its job.

To make this more concrete, consider how the trampoline code operates in each of the architectures described above:

PowerPC

A separate trampoline is contained in each of the vector locations. This code saves a few work registers away to the special purposes registers available, loads the exception number into a register and then uses that to index the VSR table and jump to the VSR. The VSR is entered with some registers move to the SPRs, and one of the data register containing the number of the vector taken.

MIPS

A single trampoline routine attached to the common vector reads the exception code out of the `cause` register and uses that value to index the VSR table and jump to the VSR. The trampoline uses the two registers defined in the ABI for kernel use to do this, one of these will contain the exception vector number for the VSR.

IA32

There is a separate 3 or 4 instruction trampoline pointed to by each active IDT table entry. The trampoline for exceptions that also have an error code pop it from the stack and put it into a memory location. Trampolines for non-error-code exceptions just zero the memory location. Then all trampolines push an interrupt/exception number onto the stack, and take an indirect jump through a precalculated offset in the VSR table. This is all done without saving any registers, using memory-only operations. The VSR is entered with the vector number pushed onto the stack on top of the standard hardware saved state.

ARM

The trampoline consists solely of the single instruction at the exception entry point. This is an indirect jump via a location 32 bytes higher in memory. These locations, from `0x20` up, form the VSR table. Since each VSR is entered in a different CPU mode (`SVC`, `UNDEF`, `ABORT`, `IRQ` or `FIQ`) there has to be a different VSR for each exception that knows how to save the CPU state correctly.

Default Synchronous Exception Handling

Most synchronous exception VSR table entries will point to a default exception VSR which is responsible for handling all exceptions in a generic manner. The default VSR simply saves the CPU state, makes any adjustments to the CPU state that is necessary, and calls `cyg_hal_exception_handler()`.

`cyg_hal_exception_handler()` needs to pass the exception on to some handling code. There are two basic destinations: enter GDB or pass the exception up to eCos. Exactly which destination is taken depends on the configuration. When the GDB stubs are included then the exception is passed to them, otherwise it is passed to eCos.

If an eCos application has been loaded by RedBoot then the VSR table entries will all point into RedBoot's exception VSR, and will therefore enter GDB if an exception occurs. If the eCos application wants to handle an exception itself, it needs to replace the the VSR table entry with one pointing to its own VSR. It can do this with the `HAL_VSR_SET_TO_ECOS_HANDLER()` macro.

Default Interrupt Handling

Most asynchronous external interrupt vectors will point to a default interrupt VSR which decodes the actual interrupt being delivered from the interrupt controller and invokes the appropriate ISR.

The default interrupt VSR has a number of responsibilities if it is going to interact with the Kernel cleanly and allow interrupts to cause thread preemption.

To support this VSR an ISR vector table is needed. For each valid vector three pointers need to be stored: the ISR, its data pointer and an opaque (to the HAL) interrupt object pointer needed by the kernel. It is implementation defined whether these are stored in a single table of triples, or in three separate tables.

The VSR follows the following approximate plan:

1. Save the CPU state. In non-debug configurations, it may be possible to get away with saving less than the entire machine state. The option `CYGDBG_HAL_COMMON_INTERRUPTS_SAVE_MINIMUM_CONTEXT` is supported in some targets to do this.
2. Increment the kernel scheduler lock. This is a static member of the `Cyg_Scheduler` class, however it has also been aliased to `cyg_scheduler_sched_lock` so that it can be accessed from assembly code.
3. (Optional) Switch to an interrupt stack if not already running on it. This allows nested interrupts to be delivered without needing every thread to have a stack large enough to take the maximum possible nesting. It is implementation defined how to detect whether this is a nested interrupt but there are two basic techniques. The first is to inspect the stack pointer and switch only if it is not currently within the interrupt stack range; the second is to maintain a counter of the interrupt nesting level and switch only if it is zero. The option `CYGIMP_HAL_COMMON_INTERRUPTS_USE_INTERRUPT_STACK` controls whether this happens.
4. Decode the actual external interrupt being delivered from the interrupt controller. This will yield the ISR vector number. The code to do this usually needs to come from the variant or platform HAL, so is usually present in the form of a macro or procedure callout.
5. (Optional) Re-enable interrupts to permit nesting. At this point we can potentially allow higher priority interrupts to occur. It depends on the interrupt architecture of the CPU and platform whether more interrupts will occur at this point, or whether they will only be delivered after the current interrupt has been acknowledged (by a call to `HAL_INTERRUPT_ACKNOWLEDGE()` in the ISR).
6. Using the ISR vector number as an index, retrieve the ISR pointer and its data pointer from the ISR vector table.
7. Construct a C call stack frame. This may involve making stack space for call frames, and arguments, and initializing the back pointers to halt a GDB backtrace operation.
8. Call the ISR, passing the vector number and data pointer. The vector number and a pointer to the saved state should be preserved across this call, preferably by storing them in registers that are defined to be callee-saved by the calling conventions.
9. If this is an un-nested interrupt and a separate interrupt stack is being used, switch back to the interrupted thread's own stack.
10. Use the saved ISR vector number to get the interrupt object pointer from the ISR vector table.
11. Call `interrupt_end()` passing it the return value from the ISR, the interrupt object pointer and a pointer to the saved CPU state. This function is implemented by the Kernel and is responsible for finishing off the interrupt handling. Specifically, it may post a DSR depending on the ISR return value, and will decrement the scheduler lock. If the lock is zeroed by this operation then any posted DSRs may be called and may in turn result in a thread context switch.
12. The return from `interrupt_end()` may occur some time after the call. Many other threads may have executed in the meantime. So here all we may do is restore the machine state and resume execution of the interrupted thread. Depending on the architecture, it may be necessary to disable interrupts again for part of this.

The detailed order of these steps may vary slightly depending on the architecture, in particular where interrupts are enabled and disabled.

HAL GDB File I/O Routines

Name

`hal_gdb_fileio` — access host file system

Synopsis

```
#include <cyg/hal/hal_gdb_fileio.h>

int hal_gdb_fileio_open(const char* path, int flags, int mode);
int hal_gdb_fileio_close(int fd);
int hal_gdb_fileio_read(int fd, void* buffer, int count);
int hal_gdb_fileio_write(int fd, const void* buffer, int count);
cyg_int32 hal_gdb_fileio_lseek(int fd, cyg_int32 offset, int whence);
int hal_gdb_fileio_rename(const char* oldpath, const char* newpath);
int hal_gdb_fileio_unlink(const char* path);
int hal_gdb_fileio_stat(const char* path, struct hal_gdb_fileio_stat* stat);
int hal_gdb_fileio_fstat(int fd, struct hal_gdb_fileio_stat* stat);
int hal_gdb_fileio_gettimeofday(struct hal_gdb_fileio_timeval* tv, void * tz);
int hal_gdb_fileio_isatty(int fd);
int hal_gdb_fileio_system(const char* command);
```

Description

In some configurations an eCos application can perform a number of file I/O and other operations on the host by interacting with gdb. For example the application can open a log file to the host and write very large amounts of debug data to that file over a period of time while consuming minimal target-side resources. However, the application will be completely blocked for the duration of the I/O operation with interrupts globally disabled. The functionality uses the gdb File I/O Remote Protocol Extension, described in the Remote Protocol appendix of the gdb documentation.

The gdb file I/O support is only available when the configuration option `CYGFUN_HAL_GDB_FILEIO` is enabled. In turn that option will have dependencies on other parts of the HAL, and the required functionality will not be available for all targets.

When debugging involves a hardware debug solution such as jtag or BDM, typically gdb will interact with a remote protocol server running inside or controlling the hardware debug unit. That server will implement the core parts of the remote protocol such as accessing memory, but typically there will be no way for the eCos application to get the server to send specific requests such as for file I/O. Instead a different approach is used. From inside the gdb session the command **set hwdebug** should be used. The next time the eCos application attempts a file I/O operation it will cause execution to halt at `_gdb_hwdebug_breakpoint`. Code inside gdb recognises that address, retrieves details of the I/O request from the target's memory, and then acts as if the request had come in a remote protocol message. The target resumes execution automatically once the I/O operation has been performed. If the `hwdebug` flag has not been set or if the application is running outside a gdb debug session then all file I/O operations will fail with error code `HAL_GDB_FILEIO_ENOSYS`.

The Functions

Full details of the functions, parameters, data structures and error codes can be found in the header file `cyg/hal/hal_gdb_fileio.h`. The I/O calls are loosely modelled after the equivalent POSIX calls. They return 0 or a positive number for success, a negative number to indicate an error. The specific error code is the absolute value of the return value, so for example `hal_gdb_fileio_open` will return `-HAL_GDB_FILEIO_ENOENT` when attempting to open a file that does not exist. Some example code can be found in the testcase `gdb_fileio.c`.

`hal_gdb_fileio_open` is used to open a file on the host file system. It should only be used on files, not on special devices such as serial port or Unix-domain sockets: the gdb file I/O functionality is limited and has no support for `select`, non-blocking I/O, `ioctl`-style control, and so on. Hence if the eCos application does attempt to open and read from a serial port that will cause gdb to block and both the application and the debug session will freeze. Valid flags include `HAL_GDB_FILEIO_O_RDONLY`, `HAL_GDB_FILEIO_O_WRONLY`, and `HAL_GDB_FILEIO_O_CREAT`. The *mode* argument is used only when creating a new file and is used to set the access rights, for example `HAL_GDB_FILEIO_S_IURSR+HAL_GDB_FILEIO_S_IWUSR`.

The return value of `hal_gdb_fileio_open` is an integer file descriptor. Note that this is distinct from the file descriptor returned by the eCos `open` call. The two types of file descriptor are not interchangeable. For example `hal_gdb_fileio_read` should only be used with a file descriptor returned from `hal_gdb_fileio_open`, not with the return value of `open`.

`hal_gdb_fileio_read`, `hal_gdb_fileio_write`, `hal_gdb_fileio_lseek`, `hal_gdb_fileio_fstat` and `hal_gdb_fileio_isatty` perform operations on a file opened with `hal_gdb_fileio_open`. `hal_gdb_fileio_write` can also be used with the predefined file descriptor `HAL_GDB_FILEIO_STDOUT`, corresponding to gdb's standard output. For `hal_gdb_fileio_lseek` valid *whence* parameters are `HAL_GDB_FILEIO_SEEK_SET`, `HAL_GDB_FILEIO_SEEK_CUR` and `HAL_GDB_FILEIO_SEEK_END`. Due to limitations within the protocol and the implementation `hal_gdb_fileio_lseek` cannot fully support files of 2GB or larger. In other words offsets are limited to 31 bits.

The `hal_gdb_fileio_stat` and `hal_gdb_fileio_fstat` functions should be called with a struct `hal_gdb_fileio_stat` buffer:

```
struct hal_gdb_fileio_stat
{
    cyg_uint32 st_dev;
    cyg_uint32 st_ino;
    cyg_uint32 st_mode;
    cyg_uint32 st_nlink;
    cyg_uint32 st_uid;
    cyg_uint32 st_gid;
    cyg_uint32 st_rdev;
    cyg_uint64 st_size;
    cyg_uint64 st_blksize;
    cyg_uint64 st_blocks;
    cyg_uint32 st_atime;
    cyg_uint32 st_mtime;
    cyg_uint32 st_ctime;
};
```

The first argument to `hal_gdb_fileio_gettimeofday` should be `hal_gdb_fileio_timeval` structure:

```
struct hal_gdb_fileio_timeval
{
    cyg_uint32 tv_sec;
    cyg_uint32 tv_usec;
};
```

The second argument to `hal_gdb_fileio_gettimeofday` is not currently used and application code should use a NULL pointer for this.

`hal_gdb_fileio_system` can be used to invoke an arbitrary command on the host. For obvious security reasons this functionality is disabled within gdb by default. It must be explicitly enabled within gdb using a **set remote system-call-allowed** command.

Diagnostics Support

When the eCos application is built stand-alone and will be debugged via a hardware debug solution such as jtag or BDM, some platforms will allow HAL diagnostics to be sent a destination `gdb_hwdebug_fileio`. This output will end up being written to the gdb console via `hal_gdb_fileio_write`. Hence the output will be discarded unless the application is running inside a gdb session and the **set hwdebug** command has been used.

Chapter 6. Porting Guide

Introduction

eCos has been designed to be fairly easy to port to new targets. A target is a specific platform (board) using a given architecture (CPU type). The porting is facilitated by the hierarchical layering of the eCos sources - all architecture and platform specific code is implemented in a HAL (hardware abstraction layer).

By porting the eCos HAL to a new target the core functionality of eCos (infra, kernel, uITRON, etc) will be able to run on the target. It may be necessary to add further platform specific code such as serial drivers, display drivers, ethernet drivers, etc. to get a fully capable system.

This document is intended as a help to the HAL porting process. Due to the nature of a porting job, it is impossible to give a complete description of what has to be done for each and every potential target. This should not be considered a clear-cut recipe - you will probably need to make some implementation decisions, tweak a few things, and just plain have to rely on common sense.

However, what is covered here should be a large part of the process. If you get stuck, you are advised to read the ecos-discuss archive (<http://ecos.sourceware.org/ml/ecos-discuss/>) where you may find discussions which apply to the problem at hand. You are also invited to ask questions on the ecos-discuss mailing list (<http://ecos.sourceware.org/intouch.html>) to help you resolve problems - but as is always the case with community lists, do not consider it an oracle for any and all questions. Use common sense - if you ask too many questions which could have been answered by reading the documentation (<http://ecos.sourceware.org/ecos/docs-latest/>), FAQ (<http://ecos.sourceware.org/fom/ecos>) or source code (<http://ecos.sourceware.org/cgi-bin/cvsweb.cgi/ecos/packages/?cvsroot=ecos>), you are likely to be ignored.

This document will be continually improved by Red Hat engineers as time allows. Feedback and help with improving the document is sought, so if you have any comments at all, please do not hesitate to post them on ecos-discuss ([mailto:ecos-discuss@ecos.sourceware.org?subject=\[porting\]<subject>](mailto:ecos-discuss@ecos.sourceware.org?subject=[porting]<subject>)) (please prefix the subject with [porting]).

At the moment this document is mostly an outline. There are many details to fill in before it becomes complete. Many places you'll just find a list of keywords / concepts that should be described (please post on ecos-discuss if there are areas you think are not covered).

All pages or sections where the caption ends in [TBD] contain little more than key words and/or random thoughts - there has been no work done as such on the content. The word FIXME may appear in the text to highlight places where information is missing.

HAL Structure

In order to write an eCos HAL it's a good idea to have at least a passing understanding of how the HAL interacts with the rest of the system.

HAL Classes

The eCos HAL consists of four HAL sub-classes. This table gives a brief description of each class and partly reiterates the description in [Chapter 2](#). The links refer to the on-line CVS tree (specifically to the sub-HALs used by the PowerPC MBX target).

HAL type	Description	Functionality Overview
----------	-------------	------------------------

HAL type	Description	Functionality Overview
Common HAL (hal/common) (http://ecos.sourceware.org/cgi-bin/cvsweb.cgi/ecos/packages/hal/common/current?cvsroot=ecos)	Configuration options and functionality shared by all HALs.	Generic debugging functionality, driver API, eCos/ROM monitor calling interface, and tests.
Architecture HAL (hal/<architecture>/arch) (http://ecos.sourceware.org/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/mbox/current?cvsroot=ecos)	Functionality specific to the given architecture. Also default implementations of some functions which can be overridden by variant or platform HALs.	Architecture specific debugger functionality (handles single stepping, exception-to-signal conversion, etc.), exception/interrupt vector definitions and handlers, cache definition and control macros, context switching code, assembler functions for early system initialization, configuration options, and possibly tests.
Variant HAL (hal/<architecture>/<variant>) (http://ecos.sourceware.org/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/mbox/current?cvsroot=ecos)	Some CPU architectures consist of a number variants, for example MIPS CPUs come in both 32 and 64 bit versions, and some variants have embedded features additional to the CPU core.	Variant extensions to the architecture code (cache, exception/interrupt), configuration options, possibly drivers for variant on-core devices, and possibly tests.
Platform HAL (hal/<architecture>/<platform>) (http://ecos.sourceware.org/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/mbox/current?cvsroot=ecos)	Contains functionality and configuration options specific to the platform.	Early platform initialization code, platform memory layout specification, configuration options (processor speed, compiler options), diagnostic IO functions, debugger IO functions, platform specific extensions to architecture or variant code (off-core interrupt controller), and possibly tests.
Auxiliary HAL (hal/<architecture>/<module>) (http://ecos.sourceware.org/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/mbox/current?cvsroot=ecos)	Some variants share common modules on the core. Motorola's PowerPC QUICC is an example of such a module.	Module specific functionality (interrupt controller, simple device drivers), possibly tests.

File Descriptions

Listed below are the files found in various HALs, with a short description of what each file contains. When looking in existing HALs beware that they do not necessarily follow this naming scheme. If you are writing a new HAL, please try to follow it as closely as possible. Still, no two targets are the same, so sometimes it makes sense to use additional files.

Common HAL

File	Description
------	-------------

File	Description
include/dbg-thread-syscall.h	Defines the thread debugging syscall function. This is used by the ROM monitor to access the thread debugging API in the RAM application. .
include/dbg-threads-api.h	Defines the thread debugging API. .
include/drv_api.h	Defines the driver API.
include/generic-stub.h	Defines the generic stub features.
include/hal_if.h	Defines the ROM/RAM calling interface API.
include/hal_misc.h	Defines miscellaneous helper functions shared by all HALs.
include/hal_stub.h	Defines eCos mappings of GDB stub features.
src/dbg-threads-syscall.c	Thread debugging implementation.
src/drv_api.c	Driver API implementation. Depending on configuration this provides either wrappers for the kernel API, or a minimal implementation of these features. This allows drivers to be written relying only on HAL features.
src/dummy.c	Empty dummy file ensuring creation of libtarget.a.
src/generic-stub.c	Generic GDB stub implementation. This provides the communication protocol used to communicate with GDB over a serial device or via the network.
src/hal_if.c	ROM/RAM calling interface implementation. Provides wrappers from the calling interface API to the eCos features used for the implementation.
src/hal_misc.c	Various helper functions shared by all platforms and architectures.
src/hal_stub.c	Wrappers from eCos HAL features to the features required by the generic GDB stub.
src/stubrom/stubrom.c	The file used to build eCos GDB stub images. Basically a cyg_start function with a hard coded breakpoint.
src/thread-packets.c	More thread debugging related functions.
src/thread-pkts.h	Defines more thread debugging related function.

Architecture HAL

Some architecture HALs may add extra files for architecture specific serial drivers, or for handling interrupts and exceptions if it makes sense.

Note that many of the definitions in these files are only conditionally defined - if the equivalent variant or platform headers provide the definitions, those override the generic architecture definitions.

File	Description
include/arch.inc	Various assembly macros used during system initialization.

File	Description
include/basetype.h	Endian, label, alignment, and type size definitions. These override common defaults in CYGPKG_INFRA.
include/hal_arch.h	Saved register frame format, various thread, register and stack related macros.
include/hal_cache.h	Cache definitions and cache control macros.
include/hal_intr.h	Exception and interrupt definitions. Macros for configuring and controlling interrupts. eCos real-time clock control macros.
include/hal_io.h	Macros for accessing IO devices.
include/<arch>_regs.h	Architecture register definitions.
include/<arch>_stub.h	Architecture stub definitions. In particular the register frame layout used by GDB. This may differ from the one used by eCos.
include/<arch>.inc	Architecture convenience assembly macros.
src/<arch>.ld	Linker macros.
src/context.S	Functions handling context switching and setjmp/longjmp.
src/hal_misc.c	Exception and interrupt handlers in C. Various other utility functions.
src/hal_mk_defs.c	Used to export definitions from C header files to assembler header files.
src/hal_intr.c	Any necessary interrupt handling functions.
src/<arch>stub.c	Architecture stub code. Contains functions for translating eCos exceptions to UNIX signals and functions for single-stepping.
src/vectors.S	Exception, interrupt and early initialization code.

Variant HAL

Some variant HALs may add extra files for variant specific serial drivers, or for handling interrupts/exceptions if it makes sense.

Note that these files may be mostly empty if the CPU variant can be controlled by the generic architecture macros. The definitions present are only conditionally defined - if the equivalent platform headers provide the definitions, those override the variant definitions.

File	Description
include/var_arch.h	Saved register frame format, various thread, register and stack related macros.
include/var_cache.h	Cache related macros.
include/var_intr.h	Interrupt related macros.
include/var_regs.h	Extra register definitions for the CPU variant.
include/variant.inc	Various assembly macros used during system initialization.
src/var_intr.c	Interrupt functions if necessary.

File	Description
src/var_misc.c	hal_variant_init function and any necessary extra functions.
src/variant.S	Interrupt handler table definition.
src/<arch>_<variant>.ld	Linker macros.

Platform HAL

Extras files may be added for platform specific serial drivers. Extra files for handling interrupts and exceptions will be present if it makes sense.

File	Description
include/hal_diag.h	Defines functions used for HAL diagnostics output. This would normally be the ROM calling interface wrappers, but may also be the low-level IO functions themselves, saving a little overhead.
include/platform.inc	Platform initialization code. This includes memory controller, vectors, and monitor initialization. Depending on the architecture, other things may need defining here as well: interrupt decoding, status register initialization value, etc.
include/plf_cache.h	Platform specific cache handling.
include/plf_intr.h	Platform specific interrupt handling.
include/plf_io.h	PCI IO definitions and macros. May also be used to override generic HAL IO macros if the platform endianness differs from that of the CPU.
include/plf_stub.h	Defines stub initializer and board reset details.
src/hal_diag.c	May contain the low-level device drivers. But these may also reside in plf_stub.c
src/platform.S	Memory controller setup macro, and if necessary interrupt springboard code.
src/plf_misc.c	Platform initialization code.
src/plf_mk_defs.c	Used to export definitions from C header files to assembler header files.
src/plf_stub.c	Platform specific stub initialization and possibly the low-level device driver.

The platform HAL also contains files specifying the platform's memory layout. These files are located in include/pkgconf.

Auxiliary HAL

Auxiliary HALs contain whatever files are necessary to provide the required functionality. There are no predefined set of files required in an auxiliary HAL.

Virtual Vectors (eCos/ROM Monitor Calling Interface)

Virtually all eCos platforms provide full debugging capabilities via RedBoot. This environment contains not only debug stubs based on GDB, but also rich I/O support which can be exported to loaded programs. Such programs can take advantage of the I/O capabilities using a special ROM/RAM calling interface (also referred to as virtual vector table). eCos programs make use of the virtual vector mechanism implicitly. Non-eCos programs can access these functions using the support from the *newlib* library.

Virtual Vectors

What are virtual vectors, what do they do, and why are they needed?

"Virtual vectors" is the name of a table located at a static location in the target address space. This table contains 64 vectors that point to *service* functions or data.

The fact that the vectors are always placed at the same location in the address space means that both ROM and RAM startup configurations can access these and thus the services pointed to.

The primary goal is to allow services to be provided by ROM configurations (ROM monitors such as RedBoot in particular) with *clients* in RAM configurations being able to use these services.

Without the table of pointers this would be impossible since the ROM and RAM applications would be linked separately - in effect having separate name spaces - preventing direct references from one to the other.

This decoupling of service from client is needed by RedBoot, allowing among other things debugging of applications which do not contain debugging client code (stubs).

Initialization (or Mechanism vs. Policy)

Virtual vectors are a *mechanism* for decoupling services from clients in the address space.

The mechanism allows services to be implemented by a ROM monitor, a RAM application, to be switched out at run-time, to be disabled by installing pointers to dummy functions, etc.

The appropriate use of the mechanism is specified loosely by a *policy*. The general policy dictates that the vectors are initialized in whole by ROM monitors (built for ROM or RAM), or by stand-alone applications.

For configurations relying on a ROM monitor environment, the policy is to allow initialization on a service by service basis. The default is to initialize all services, except COMMS services since these are presumed to already be carrying a communication session to the debugger / console which was used for launching the application. This means that the bulk of the code gets tested in normal builds, and not just once in a blue moon when building new stubs or a ROM configuration.

The configuration options are written to comply with this policy by default, but can be overridden by the user if desired. Defaults are:

- For application development: the ROM monitor provides debugging and diagnostic IO services, the RAM application relies on these by default.
- For production systems: the application contains all the necessary services.

Pros and Cons of Virtual Vectors

There are pros and cons associated with the use of virtual vectors. We do believe that the pros generally outweigh the cons by a great margin, but there may be situations where the opposite is true.

The use of the services are implemented by way of macros, meaning that it is possible to circumvent the virtual vectors if desired. There is (as yet) no implementation for doing this, but it is possible.

Here is a list of pros and cons:

Pro: Allows debugging without including stubs

This is the primary reason for using virtual vectors. It allows the ROM monitor to provide most of the debugging infrastructure, requiring only the application to provide hooks for asynchronous debugger interrupts and for accessing kernel thread information.

Pro: Allows debugging to be initiated from arbitrary channel

While this is only true where the application does not actively override the debugging channel setup, it is a very nice feature during development. In particular it makes it possible to launch (and/or debug) applications via Ethernet even though the application configuration does not contain networking support.

Pro: Image smaller due to services being provided by ROM monitor

All service functions except HAL IO are included in the default configuration. But if these are all disabled the image for download will be a little smaller. Probably doesn't matter much for regular development, but it is a worthwhile saving for the 20000 daily tests run in the Red Hat eCos test farm.

Con: The vectors add a layer of indirection, increasing application size and reducing performance.

The size increase is a fraction of what is required to implement the services. So for RAM configurations there is a net saving, while for ROM configurations there is a small overhead.

The performance loss means little for most of the services (of which the most commonly used is diagnostic IO which happens via polled routines anyway).

Con: The layer of indirection is another point of failure.

The concern primarily being that of vectors being trashed by rogue writes from bad code, causing a complete loss of the service and possibly a crash. But this does not differ much from a rogue write to anywhere else in the address space which could cause the same amount of mayhem. But it is arguably an additional point of failure for the service in question.

Con: All the indirection stuff makes it harder to bring a HAL up

This is a valid concern. However, seeing as most of the code in question is shared between all HALs and should remain unchanged over time, the risk of it being broken when a new HAL is being worked on should be minimal.

When starting a new port, be sure to implement the HAL IO drivers according to the scheme used in other drivers, and there should be no problem.

However, it is still possible to circumvent the vectors if they are suspect of causing problems: simply change the HAL_DIAG_INIT and HAL_DIAG_WRITE_CHAR macros to use the raw IO functions.

Available services

The `hal_if.h` file in the common HAL defines the complete list of available services. A few worth mentioning in particular:

- COMMS services. All HAL IO happens via the communication channels.
- uS delay. Fine granularity (busy wait) delay function.
- Reset. Allows a software initiated reset of the board.

The COMMS channels

As all HAL IO happens via the COMMS channels these deserve to be described in a little more detail. In particular the controls of where diagnostic output is routed and how it is treated to allow for display in debuggers.

Console and Debugging Channels

There are two COMMS channels - one for console IO and one for debugging IO. They can be individually configured to use any of the actual IO ports (serial or Ethernet) available on the platform.

The console channel is used for any IO initiated by calling the `diag_*` functions. Note that these should only be used during development for debugging, assertion and possibly tracing messages. All proper IO should happen via proper devices. This means it should be possible to remove the HAL device drivers from production configurations where assertions are disabled.

The debugging channel is used for communication between the debugger and the stub which remotely controls the target for the debugger (the stub runs on the target). This usually happens via some protocol, encoding commands and replies in some suitable form.

Having two separate channels allows, e.g., for simple logging without conflicts with the debugger or interactive IO which some debuggers do not allow.

Mangling

As debuggers usually have a protocol using specialized commands when communicating with the stub on the target, sending out text as raw ASCII from the target on the same channel will either result in protocol errors (with loss of control over the target) or the text may just be ignored as junk by the debugger.

To get around this, some debuggers have a special command for text output. Mangling is the process of encoding diagnostic ASCII text output in the form specified by the debugger protocol.

When it is necessary to use mangling, i.e. when writing console output to the same port used for debugging, a mangler function is installed on the console channel which mangles the text and passes it on to the debugger channel.

Controlling the Console Channel

Console output configuration is either inherited from the ROM monitor launching the application, or it is specified by the application. This is controlled by the new option `CYGSEM_HAL_VIRTUAL_VECTOR_INHERIT_CONSOLE` which defaults to enabled when the configuration is set to use a ROM monitor.

If the user wants to specify the console configuration in the application image, there are two new options that are used for this.

Defaults are to direct diagnostic output via a mangler to the debugging channel (`CYGDBG_HAL_DIAG_TO_DEBUG_CHAN` enabled). The mangler type is controlled by the option `CYGSEM_HAL_DIAG_MANGLER`. At present there are only two mangler types:

GDB

This causes a mangler appropriate for debugging with GDB to be installed on the console channel.

None

This causes a NULL mangler to be installed on the console channel. It will redirect the IO to/from the debug channel without mangling of the data. This option differs from setting the console channel to the same IO port as the debugging channel in that it will keep redirecting data to the debugging channel even if that is changed to some other port.

Finally, by disabling `CYGDBG_HAL_DIAG_TO_DEBUG_CHAN`, the diagnostic output is directed in raw form to the specified console IO port.

In summary this results in the following common configuration scenarios for RAM startup configurations:

- For regular debugging with diagnostic output appearing in the debugger, mangling is enabled and stubs disabled.

Diagnostic output appears via the debugging channel as initiated by the ROM monitor, allowing for correct behavior whether the application was launched via serial or Ethernet, from the RedBoot command line or from a debugger.

- For debugging with raw diagnostic output, mangling is disabled.

Debugging session continues as initiated by the ROM monitor, whether the application was launched via serial or Ethernet. Diagnostic output is directed at the IO port configured in the application configuration.

Note:: There is one caveat to be aware of. If the application uses proper devices (be it serial or Ethernet) on the same ports as those used by the ROM monitor, the connections initiated by the ROM monitor will be terminated.

And for ROM startup configurations:

- Production configuration with raw output and no debugging features (configured for RAM or ROM), mangling is disabled, no stubs are included.

Diagnostic output appears (in unmangled form) on the specified IO port.

- RedBoot configuration, includes debugging features and necessary mangling.

Diagnostic and debugging output port is auto-selected by the first connection to any of the supported IO ports. Can change from interactive mode to debugging mode when a debugger is detected - when this happens a mangler will be installed as required.

- GDB stubs configuration (obsoleted by RedBoot configuration), includes debugging features, mangling is hardwired to GDB protocol.

Diagnostic and debugging output is hardwired to configured IO ports, mangling is hardwired.

Footnote: Design Reasoning for Control of Console Channel

The current code for controlling the console channel is a replacement for an older implementation which had some shortcomings which addressed by the new implementation.

This is what the old implementation did: on initialization it would check if the CDL configured console channel differed from the active debug channel - and if so, set the console channel, thereby disabling mangling.

The idea was that whatever channel was configured to be used for console (i.e., diagnostic output) in the application was what should be used. Also, it meant that if debug and console channels were normally the same, a changed console channel would imply a request for unmangled output.

But this prevented at least two things:

- It was impossible to inherit the existing connection by which the application was launched (either by Red-Boot commands via telnet, or by via a debugger).

This was mostly a problem on targets supporting Ethernet access since the diagnostic output would not be returned via the Ethernet connection, but on the configured serial port.

The problem also occurred on any targets with multiple serial ports where the ROM monitor was configured to use a different port than the CDL defaults.

- Proper control of when to mangle or just write out raw ASCII text.

Sometimes it's desirable to disable mangling, even if the channel specified is the same as that used for debugging. This usually happens if GDB is used to download the application, but direct interaction with the application on the same channel is desired (GDB protocol only allows output from the target, no input).

The calling Interface API

The calling interface API is defined by `hal_if.h` and `hal_if.c` in `hal/common`.

The API provides a set of services. Different platforms, or different versions of the ROM monitor for a single platform, may implement fewer or extra service. The table has room for growth, and any entries which are not supported map to a NOP-service (when called it returns 0 (`false`)).

A client of a service should either be selected by configuration, or have suitable fall back alternatives in case the feature is not implemented by the ROM monitor.

Note:: Checking for unimplemented service when this may be a data field/pointer instead of a function: suggest reserving the last entry in the table as the NOP-service pointer. Then clients can compare a service entry with this pointer to determine whether it's initialized or not.

The header file `cyg/hal/hal_if.h` defines the table layout and accessor macros (allowing primitive type checking and alternative implementations should it become necessary).

The source file `hal_if.c` defines the table initialization function. All HALs should call this during platform initialization - the table will get initialized according to configuration. Also defined here are wrapper functions which map between the calling interface API and the API of the used eCos functions.

Implemented Services

This is a brief description of the services, some of which are described in further detail below.

VERSION

Version of table. Serves as a way to check for how many features are available in the table. This is the index of the last service in the table.

KILL_VECTOR

[Presently unused by the stub code, but initialized] This vector defines a function to execute when the system receives a kill signal from the debugger. It is initialized with the reset function (see below), but the application (or eCos) can override it if necessary.

CONSOLE_PROCS

The communication procedure table used for console IO (see [the Section called *IO channels*](#)).

DEBUG_PROCS

The communication procedure table used for debugger IO (see [the Section called *IO channels*](#)).

FLUSH_DCACHE

Flushes the data cache for the specified region. Some implementations may flush the entire data cache.

FLUSH_ICACHE

Flushes (invalidates) the instruction cache for the specified region. Some implementations may flush the entire instruction cache.

SET_DEBUG_COMM

Change debugging communication channel.

SET_CONSOLE_COMM

Change console communication channel.

DBG_SYSCALL

Vector used to communication between debugger functions in ROM and in RAM. RAM eCos configurations may install a function pointer here which the ROM monitor uses to get thread information from the kernel running in RAM.

RESET

Resets the board on call. If it is not possible to reset the board from software, it will jump to the ROM entry point which will perform a "software" reset of the board.

CONSOLE_INTERRUPT_FLAG

Set if a debugger interrupt request was detected while processing console IO. Allows the actual breakpoint action to be handled after return to RAM, ensuring proper backtraces etc.

DELAY_US

Will delay the specified number of microseconds. The precision is platform dependent to some extent - a small value (<100us) is likely to cause bigger delays than requested.

FLASH_CFG_OP

For accessing configuration settings kept in flash memory.

INSTALL_BPT_FN

Installs a breakpoint at the specified address. This is used by the asynchronous breakpoint support (see).

Compatibility

When a platform is changed to support the calling interface, applications will use it if so configured. That means that if an application is run on a platform with an older ROM monitor, the service is almost guaranteed to fail.

For this reason, applications should only use Console Comm for HAL diagnostics output if explicitly configured to do so (CYGSEM_HAL_VIRTUAL_VECTOR_DIAG).

As for asynchronous GDB interrupts, the service will always be used. This is likely to cause a crash under older ROM monitors, but this crash may be caught by the debugger. The old workaround still applies: if you need asynchronous breakpoints or thread debugging under older ROM monitors, you may have to include the debugging support when configuring eCos.

Implementation details

During the startup of a ROM monitor, the calling table will be initialized. This also happens if eCos is configured *not* to rely on a ROM monitor.

Note:: There is reserved space (256 bytes) for the vector table whether it gets used or not. This may be something that we want to change if we ever have to shave off every last byte for a given target.

If thread debugging features are enabled, the function for accessing the thread information gets registered in the table during startup of a RAM startup configuration.

Further implementation details are described where the service itself is described.

New Platform Ports

The `hal_platform_init()` function must call `hal_if_init()`.

The HAL serial driver must, when called via `cyg_hal_plf_comms_init()` must initialize the communication channels.

The `reset()` function defined in `hal_if.c` will attempt to do a hardware reset, but if this fails it will fall back to simply jumping to the reset entry-point. On most platforms the startup initialization will go a long way to reset the target to a sane state (there will be exceptions, of course). For this reason, make sure to define `HAL_STUB_PLATFORM_RESET_ENTRY` in `plf_stub.h`.

All debugging features must be in place in order for the debugging services to be functional. See general platform porting notes.

New architecture ports

There are no specific requirements for a new architecture port in order to support the calling interface, but the basic debugging features must be in place. See general architecture porting notes.

IO channels

The calling interface provides procedure tables for all IO channels on the platform. These are used for console (diagnostic) and debugger IO, allowing a ROM monitor to provide all the needed IO routines. At the same time, this makes it easy to switch console/debugger channels at run-time (the old implementation had hardwired drivers for console and debugger IO, preventing these to change at run-time).

The `hal_if` provides wrappers which interface these services to the eCos infrastructure diagnostics routines. This is done in a way which ensures proper string mangling of the diagnostics output when required (e.g. O-packetization when using a GDB compatible ROM monitor).

Available Procedures

This is a brief description of the procedures

CH_DATA

Pointer to the controller IO base (or a pointer to a per-device structure if more data than the IO base is required). All the procedures below are called with this data item as the first argument.

WRITE

Writes the buffer to the device.

READ

Fills a buffer from the device.

PUTC

Write a character to the device.

GETC

Read a character from the device.

CONTROL

Device feature control. Second argument specifies function:

SETBAUD

Changes baud rate.

GETBAUD

Returns the current baud rate.

INSTALL_DBG_ISR

[Unused]

REMOVE_DBG_ISR

[Unused]

IRQ_DISABLE

Disable debugging receive interrupts on the device.

IRQ_ENABLE

Enable debugging receive interrupts on the device.

DBG_ISR_VECTOR

Returns the ISR vector used by the device for debugging receive interrupts.

SET_TIMEOUT

Set GETC timeout in milliseconds.

FLUSH_OUTPUT

Forces driver to flush data in its buffers. Note that this may not affect hardware buffers (e.g. FIFOs).

DBG_ISR

ISR used to handle receive interrupts from the device (see).

GETC_TIMEOUT

Read a character from the device with timeout.

Usage

The standard eCos diagnostics IO functions use the channel procedure table when `CYGSEM_HAL_VIRTUAL_VECTOR_DIAG` is enabled. That means that when you use `diag_printf` (or the libc `printf` function) the stream goes through the selected console procedure table. If you use the virtual vector function `SET_CONSOLE_COMM` you can change the device which the diagnostics output goes to at run-time.

You can also use the table functions directly if desired (regardless of the `CYGSEM_HAL_VIRTUAL_VECTOR_DIAG` setting - assuming the ROM monitor provides the services). Here is a small example which changes the console to use channel 2, fetches the comm procs pointer and calls the write function from that table, then restores the console to the original channel:

```
#define T "Hello World!\n"

int
main(void)
{
    hal_virtual_comm_table_t* comm;
    int cur = CYGACC_CALL_IF_SET_CONSOLE_COMM(CYGNUM_CALL_IF_SET_COMM_ID_QUERY_CURRENT);

    CYGACC_CALL_IF_SET_CONSOLE_COMM(2);

    comm = CYGACC_CALL_IF_CONSOLE_PROCS();
    CYGACC_COMM_IF_WRITE(*comm, T, strlen(T));

    CYGACC_CALL_IF_SET_CONSOLE_COMM(cur);
}
```

Beware that if doing something like the above, you should only do it to a channel which does not have GDB at the other end: GDB ignores raw data, so you would not see the output.

Compatibility

The use of this service is controlled by the option `CYGSEM_HAL_VIRTUAL_VECTOR_DIAG` which is disabled per default on most older platforms (thus preserving backwards compatibility with older stubs). On newer ports, this option should always be set.

Implementation Details

There is an array of procedure tables (raw comm channels) for each IO device of the platform which get initialized by the ROM monitor, or optionally by a RAM startup configuration (allowing the RAM configuration to take full control of the target). In addition to this, there's a special table which is used to hold mangler procedures.

The vector table defines which of these channels are selected for console and debugging IO respectively: console entry can be empty, point to mangler channel, or point to a raw channel. The debugger entry should always point to a raw channel.

During normal console output (i.e., diagnostic output) the console table will be used to handle IO if defined. If not defined, the debug table will be used.

This means that debuggers (such as GDB) which require text streams to be mangled (O-packetized in the case of GDB), can rely on the ROM monitor install mangling IO routines in the special mangler table and select this for console output. The mangler will pass the mangled data on to the selected debugging channel.

If the eCos configuration specifies a different console channel from that used by the debugger, the console entry will point to the selected raw channel, thus overriding any mangler provided by the ROM monitor.

See `hal_if_diag_*` routines in `hal_if.c` for more details of the stream path of diagnostic output. See `cyg_hal_gdb_diag_*` routines in `hal_stub.c` for the mangler used for GDB communication.

New Platform Ports

Define CDL options `CYGNUM_HAL_VIRTUAL_VECTOR_COMM_CHANNELS`, `CYGNUM_HAL_VIRTUAL_VECTOR_DEBUG_CHANNEL`, and `CYGNUM_HAL_VIRTUAL_VECTOR_CONSOLE_CHANNEL`.

If `CYGSEM_HAL_VIRTUAL_VECTOR_DIAG` is set, make sure the infra diag code uses the `hal_if` diag functions:

```
#define HAL_DIAG_INIT() hal_if_diag_init()
#define HAL_DIAG_WRITE_CHAR(_c_) hal_if_diag_write_char(_c_)
#define HAL_DIAG_READ_CHAR(_c_) hal_if_diag_read_char(&_c_)
```

In addition to the above functions, the platform HAL must also provide a function `cyg_hal_plf_comms_init` which initializes the drivers and the channel procedure tables.

Most of the other functionality in the table is more or less possible to copy unchanged from existing ports. Some care is necessary though to ensure the proper handling of interrupt vectors and timeouts for various devices handled by the same driver. See PowerPC/Cogent platform HAL for an example implementation.

Note:: When vector table console code is *not* used, the platform HAL must map the `HAL_DIAG_INIT`, `HAL_DIAG_WRITE_CHAR` and `HAL_DIAG_READ_CHAR` macros directly to the low-level IO functions, hardwired to use a compile-time configured channel.

Note:: On old ports the hardwired `HAL_DIAG_INIT`, `HAL_DIAG_WRITE_CHAR` and `HAL_DIAG_READ_CHAR` implementations will also contain code to O-packetize the output for GDB. This should *not* be adopted for new ports! On new ports the ROM monitor is guaranteed to provide the necessary mangling via the vector table. The hardwired configuration should be reserved for ROM startups where achieving minimal image size is crucial.

HAL Coding Conventions

To get changes and larger submissions included into the eCos source repository, we ask that you adhere to a set of coding conventions. The conventions are defined as an attempt to make a consistent tree. Consistency makes it easier for people to read, understand and maintain the code, which is important when many people work on the same project.

The below is only a brief, and probably incomplete, summary of the rules. Please look through files in the area where you are making changes to get a feel for any additional conventions. Also feel free to ask on the list if you have specific questions.

Implementation issues

There are a few implementation issues that should be kept in mind:

HALs

HALs must be written in C and assembly only. C++ must not be used. This is in part to keep the HALs simple since this is usually the first part of eCos a newcomer will see, and in part to maintain the existing de facto standard.

IO access

Use HAL IO access macros for code that might be reused on different platforms than the one you are writing it for.

MMU

If it is necessary to use the MMU (e.g., to prevent caching of IO areas), use a simple 1-1 mapping of memory if possible. On most platforms where using the MMU is necessary, it will be possible to achieve the 1-1 mapping using the MMU's provision for mapping large continuous areas (hardwired TLBs or BATs). This reduces the footprint (no MMU table) and avoids execution overhead (no MMU-related exceptions).

Assertions

The code should contain assertions to validate argument values, state information and any assumptions the code may be making. Assertions are not enabled in production builds, so liberally sprinkling assertions throughout the code is good.

Testing

The ability to test your code is very important. In general, do not add new code to the eCos runtime unless you also add a new test to exercise that code. The test also serves as an example of how to use the new code.

Source code details

Line length

Keep line length below 78 columns whenever possible.

Comments

Whenever possible, use `//` comments instead of `/**/`.

Indentation

Use spaces instead of TABs. Indentation level is 4. Braces start on the same line as the expression. See below for emacs mode details.

```

;=====
;; eCos C/C++ mode Setup.
;;
;; bsd mode: indent = 4
;; tail comments are at col 40.
;; uses spaces not tabs in C

(defun ecos-c-mode ()
  "C mode with adjusted defaults for use with the eCos sources."
  (interactive)
  (c++-mode)
  (c-set-style "bsd")
  (setq comment-column 40)
  (setq indent-tabs-mode nil)
  (show-paren-mode 1)
  (setq c-basic-offset 4)

  (set-variable 'add-log-full-name "Your Name")
  (set-variable 'add-log-mailing-address "Your email address"))

(defun ecos-asm-mode ()
  "ASM mode with adjusted defaults for use with the eCos sources."
  (interactive)
  (setq comment-column 40)
  (setq indent-tabs-mode nil)
  (asm-mode)
  (setq c-basic-offset 4)

  (set-variable 'add-log-full-name "Your Name")
  (set-variable 'add-log-mailing-address "Your email address"))

(setq auto-mode-alist
  (append '("/local/ecc/*.\\*.C$" . ecos-c-mode)
    ("/local/ecc/*.\\*.cc$" . ecos-c-mode)
    ("/local/ecc/*.\\*.cpp$" . ecos-c-mode)
    ("/local/ecc/*.\\*.inl$" . ecos-c-mode)
    ("/local/ecc/*.\\*.c$" . ecos-c-mode)
    ("/local/ecc/*.\\*.h$" . ecos-c-mode)
    ("/local/ecc/*.\\*.S$" . ecos-asm-mode)
    ("/local/ecc/*.\\*.inc$" . ecos-asm-mode)
    ("/local/ecc/*.\\*.cdl$" . tcl-mode)
    ) auto-mode-alist))

```

Nested Headers

In order to allow platforms to define all necessary details, while still maintaining the ability to share code between common platforms, all HAL headers are included in a nested fashion.

The architecture header (usually `hal_XXX.h`) includes the variant equivalent of the header (`var_XXX.h`) which in turn includes the platform equivalent of the header (`plf_XXX.h`).

All definitions that may need to be overridden by a platform are then only conditionally defined, depending on whether a lower layer has already made the definition:

```
hal_intr.h:      #include <var_intr.h>

                 #ifndef MACRO_DEFINED
                 # define MACRO ...
                 # define MACRO_DEFINED
                 #endif

var_intr.h:      #include <plf_intr.h>

                 #ifndef MACRO_DEFINED
                 # define MACRO ...
                 # define MACRO_DEFINED
                 #endif

plf_intr.h:

                 # define MACRO ...
                 # define MACRO_DEFINED
```

This means a platform can opt to rely on the variant or architecture implementation of a feature, or implement it itself.

Platform HAL Porting

This is the type of port that takes the least effort. It basically consists of describing the platform (board) for the HAL: memory layout, early platform initialization, interrupt controllers, and a simple serial device driver.

Doing a platform port requires a preexisting architecture and possibly a variant HAL port.

HAL Platform Porting Process

Brief overview

The easiest way to make a new platform HAL is simply to copy an existing platform HAL of the same architecture/variant and change all the files to match the new one. In case this is the first platform for the architecture/variant, a platform HAL from another architecture should be used as a template.

The best way to start a platform port is to concentrate on getting RedBoot to run. RedBoot is a simpler environment than full eCos, it does not use interrupts or threads, but covers most of the basic startup requirements.

RedBoot normally runs out of FLASH or ROM and provides program loading and debugging facilities. This allows further HAL development to happen using RAM startup configurations, which is desirable for the simple reason that downloading an image which you need to test is often many times faster than either updating a flash part, or indeed, erasing and reprogramming an EPROM.

There are two approaches to getting to this first goal:

1. The board is equipped with a ROM monitor which allows "load and go" of ELF, binary, S-record or some other image type which can be created using objcopy. This allows you to develop RedBoot by downloading and running the code (saving time).

When the stub is running it is a good idea to examine the various hardware registers to help you write the platform initialization code.

Then you may have to fiddle a bit going through step two (getting it to run from ROM startup). If at all possible, preserve the original ROM monitor so you can revert to it if necessary.

2. The board has no ROM monitor. You need to get the platform initialization and stub working by repeatedly making changes, updating flash or EPROM and testing the changes. If you are lucky, you have a JTAG or similar CPU debugger to help you. If not, you will probably learn to appreciate LEDs. This approach may also be needed during the initial phase of moving RedBoot from RAM startup to ROM, since it is very unlikely to work first time.

Step-by-step

Given that no two platforms are exactly the same, you may have to deviate from the below. Also, you should expect a fair amount of fiddling - things almost never go right the first time. See the hints section below for some suggestions that might help debugging.

The description below is based on the HAL layout used in the MIPS, PC and MN10300 HALs. Eventually all HALs should be converted to look like these - but in a transition period there will be other HALs which look substantially different. Please try to adhere to the following as much as possible without causing yourself too much grief integrating with a HAL which does not follow this layout.

Minimal requirements

These are the changes you must make before you attempt to build RedBoot. You are advised to read all the sources though.

1. Copy an existing platform HAL from the same or another architecture. Rename the files as necessary to follow the standard: CDL and MLT related files should contain the <arch>_<variant>_<platform> triplet.
2. Adjust CDL options. Primarily option naming, real-time clock/counter, and CYGHWL_MEMORY_LAYOUT variables, but also other options may need editing. Look through the architecture/variant CDL files to see if there are any requirements/features which were not used on the platform you copied. If so, add appropriate ones. See [the Section called HAL Platform CDL](#) for more details.
3. Add the necessary packages and target descriptions to the top-level `ecos.db` file. See [the Section called eCos Database](#). Initially, the target entry should only contain the HAL packages. Other hardware support packages will be added later.

4. Adjust the MLT files in `include/pkgconf` to match the memory layout on the platform. For initial testing it should be enough to just hand edit `.h` and `.ldi` files, but eventually you should generate all files using the memory layout editor in the configuration tool. See [the Section called Platform Memory Layout](#) for more details.
5. Edit the `misc/redboot_<STARTUP>.ecm` for the startup type you have chosen to begin with. Rename any platform specific options and remove any that do not apply. In the `cdl_configuration` section, comment out any extra packages that are added, particularly packages such as `CYGPKG_IO_FLASH` and `CYGPKG_IO_ETH_DRIVERS`. These are not needed for initial porting and will be added back later.
6. If the default IO macros are not correct, override them in `plf_io.h`. This may be necessary if the platform uses a different endianness from the default for the CPU.
7. Leave out/comment out code that enables caches and/or MMU if possible. Execution speed will not be a concern until the port is feature complete.
8. Implement a simple serial driver (polled mode only). Make sure the initialization function properly hooks the procedures up in the virtual vector IO channel tables. RedBoot will call the serial driver via these tables.

By copying an existing platform HAL most of this code will be already done, and will only need the platform specific hardware access code to be written.

9. Adjust/implement necessary platform initialization. This can be found in `platform.inc` and `platform.S` files (ARM: `hal_platform_setup.h` and `<platform>_misc.c`, PowerPC: `<platform>.S`). This step can be postponed if you are doing a RAM startup RedBoot first and the existing ROM monitor handles board initialization.
10. Define `HAL_STUB_PLATFORM_RESET` (optionally empty) and `HAL_STUB_PLATFORM_RESET_ENTRY` so that RedBoot can reset-on-detach - this is very handy, often removing the need for physically resetting the board between downloads.

You should now be able to build RedBoot. For ROM startup:

```
% ecosconfig new <target_name> redboot
% ecosconfig import $(ECOS_REPOSITORY)/hal/<architecture>/<platform>/<version>/misc/redboot_
% ecosconfig tree
% make
```

You may have to make further changes than suggested above to get the make command to succeed. But when it does, you should find a RedBoot image in `install/bin`. To program this image into flash or EPROM, you may need to convert to some other file type, and possibly adjust the start address. When you have the correct `objcopy` command to do this, add it to the `CYGBLD_BUILD_GDB_STUBS` custom build rule in the platform CDL file.

Having updated the flash/EPROM on the board, you should see output on the serial port looking like this when powering on the board:

```
RedBoot(tm) bootstrap and debug environment [ROMRAM]
Non-certified release, version UNKNOWN - built 15:42:24, Mar 14 2002

Platform: <PLATFORM> (<ARCHITECTURE> <VARIANT>)
Copyright (C) 2000, 2001, 2002, Free Software Foundation, Inc.

RAM: 0x00000000-0x01000000, 0x000293e8-0x00ed1000 available
FLASH: 0x24000000 - 0x26000000, 256 blocks of 0x00020000 bytes each.
RedBoot>
```

If you do not see this output, you need to go through all your changes and figure out what's wrong. If there's a user programmable LED or LCD on the board it may help you figure out how far RedBoot gets before it hangs. Unfortunately there's no good way to describe what to do in this situation - other than that you have to play with the code and the board.

Adding features

Now you should have a basic RedBoot running on the board. This means you have a the correct board initialization and a working serial driver. It's time to flesh out the remaining HAL features.

1. Reset. As mentioned above it is desirable to get the board to reset when GDB disconnects. When GDB disconnects it sends RedBoot a kill-packet, and RedBoot first calls `HAL_STUB_PLATFORM_RESET()`, attempting to perform a software-invoked reset. Most embedded CPUs/boards have a watchdog which is capable of triggering a reset. If your target does not have a watchdog, leave `HAL_STUB_PLATFORM_RESET()` empty and rely on the fallback approach.

If `HAL_STUB_PLATFORM_RESET()` did not cause a reset, RedBoot will jump to `HAL_STUB_PLATFORM_RESET_ENTRY` - this should be the address where the CPU will start execution after a reset. Re-initializing the board and drivers will *usually* be good enough to make a hardware reset unnecessary.

After the reset caused by the kill-packet, the target will be ready for GDB to connect again. During a days work, this will save you from pressing the reset button many times.

Note that it is possible to disconnect from the board without causing it to reset by using the GDB command "detach".

2. Single-stepping is necessary for both instruction-level debugging and for breakpoint support. Single-stepping support should already be in place as part of the architecture/variant HAL, but you want to give it a quick test since you will come to rely on it.
3. Real-time clock interrupts drive the eCos scheduler clock. Many embedded CPUs have an on-core timer (e.g. SH) or decrementer (e.g. MIPS, PPC) that can be used, and in this case it will already be supported by the architecture/variant HAL. You only have to calculate and enter the proper `CYGNUM_HAL_RTC_CONSTANTS` definitions in the platform CDL file.

On some targets it may be necessary to use a platform-specific timer source for driving the real-time clock. In this case you also have to enter the proper CDL definitions, but must also define suitable versions of the `HAL_CLOCK_XXXX` macros.

4. Interrupt decoding usually differs between platforms because the number and type of devices on the board differ. In `plf_intr.h` (ARM: `hal_platform_ints.h`) you must either extend or replace the default vector definitions provided by the architecture or variant interrupt headers. You may also have to define `HAL_INTERRUPT_XXXX` control macros.
5. Caching may also differ from architecture/variant definitions. This maybe just the cache sizes, but there can also be bigger differences for example if the platform supports 2nd level caches.

When cache definitions are in place, enable the caches on startup. First verify that the system is stable for RAM startups, then build a new RedBoot and install it. This will test if caching, and in particular the cache sync/flush operations, also work for ROM startup.

6. Asynchronous breakpoints allow you to stop application execution and enter the debugger. Asynchronous breakpoint details are described in .

You should now have a completed platform HAL port. Verify its stability and completeness by running all the eCos tests and fix any problems that show up (you have a working RedBoot now, remember! That means you can debug the code to see why it fails).

Given the many configuration options in eCos, there may be hidden bugs or missing features that do not show up even if you run all the tests successfully with a default configuration. A comprehensive test of the entire system will take many configuration permutations and many many thousands of tests executed.

Hints

- JTAG or similar CPU debugging hardware can greatly reduce the time it takes to write a HAL port since you always have full visibility of what the CPU is doing.
- LEDs can be your friends if you don't have a JTAG device. Especially in the start of the porting effort if you don't already have a working ROM monitor on the target. Then you have to get a basic RedBoot working while basically being blindfolded. The LED can make it little easier, as you'll be able to do limited tracking of program flow and behavior by switching the LED on and off. If the board has multiple LEDs you can show a number (using binary notation with the LEDs) and sprinkle code which sets different numbers throughout the code.
- Debugging the interrupt processing is possible if you are careful with the way you program the very early interrupt entry handling. Write it so that as soon as possible in the interrupt path, taking a trap (exception) does not harm execution. See the SH vectors.S code for an example. Look for `cyg_hal_default_interrupt_vsr` and the label `cyg_hal_default_interrupt_vsr_bp_safe`, which marks the point after which traps/single-stepping is safe.

Being able to display memory content, CPU registers, interrupt controller details at the time of an interrupt can save a lot of time.

- Using assertions is a good idea. They can sometimes reveal subtle bugs or missing features long before you would otherwise have found them, let alone notice them.

The default eCos configuration does not use assertions, so you have to enable them by switching on the option `CYGPKG_INFRA_DEBUG` in the `infra` package.

- The idle loop can be used to help debug the system.

Triggering clock from the idle loop is a neat trick for examining system behavior either before interrupts are fully working, or to speed up "the clock".

Use the idle loop to monitor and/or print out variables or hardware registers.

- `hal_mk_defs` is used in some of the HALs (ARM, SH) as a way to generate assembler symbol definitions from C header files without imposing an assembler/C syntax separation in the C header files.

HAL Platform CDL

The platform CDL both contains details necessary for the building of eCos, and platform-specific configuration options. For this reason the options differ between platforms, and the below is just a brief description of the most common options.

See Components Writers Guide for more details on CDL. Also have a quick look around in existing platform CDL files to get an idea of what is possible and how various configuration issues can be represented with CDL.

eCos Database

The eCos configuration system is made aware of a package by adding a package description in `ecos.db`. As an example we use the `TX39/JMR3904` platform:

```
package CYGPKG_HAL_MIPS_TX39_JMR3904 {
  alias { "Toshiba JMR-TX3904 board" hal_tx39_jmr3904 tx39_jmr3904_hal }
  directory hal/mips/jmr3904
  script hal_mips_tx39_jmr3904.cdl
  hardware
  description "
    The JMR3904 HAL package should be used when targeting the
    actual hardware. The same package can also be used when
    running on the full simulator, since this provides an
    accurate simulation of the hardware including I/O devices.
    To use the simulator in this mode the command
    'target sim --board=jmr3904' should be used from inside gdb."
}
```

This contains the title and description presented in the Configuration Tool when the package is selected. It also specifies where in the tree the package files can be found (`directory`) and the name of the CDL file which contains the package details (`script`).

To be able to build and test a configuration for the new target, there also needs to be a `target` entry in the `ecos.db` file.

```
target jmr3904 {
  alias { "Toshiba JMR-TX3904 board" jmr tx39 }
  packages { CYGPKG_HAL_MIPS
             CYGPKG_HAL_MIPS_TX39
             CYGPKG_HAL_MIPS_TX39_JMR3904
           }
  description "
    The jmr3904 target provides the packages needed to run
    eCos on a Toshiba JMR-TX3904 board. This target can also
    be used when running in the full simulator, since the simulator provides an
    accurate simulation of the hardware including I/O devices.
    To use the simulator in this mode the command
    'target sim --board=jmr3904' should be used from inside gdb."
}
```

The important part here is the `packages` section which defines the various hardware specific packages that contribute to support for this target. In this case the MIPS architecture package, the TX39 variant package, and the JMR-TX3904 platform packages are selected. Other packages, for serial drivers, ethernet drivers and FLASH memory drivers may also appear here.

CDL File Layout

All the platform options are contained in a CDL package named `CYGPKG_HAL_<architecture>_<variant>_<platform>`. They all share more or less the same `cdl_package` details:

```
cdl_package CYGPKG_HAL_MIPS_TX39_JMR3904 {
    display      "JMR3904 evaluation board"
    parent       CYGPKG_HAL_MIPS
    requires      CYGPKG_HAL_MIPS_TX39
    define_header hal_mips_tx39_jmr3904.h
    include_dir   cyg/hal
    description   "
        The JMR3904 HAL package should be used when targeting the
        actual hardware. The same package can also be used when
        running on the full simulator, since this provides an
        accurate simulation of the hardware including I/O devices.
        To use the simulator in this mode the command
        'target sim --board=jmr3904' should be used from inside gdb."

    compile      platform.S plf_misc.c plf_stub.c

    define_proc {
        puts $::cdl_system_header "#define CYGBLD_HAL_TARGET_H    <pkgconf/hal_mips_tx39.h>"
        puts $::cdl_system_header "#define CYGBLD_HAL_PLATFORM_H <pkgconf/hal_mips_tx39_jmr3904.h>"
    }

    ...
}
```

This specifies that the platform package should be parented under the MIPS packages, requires the TX39 variant HAL and all configuration settings should be saved in `cyg/hal/hal_mips_tx39_jmr3904.h`.

The `compile` line specifies which files should be built when this package is enabled, and the `define_proc` defines some macros that are used to access the variant or architecture (the `_TARGET_` name is a bit of a misnomer) and platform configuration options.

Startup Type

eCos uses an option to select between a set of valid startup configurations. These are normally RAM, ROM and possibly ROMRAM. This setting is used to select which linker map to use (i.e., where to link eCos and the application in the memory space), and how the startup code should behave.

```
cdl_component CYG_HAL_STARTUP {
    display      "Startup type"
    flavor       data
    legal_values {"RAM" "ROM"}
    default_value {"RAM"}
    no_define
    define -file system.h CYG_HAL_STARTUP
    description  "
        When targeting the JMR3904 board it is possible to build
        the system for either RAM bootstrap, ROM bootstrap, or STUB
        bootstrap. RAM bootstrap generally requires that the board
        is equipped with ROMs containing a suitable ROM monitor or
        equivalent software that allows GDB to download the eCos
        application on to the board. The ROM bootstrap typically
        requires that the eCos application be blown into EPROMs or
        equivalent technology."
```



```
}
```

The `no_define` and `define` pair is used to make the setting of this option appear in the file `system.h` instead of the default specified in the header.

Build options

A set of options under the components `CYGBLD_GLOBAL_OPTIONS` and `CYGHWR_MEMORY_LAYOUT` specify how eCos should be built: what tools and compiler options should be used, and which linker fragments should be used.

```
cdl_component CYGBLD_GLOBAL_OPTIONS {
    display "Global build options"
    flavor none
    parent CYGPKG_NONE
    description "
        Global build options including control over
        compiler flags, linker flags and choice of toolchain."

    cdl_option CYGBLD_GLOBAL_COMMAND_PREFIX {
        display "Global command prefix"
        flavor data
        no_define
        default_value { "mips-tx39-elf" }
        description "
            This option specifies the command prefix used when
            invoking the build tools."
    }
}

cdl_option CYGBLD_GLOBAL_CFLAGS {
    display "Global compiler flags"
    flavor data
    no_define
    default_value { "-Wall -Wpointer-arith -Wstrict-prototypes -Winline -Wundef -Woverloaded-v"
    description "
        This option controls the global compiler flags which
        are used to compile all packages by
        default. Individual packages may define
        options which override these global flags."
}

cdl_option CYGBLD_GLOBAL_LDFLAGS {
    display "Global linker flags"
    flavor data
    no_define
    default_value { "-g -nostdlib -Wl,--gc-sections -Wl,-static" }
    description "
        This option controls the global linker flags. Individual
        packages may define options which override these global flags."
}
}

cdl_component CYGHWR_MEMORY_LAYOUT {
    display "Memory layout"
    flavor data
    no_define
    calculated { CYG_HAL_STARTUP == "RAM" ? "mips_tx39_jmr3904_ram" : \
        "mips_tx39_jmr3904_rom" }
```

```

cdl_option CYGHWR_MEMORY_LAYOUT_LDI {
    display "Memory layout linker script fragment"
    flavor data
    no_define
    define -file system.h CYGHWR_MEMORY_LAYOUT_LDI
    calculated { CYG_HAL_STARTUP == "RAM" ? "<pkgconf/mlt_mips_tx39_jmr3904_ram.ldi>" : \
        "<pkgconf/mlt_mips_tx39_jmr3904_rom.ldi>" }
}

cdl_option CYGHWR_MEMORY_LAYOUT_H {
    display "Memory layout header file"
    flavor data
    no_define
    define -file system.h CYGHWR_MEMORY_LAYOUT_H
    calculated { CYG_HAL_STARTUP == "RAM" ? "<pkgconf/mlt_mips_tx39_jmr3904_ram.h>" : \
        "<pkgconf/mlt_mips_tx39_jmr3904_rom.h>" }
}
}

```

Common Target Options

All platforms also specify real-time clock details:

```

# Real-time clock/counter specifics
cdl_component CYGNUM_HAL_RTC_CONSTANTS {
    display      "Real-time clock constants."
    flavor       none

    cdl_option CYGNUM_HAL_RTC_NUMERATOR {
        display      "Real-time clock numerator"
        flavor       data
        calculated    1000000000
    }
    cdl_option CYGNUM_HAL_RTC_DENOMINATOR {
        display      "Real-time clock denominator"
        flavor       data
        calculated    100
    }
}
# Isn't a nice way to handle freq requirement!
cdl_option CYGNUM_HAL_RTC_PERIOD {
    display      "Real-time clock period"
    flavor       data
    legal_values { 15360 20736 }
    calculated    { CYGHWR_HAL_MIPS_CPU_FREQ == 50 ? 15360 : \
        CYGHWR_HAL_MIPS_CPU_FREQ == 66 ? 20736 : 0 }
}
}

```

The `NUMERATOR` divided by the `DENOMINATOR` gives the number of nanoseconds per tick. The `PERIOD` is the divider to be programmed into a hardware timer that is driven from an appropriate hardware clock, such that the timer overflows once per tick (normally generating a CPU interrupt to mark the end of a tick). The tick default rate is typically 100Hz.

Platforms that make use of the virtual vector ROM calling interface (see [the Section called *Virtual Vectors \(eCos/ROM Monitor Calling Interface\)*](#)) will also specify details necessary to define configuration channels (these options are from the SH/EDK7707 HAL) :

```

cdl_option CYGNUM_HAL_VIRTUAL_VECTOR_COMM_CHANNELS {

```

```

    display      "Number of communication channels on the board"
    flavor       data
    calculated    1
}

cdl_option CYGNUM_HAL_VIRTUAL_VECTOR_DEBUG_CHANNEL {
    display      "Debug serial port"
    flavor data
    legal_values 0 to CYGNUM_HAL_VIRTUAL_VECTOR_COMM_CHANNELS-1
    default_value 0
    description  "
        The EDK/7708 board has only one serial port. This option
        chooses which port will be used to connect to a host
        running GDB."
}

cdl_option CYGNUM_HAL_VIRTUAL_VECTOR_CONSOLE_CHANNEL {
    display      "Diagnostic serial port"
    flavor data
    legal_values 0 to CYGNUM_HAL_VIRTUAL_VECTOR_COMM_CHANNELS-1
    default_value 0
    description  "
        The EDK/7708 board has only one serial port. This option
        chooses which port will be used for diagnostic output."
}

```

The platform usually also specify an option controlling the ability to co-exist with a ROM monitor:

```

cdl_option CYGSEM_HAL_USE_ROM_MONITOR {
    display      "Work with a ROM monitor"
    flavor       booldata
    legal_values { "Generic" "CygMon" "GDB_stubs" }
    default_value { CYG_HAL_STARTUP == "RAM" ? "CygMon" : 0 }
    parent       CYGPKG_HAL_ROM_MONITOR
    requires      { CYG_HAL_STARTUP == "RAM" }
    description  "
        Support can be enabled for three different varieties of ROM monitor.
        This support changes various eCos semantics such as the encoding
        of diagnostic output, or the overriding of hardware interrupt
        vectors.
        Firstly there is \"Generic\" support which prevents the HAL
        from overriding the hardware vectors that it does not use, to
        instead allow an installed ROM monitor to handle them. This is
        the most basic support which is likely to be common to most
        implementations of ROM monitor.
        \"CygMon\" provides support for the Cygnus ROM Monitor.
        And finally, \"GDB_stubs\" provides support when GDB stubs are
        included in the ROM monitor or boot ROM."
}

```

Or the ability to be configured as a ROM monitor:

```

cdl_option CYGSEM_HAL_ROM_MONITOR {
    display      "Behave as a ROM monitor"
    flavor       bool
    default_value 0
    parent       CYGPKG_HAL_ROM_MONITOR
    requires      { CYG_HAL_STARTUP == "ROM" }
    description  "
        Enable this option if this program is to be used as a ROM monitor,
        i.e. applications will be loaded into RAM on the board, and this

```

```

        ROM monitor may process exceptions or interrupts generated from the
        application. This enables features such as utilizing a separate
        interrupt stack when exceptions are generated."
    }

```

The latter option is accompanied by a special build rule that extends the generic ROM monitor build rule in the common HAL:

```

cdl_option CYGBLD_BUILD_GDB_STUBS {
    display "Build GDB stub ROM image"
    default_value 0
    requires { CYG_HAL_STARTUP == "ROM" }
    requires CYGSEM_HAL_ROM_MONITOR
    requires CYGBLD_BUILD_COMMON_GDB_STUBS
    requires CYGDBG_HAL_DEBUG_GDB_INCLUDE_STUBS
    requires ! CYGDBG_HAL_DEBUG_GDB_BREAK_SUPPORT
    requires ! CYGDBG_HAL_DEBUG_GDB_THREAD_SUPPORT
    requires ! CYGDBG_HAL_COMMON_INTERRUPTS_SAVE_MINIMUM_CONTEXT
    requires ! CYGDBG_HAL_COMMON_CONTEXT_SAVE_MINIMUM
    no_define
    description "
        This option enables the building of the GDB stubs for the
        board. The common HAL controls takes care of most of the
        build process, but the final conversion from ELF image to
        binary data is handled by the platform CDL, allowing
        relocation of the data if necessary."

    make -priority 320 {
        <PREFIX>/bin/gdb_module.bin : <PREFIX>/bin/gdb_module.img
        $(OBJCOPY) -O binary $< $@
    }
}

```

Most platforms support RedBoot, and some options are needed to configure for RedBoot.

```

cdl_component CYGPKG_REDBOOT_HAL_OPTIONS {
    display "Redboot HAL options"
    flavor none
    no_define
    parent CYGPKG_REDBOOT
    active_if CYGPKG_REDBOOT
    description "
        This option lists the target's requirements for a valid Redboot
        configuration."

    cdl_option CYGBLD_BUILD_REDBOOT_BIN {
        display "Build Redboot ROM binary image"
        active_if CYGBLD_BUILD_REDBOOT
        default_value 1
        no_define
        description "This option enables the conversion of the Redboot ELF
            image to a binary image suitable for ROM programming."

        make -priority 325 {
            <PREFIX>/bin/redboot.bin : <PREFIX>/bin/redboot.elf
            $(OBJCOPY) --strip-debug $< $@:.bin=.img
            $(OBJCOPY) -O srec $< $@:.bin=.srec
            $(OBJCOPY) -O binary $< $@
        }
    }
}

```

```
}
```

The important part here is the `make` command in the `CYGBLD_BUILD_REDBOOT_BIN` option which emits makefile commands to translate the `.elf` file generated by the link phase into both a binary file and an S-Record file. If a different format is required by a PROM programmer or ROM monitor, then different output formats would need to be generated here.

Platform Memory Layout

The platform memory layout is defined using the Memory Configuration Window in the Configuration Tool.

Note: If you do not have access to a Windows machine, you can hand edit the `.h` and `.ldi` files to match the properties of your platform. If you want to contribute your port back to the eCos community, ask someone on the list to make proper memory map files for you.

Layout Files

The memory configuration details are saved in three files:

`.mlt`

This is the Configuration Tool save-file. It is only used by the Configuration Tool.

`.ldi`

This is the linker script fragment. It defines the memory and location of sections by way of macros defined in the architecture or variant linker script.

`.h`

This file describes some of the memory region details as C macros, allowing eCos or the application adapt the memory layout of a specific configuration.

These three files are generated for each startup-type, since the memory details usually differ.

Reserved Regions

Some areas of the memory space are reserved for specific purposes, making room for exception vectors and various tables. RAM startup configurations also need to reserve some space at the bottom of the memory map for the ROM monitor.

These reserved areas are named with the prefix "reserved_" which is handled specially by the Configuration Tool: instead of referring to a linker macro, the start of the area is labeled and a gap left in the memory map.

Platform Serial Device Support

The first step is to set up the CDL definitions. The configuration options that need to be set are the following:

CYGNUM_HAL_VIRTUAL_VECTOR_COMM_CHANNELS

The number of channels, usually 0, 1 or 2.

CYGNUM_HAL_VIRTUAL_VECTOR_DEBUG_CHANNEL

The channel to use for GDB.

CYGNUM_HAL_VIRTUAL_VECTOR_DEBUG_CHANNEL_BAUD

Initial baud rate for debug channel.

CYGNUM_HAL_VIRTUAL_VECTOR_CONSOLE_CHANNEL

The channel to use for the console.

CYGNUM_HAL_VIRTUAL_VECTOR_CONSOLE_CHANNEL_BAUD

The initial baud rate for the console channel.

CYGNUM_HAL_VIRTUAL_VECTOR_CONSOLE_CHANNEL_DEFAULT

The default console channel.

The code in `hal_diag.c` need to be converted to support the new serial device. If this the same as a device already supported, copy that.

The following functions and types need to be rewritten to support a new serial device.

```
struct channel_data_t;
```

Structure containing base address, timeout and ISR vector number for each serial device supported. Extra fields may be added if necessary for the device. For example some devices have write-only control registers, so keeping a shadow of the last value written here can be useful.

```
xxxx_ser_channels[];
```

Array of `channel_data_t`, initialized with parameters of each channel. The index into this array is the channel number used in the CDL options above and is used by the virtual vector mechanism to refer to each channel.

```
void cyg_hal_plf_serial_init_channel(void *__ch_data)
```

Initialize the serial device. The parameter is actually a pointer to a `channel_data_t` and should be cast back to this type before use. This function should use the CDL definition for the baud rate for the channel it is initializing.

```
void cyg_hal_plf_serial_putc(void *__ch_data, char *c)
```

Send a character to the serial device. This function should poll for the device being ready to send and then write the character. Since this is intended to be a diagnostic/debug channel, it is often also a good idea to poll for end of transmission too. This ensures that as much data gets out of the system as possible.

```
bool cyg_hal_plf_serial_getc_nonblock(void* __ch_data, cyg_uint8* ch)
```

This function tests the device and if a character is available, places it in `*ch` and returns `TRUE`. If no character is available, then the function returns `FALSE` immediately.

```
int cyg_hal_plf_serial_control(void *__ch_data, __comm_control_cmd_t __func, ...)
```

This is an IOCTL-like function for controlling various aspects of the serial device. The only part in which you may need to do some work initially is in the `__COMMCTL_IRQ_ENABLE` and `__COMMCTL_IRQ_DISABLE` cases to enable/disable interrupts.

```
int cyg_hal_plf_serial_isr(void *__ch_data, int* __ctrlc, CYG_ADDRWORD __vector,
CYG_ADDRWORD __data)
```

This interrupt handler, called from the spurious interrupt vector, is specifically for dealing with `Ctrl-C` interrupts from GDB. When called this function should do the following:

1. Check for an incoming character. The code here is very similar to that in `cyg_hal_plf_serial_getc_nonblock()`.
2. Read the character and call `cyg_hal_is_break()`.
3. If result is true, set `*__ctrlc` to 1.
4. Return `CYG_ISR_HANDLED`.

```
void cyg_hal_plf_serial_init()
```

Initialize each of the serial channels. First call `cyg_hal_plf_serial_init_channel()` for each channel. Then call the `CYGACC_COMM_IF_*` macros for each channel. This latter set of calls are identical for all channels, so the best way to do this is to copy and edit an existing example.

Variant HAL Porting

A variant port can be a fairly limited job, but can also require quite a lot of work. A variant HAL describes how a specific CPU variant differs from the generic CPU architecture. The variant HAL can re-define cache, MMU, interrupt, and other features which override the default implementation provided by the architecture HAL.

Doing a variant port requires a preexisting architecture HAL port. It is also likely that a platform port will have to be done at the same time if it is to be tested.

HAL Variant Porting Process

The easiest way to make a new variant HAL is simply to copy an existing variant HAL and change all the files to match the new variant. If this is the first variant for an architecture, it may be hard to decide which parts should be put in the variant - knowledge of other variants of the architecture is required.

Looking at existing variant HALs (e.g., MIPS tx39, tx49) may be a help - usually things such as caching, interrupt and exception handling differ between variants. Initialization code, and code for handling various core components (FPU, DSP, MMU, etc.) may also differ or be missing altogether on some variants. Linker scripts may also require specific variant versions.

Note: Some CPU variants may require specific compiler support. That support must be in place before you can undertake the eCos variant port.

HAL Variant CDL

The CDL in a variant HAL tends to depend on the exact functionality supported by the variant. If it implements some of the devices described in the platform HAL, then the CDL for those will be here rather than there (for example the real-time clock).

There may also be CDL to select options in the architecture HAL to configure it to a particular architectural variant.

Each variant needs an entry in the `ecos.db` file. This is the one for the SH3:

```
package CYGPKG_HAL_SH_SH3 {
    alias          { "SH3 architecture" hal_sh_sh3 }
    directory      hal/sh/sh3
    script         hal_sh_sh3.cdl
    hardware
    description    "
        The SH3 (SuperH 3) variant HAL package provides generic
        support for SH3 variant CPUs."
}
```

As you can see, it is very similar to the platform entry.

The variant CDL file will contain a package entry named for the architecture and variant, matching the package name in the `ecos.db` file. Here is the initial part of the MIPS VR4300 CDL file:

```
cdl_package CYGPKG_HAL_MIPS_VR4300 {
    display        "VR4300 variant"
    parent         CYGPKG_HAL_MIPS
    implements     CYGINT_HAL_MIPS_VARIANT
    hardware
    include_dir    cyg/hal
    define_header  hal_mips_vr4300.h
    description    "
        The VR4300 variant HAL package provides generic support
        for this processor architecture. It is also necessary to
        select a specific target platform HAL package."
```

This defines the package, placing it under the MIPS architecture package in the hierarchy. The `implements` line indicates that this is a MIPS variant. The architecture package uses this to check that exactly one variant is configured in.

The variant defines some options that cause the architecture HAL to configure itself to support this variant.

```
cdl_option CYGHWR_HAL_MIPS_64BIT {
    display        "Variant 64 bit architecture support"
    calculated 1
}

cdl_option CYGHWR_HAL_MIPS_FPU {
    display        "Variant FPU support"
    calculated 1
}

cdl_option CYGHWR_HAL_MIPS_FPU_64BIT {
    display        "Variant 64 bit FPU support"
    calculated 1
}
```


These tell the architecture that this is a 64 bit MIPS architecture, that it has a floating point unit, and that we are going to use it in 64 bit mode rather than 32 bit mode.

The CDL file finishes off with some build options.

```
define_proc {
    puts $::cdl_header "#include <pkgconf/hal_mips.h>"
}

compile          var_misc.c

make {
    <PREFIX>/lib/target.ld: <PACKAGE>/src/mips_vr4300.ld
    $(CC) -E -P -Wp,-MD,target.tmp -DEXTRAS=1 -xc $(INCLUDE_PATH) $(CFLAGS) -o $@ $<
    @echo $@ ": \\" > $(notdir $@).deps
    @tail +2 target.tmp >> $(notdir $@).deps
    @echo >> $(notdir $@).deps
    @rm target.tmp
}

cdl_option CYGBLD_LINKER_SCRIPT {
    display "Linker script"
    flavor data
no_define
    calculated { "src/mips_vr4300.ld" }
}

}
```

The `define_proc` causes the architecture configuration file to be included into the configuration file for the variant. The `compile` causes the single source file for this variant, `var_misc.c` to be compiled. The `make` command emits makefile rules to combine the linker script with the `.ldi` file to generate `target.ld`. Finally, in the MIPS HALs, the main linker script is defined in the variant, rather than the architecture, so `CYGBLD_LINKER_SCRIPT` is defined here.

Cache Support

The main area where the variant is likely to be involved is in cache support. Often the only thing that distinguishes one CPU variant from another is the size of its caches.

In architectures such as the MIPS and PowerPC where cache instructions are part of the ISA, most of the actual cache operations are implemented in the architecture HAL. In this case the variant HAL only needs to define the cache dimensions. The following are the cache dimensions defined in the MIPS VR4300 variant `var_cache.h`.

```
// Data cache
#define HAL_DCACHE_SIZE          (8*1024)          // Size of data cache in bytes
#define HAL_DCACHE_LINE_SIZE    16                // Size of a data cache line
#define HAL_DCACHE_WAYS         1                 // Associativity of the cache

// Instruction cache
#define HAL_ICACHE_SIZE          (16*1024)         // Size of cache in bytes
#define HAL_ICACHE_LINE_SIZE    32                // Size of a cache line
#define HAL_ICACHE_WAYS         1                 // Associativity of the cache

#define HAL_DCACHE_SETS (HAL_DCACHE_SIZE/(HAL_DCACHE_LINE_SIZE*HAL_DCACHE_WAYS))
#define HAL_ICACHE_SETS (HAL_ICACHE_SIZE/(HAL_ICACHE_LINE_SIZE*HAL_ICACHE_WAYS))
```

Additional cache macros, or overrides for the defaults, may also appear in here. While some architectures have instructions for managing cache lines, overall enable/disable operations may be handled via variant specific registers. If so then `var_cache.h` should also define the `HAL_XCACHE_ENABLE()` and `HAL_XCACHE_DISABLE()` macros.

If there are any generic features that the variant does not support (cache locking is a typical example) then `var_cache.h` may need to disable definitions of certain operations. It is architecture dependent exactly how this is done.

Architecture HAL Porting

A new architecture HAL is the most complex HAL to write, and it the least easily described. Hence this section is presently nothing more than a place holder for the future.

HAL Architecture Porting Process

The easiest way to make a new architecture HAL is simply to copy an existing architecture HAL of an, if possible, closely matching architecture and change all the files to match the new architecture. The MIPS architecture HAL should be used if possible, as it has the appropriate layout and coding conventions. Other HALs may deviate from that norm in various ways.

Note: eCos is written for GCC. It requires C and C++ compiler support as well as a few compiler features introduced during eCos development - so compilers older than eCos may not provide these features. Note that there is no C++ support for any 8 or 16 bit CPUs. Before you can undertake an eCos port, you need the required compiler support.

The following gives a rough outline of the steps needed to create a new architecture HAL. The exact order and set of steps needed will vary greatly from architecture to architecture, so a lot of flexibility is required. And of course, if the architecture HAL is to be tested, it is necessary to do variant and platform ports for the initial target simultaneously.

1. Make a new directory for the new architecture under the `hal` directory in the source repository. Make an `arch` directory under this and populate this with the standard set of package directories.
2. Copy the CDL file from an example HAL changing its name to match the new HAL. Edit the file, changing option names as appropriate. Delete any options that are specific to the original HAL, and add any new options that are necessary for the new architecture. This is likely to be a continuing process during the development of the HAL. See [the Section called *CDL Requirements*](#) for more details.
3. Copy the `hal_arch.h` file from an example HAL. Within this file you need to change or define the following:
 - Define the `HAL_SavedRegisters` structure. This may need to reflect the save order of any group register save/restore instructions, the interrupt and exception save and restore formats, and the procedure calling conventions. It may also need to cater for optional FPU's and other functional units. It can be quite difficult to develop a layout that copes with all requirements.
 - Define the bit manipulation routines, `HAL_LSBIT_INDEX()` and `HAL_MSBIT_INDEX()`. If the architecture contains instructions to perform these, or related, operations, then these should be defined as inline assembler fragments. Otherwise make them calls to functions.

- Define `HAL_THREAD_INIT_CONTEXT()`. This initializes a restorable CPU context onto a stack pointer so that a later call to `HAL_THREAD_LOAD_CONTEXT()` or `HAL_THREAD_SWITCH_CONTEXT()` will execute it correctly. This macro needs to take account of the same optional features of the architecture as the definition of `HAL_SavedRegisters`.
 - Define `HAL_THREAD_LOAD_CONTEXT()` and `HAL_THREAD_SWITCH_CONTEXT()`. These should just be calls to functions in `context.S`.
 - Define `HAL_REORDER_BARRIER()`. This prevents code being moved by the compiler and is necessary in some order-sensitive code. This macro is actually defined identically in all architecture, so it can just be copied.
 - Define breakpoint support. The macro `HAL_BREAKPOINT(label)` needs to be an inline assembly fragment that invokes a breakpoint. The breakpoint instruction should be labeled with the `label` argument. `HAL_BREAKINST` and `HAL_BREAKINST_SIZE` define the breakpoint instruction for debugging purposes.
 - Optionally provide a macro `HAL_HWDEBUG_BREAKPOINT`. This is used by the common HAL's gdb file I/O support to get the attention of gdb when using hardware debug technology such as jtag or BDM. The macro may involve a dedicated breakpoint instruction or a processor exception or trap of some sort. Only one instance of this macro will ever be invoked. It should define either one or two labels. `_gdb_hwdebug_break` should correspond to the address that will be reported to gdb. If that address is the same as the breakpoint instruction or trap, or if the instruction has side effects like pushing exception data onto the stack, then the macro should also define a label `_gdb_hwdebug_continue`. When the application is resumed gdb will transfer control to that label if defined, allowing any necessary clean-up operations to be performed.
 - Define GDB support. GDB views the registers of the target as a linear array, with each register having a well defined offset. This array may differ from the ordering defined in `HAL_SavedRegisters`. The macros `HAL_GET_GDB_REGISTERS()` and `HAL_SET_GDB_REGISTERS()` translate between the GDB array and the `HAL_SavedRegisters` structure. The `HAL_THREAD_GET_SAVED_REGISTERS()` translates a stack pointer saved by the context switch macros into a pointer to a `HAL_SavedRegisters` structure. Usually this is a one-to-one translation, but this macro allows it to differ if necessary.
 - Define long jump support. The type `hal_jmp_buf` and the functions `hal_setjmp()` and `hal_longjmp()` provide the underlying implementation of the C library `setjmp()` and `longjmp()`.
 - Define idle thread action. Generally the macro `HAL_IDLE_THREAD_ACTION()` is defined to call a function in `hal_misc.c`.
 - Define stack sizes. The macros `CYGNUM_HAL_STACK_SIZE_MINIMUM` and `CYGNUM_HAL_STACK_SIZE_TYPICAL` should be defined to the minimum size for any thread stack and a reasonable default for most threads respectively. It is usually best to construct these out of component sizes for the CPU save state and procedure call stack usage. These definitions should not use anything other than numerical values since they can be used from assembly code in some HALs.
 - Define memory access macros. These macros provide translation between cached and uncached and physical memory spaces. They usually consist of masking out bits of the supplied address and ORing in alternative address bits.
 - Define global pointer save/restore macros. These really only need defining if the calling conventions of the architecture require a global pointer (as does the MIPS architecture), they may be empty otherwise. If it is necessary to define these, then take a look at the MIPS implementation for an example.
4. Copy `hal_intr.h` from an example HAL. Within this file you should change or define the following:
- Define the exception vectors. These should be detailed in the architecture specification. Essentially for each exception entry point defined by the architecture there should be an entry in the VSR table. The

offsets of these VSR table entries should be defined here by `CYGNUM_HAL_VECTOR_*` definitions. The size of the VSR table also needs to be defined here.

- Map any hardware exceptions to standard names. There is a group of exception vector name of the form `CYGNUM_HAL_EXCEPTION_*` that define a wide variety of possible exceptions that many architectures raise. Generic code detects whether the architecture can raise a given exception by testing whether a given `CYGNUM_HAL_EXCEPTION_*` definition is present. If it is present then its value is the vector that raises that exception. This does not need to be a one-to-one correspondence, and several `CYGNUM_HAL_EXCEPTION_*` definitions may have the same value.

Interrupt vectors are usually defined in the variant or platform HALs. The interrupt number space may either be continuous with the VSR number space, where they share a vector table (as in the i386) or may be a separate space where a separate decode stage is used (as in MIPS or PowerPC).

- Declare any static data used by the HAL to handle interrupts and exceptions. This is usually three vectors for interrupts: `hal_interrupt_handlers[]`, `hal_interrupt_data[]` and `hal_interrupt_objects[]`, which are sized according to the interrupt vector definitions. In addition a definition for the VSR table, `hal_vsr_table[]` should be made. These vectors are normally defined in either `vectors.S` or `hal_misc.c`.
- Define interrupt enable/disable macros. These are normally inline assembly fragments to execute the instructions, or manipulate the CPU register, that contains the CPU interrupt enable bit.
- A feature that many HALs support is the ability to execute DSRs on the interrupt stack. This is not an essential feature, and is better left unimplemented in the initial porting effort. If this is required, then the macro `HAL_INTERRUPT_STACK_CALL_PENDING_DSRS()` should be defined to call a function in `vectors.S`.
- Define the interrupt and VSR attachment macros. If the same arrays as for other HALs have been used for VSR and interrupt vectors, then these macro can be copied across unchanged.

5. A number of other header files also need to be filled in:

- `basetype.h`. This file defines the basic types used by eCos, together with the endianness and some other characteristics. This file only really needs to contain definitions if the architecture differs significantly from the defaults defined in `cyg_type.h`
- `hal_io.h`. This file contains macros for accessing device IO registers. If the architecture uses memory mapped IO, then these can be copied unchanged from an existing HAL such as MIPS. If the architecture uses special IO instructions, then these macros must be defined as inline assembler fragments. See the I386 HAL for an example. PCI bus access macros are usually defined in the variant or platform HALs.

This file may also provide further macro definitions, if relevant for the underlying hardware:

```
HAL_MEMORY_BARRIER()
```

This causes any memory writes pending within the CPU to be flushed to memory before continuing. Frequently there is a specific instruction, such as **sync** on MIPS, to cause write buffers to be flushed. This macro is generally not relevant to be called if you also have a writeback data cache, as that needs separate treatment. However this macro is relevant for systems with no data cache, a writethrough data cache, or in code running with the data cache disabled. For the latter reason this macro should be implemented if the facility exists, irrespective of the cache properties.

```
HAL_IO_BARRIER( )
```

This causes any I/O writes pending within the CPU to be flushed to the I/O space before continuing. Frequently there is a specific instruction, such as **eieio** on PowerPC, to cause such pending writes to be guaranteed to be committed. On systems with no separate I/O space, such that all device access is instead memory-mapped, then this function may be defined to be the same as `HAL_MEMORY_BARRIER()`.

- `hal_cache.h`. This file contains cache access macros. If the architecture defines cache instructions, or control registers, then the access macros should be defined here. Otherwise they must be defined in the variant or platform HAL. Usually the cache dimensions (total size, line size, ways etc.) are defined in the variant HAL.
- `arch.inc` and `<architecture>.inc`. These files are assembler headers used by `vectors.S` and `context.S`. `<architecture>.inc` is a general purpose header that should contain things like register aliases, ABI definitions and macros useful to general assembly code. If there are no such definitions, then this file need not be provided. `arch.inc` contains macros for performing various eCos related operations such as initializing the CPU, caches, FPU etc. The definitions here may often be configured or overridden by definitions in the variant or platform HALs. See the MIPS HAL for an example of this.

6. Write `vectors.S`. This is the most important file in the HAL. It contains the CPU initialization code, exception and interrupt handlers. While other HALs should be consulted for structures and techniques, there is very little here that can be copied over without major edits.

The main pieces of code that need to be defined here are:

- Reset vector. This usually need to be positioned at the start of the ROM or FLASH, so should be in a linker section of its own. It can then be placed correctly by the linker script. Normally this code is little more than a jump to the label `_start`.
- Exception vectors. These are the trampoline routines connected to the hardware exception entry points that vector through the VSR table. In many architectures these are adjacent to the reset vector, and should occupy the same linker section. If the architecture allow the vectors to be moved then it may be necessary for these trampolines to be position independent so they can be relocated at runtime.

The trampolines should do the minimum necessary to transfer control from the hardware vector to the VSR pointed to by the matching table entry. Exactly how this is done depends on the architecture. Usually the trampoline needs to get some working registers by either saving them to CPU special registers (e.g. PowerPC SPRs), using reserved general registers (MIPS K0 and K1), using only memory based operations (IA32), or just jumping directly (ARM). The VSR table index to be used is either implicit in the entry point taken (PowerPC, IA32, ARM), or must be determined from a CPU register (MIPS).

- Write kernel startup code. This is the location the reset vector jumps to, and can be in the main text section of the executable, rather than a special section. The code here should first initialize the CPU and other hardware subsystems. The best approach is to use a set of macro calls that are defined either in `arch.inc` or overridden in the variant or platform HALs. Other jobs that this code should do are: initialize stack pointer; copy the data section from ROM to RAM if necessary; zero the BSS; call variant and platform initializers; call `cyg_hal_invoke_constructors()`; call `initialize_stub()` if necessary. Finally it should call `cyg_start()`. See [the Section called HAL Startup in Chapter 5](#) for details.

- Write the default exception VSR. This VSR is installed in the VSR table for all synchronous exception vectors. See [the Section called Default Synchronous Exception Handling in Chapter 5](#) for details of what this VSR does.
- Write the default interrupt VSR. This is installed in all VSR table entries that correspond to external interrupts. See [the Section called Default Synchronous Exception Handling in Chapter 5](#) for details of what this VSR does.
- Write `hal_interrupt_stack_call_pending_dsrs()`. If this function is defined in `hal_arch.h` then it should appear here. The purpose of this function is to call DSRs on the interrupt stack rather than the current thread's stack. This is not an essential feature, and may be left until later. However it interacts with the stack switching that goes on in the interrupt VSR, so it may make sense to write these pieces of code at the same time to ensure consistency.

When this function is implemented it should do the following:

- Take a copy of the current SP and then switch to the interrupt stack.
 - Save the old SP, together with the CPU status register (or whatever register contains the interrupt enable status) and any other registers that may be corrupted by a function call (such as any link register) to locations in the interrupt stack.
 - Enable interrupts.
 - Call `cyg_interrupt_call_pending_DSRs()`. This is a kernel functions that actually calls any pending DSRs.
 - Retrieve saved registers from the interrupt stack and switch back to the current thread stack.
 - Merge the interrupt enable state recorded in the save CPU status register with the current value of the status register to restore the previous enable state. If the status register does not contain any other persistent state then this can be a simple restore of the register. However if the register contains other state bits that might have been changed by a DSR, then care must be taken not to disturb these.
7. Write `context.S`. This file contains the context switch code. See [the Section called Thread Context Switching in Chapter 4](#) for details of how these functions operate. This file may also contain the implementation of `hal_setjmp()` and `hal_longjmp()`.
 8. Write `hal_misc.c`. This file contains any C data and functions needed by the HAL. These might include:
 - `hal_interrupt_*[]`. In some HALs, if these arrays are not defined in `vectors.S` then they must be defined here.
 - `cyg_hal_exception_handler()`. This function is called from the exception VSR. It usually does extra decoding of the exception and invokes any special handlers for things like FPU traps, bus errors or memory exceptions. If there is nothing special to be done for an exception, then it either calls into the GDB stubs, by calling `__handle_exception()`, or invokes the kernel by calling `cyg_hal_deliver_exception()`.
 - `hal_arch_default_isr()`. The `hal_interrupt_handlers[]` array is usually initialized with pointers to `hal_default_isr()`, which is defined in the common HAL. This function handles things like Ctrl-C processing, but if that is not relevant, then it will call `hal_arch_default_isr()`. Normally this function should just return zero.

- `cyg_hal_invoke_constructors()`. This calls the constructors for all static objects before the program starts. eCos relies on these being called in the correct order for it to function correctly. The exact way in which constructors are handled may differ between architectures, although most use a simple table of function pointers between labels `__CTOR_LIST__` and `__CTOR_END__` which must be called in order from the top down. Generally, this function can be copied directly from an existing architecture HAL.
- Bit indexing functions. If the macros `HAL_LSBIT_INDEX()` and `HAL_MSBIT_INDEX()` are defined as function calls, then the functions should appear here. The main reason for doing this is that the architecture does not have support for bit indexing and these functions must provide the functionality by conventional means. While the trivial implementation is a simple for loop, it is expensive and non-deterministic. Better, constant time, implementations can be found in several HALs (MIPS for example).
- `hal_delay_us()`. If the macro `HAL_DELAY_US()` is defined in `hal_intr.h` then it should be defined to call this function. While most of the time this function is called with very small values, occasionally (particularly in some ethernet drivers) it is called with values of several seconds. Hence the function should take care to avoid overflow in any calculations.
- `hal_idle_thread_action()`. This function is called from the idle thread via the `HAL_IDLE_THREAD_ACTION()` macro, if so defined. While normally this function does nothing, during development this is often a good place to report various important system parameters on LCDs, LED or other displays. This function can also monitor system state and report any anomalies. If the architecture supports a `halt` instruction then this is a good place to put an inline assembly fragment to execute it. It is also a good place to handle any power saving activity.

9. Create the `<architecture>.ld` file. While this file may need to be moved to the variant HAL in the future, it should initially be defined here, and only moved if necessary.

This file defines a set of macros that are used by the platform `.ldi` files to generate linker scripts. Most GCC toolchains are very similar so the correct approach is to copy the file from an existing architecture and edit it. The main things that will need editing are the `OUTPUT_FORMAT()` directive and maybe the creation or allocation of extra sections to various macros. Running the target linker with just the `--verbose` argument will cause it to output its default linker script. This can be compared with the `.ld` file and appropriate edits made.

10. If GDB stubs are to be supported in RedBoot or eCos, then support must be included for these. The most important of these are `include/<architecture>-stub.h` and `src/<architecture>-stub.c`. In all existing architecture HALs these files, and any support files they need, have been derived from files supplied in `libgloss`, as part of the GDB toolchain package. If this is a totally new architecture, this may not have been done, and they must be created from scratch.

`include/<architecture>-stub.h` contains definitions that are used by the GDB stubs to describe the size, type, number and names of CPU registers. This information is usually found in the GDB support files for the architecture. It also contains prototypes for the functions exported by `src/<architecture>-stub.c`; however, since this is common to all architectures, it can be copied from some other HAL.

`src/<architecture>-stub.c` implements the functions exported by the header. Most of this is fairly straight forward: the implementation in existing HALs should show exactly what needs to be done. The only complex part is the support for single-stepping. This is used a lot by GDB, so it cannot be avoided. If the architecture has support for a trace or single-step trap then that can be used for this purpose. If it does not then this must be simulated by planting a breakpoint in the next instruction. This can be quite involved since it requires some analysis of the current instruction plus the state of the CPU to determine where execution is going to go next.

CDL Requirements

The CDL needed for any particular architecture HAL depends to a large extent on the needs of that architecture. This includes issues such as support for different variants, use of FPUs, MMUs and caches. The exact split between the architecture, variant and platform HALs for various features is also somewhat fluid.

To give a rough idea about how the CDL for an architecture is structured, we will take as an example the I386 CDL.

This first section introduces the CDL package and placed it under the main HAL package. Include files from this package will be put in the `include/cyg/hal` directory, and definitions from this file will be placed in `include/pkgconf/hal_i386.h`. The `compile` line specifies the files in the `src` directory that are to be compiled as part of this package.

```
cdl_package CYGPKG_HAL_I386 {
    display      "i386 architecture"
    parent       CYGPKG_HAL
    hardware
    include_dir   cyg/hal
    define_header hal_i386.h
    description   "
        The i386 architecture HAL package provides generic
        support for this processor architecture. It is also
        necessary to select a specific target platform HAL
        package."

    compile      hal_misc.c context.S i386_stub.c hal_syscall.c
}
```

Next we need to generate some files using non-standard make rules. The first is `vectors.S`, which is not put into the library, but linked explicitly with all applications. The second is the generation of the `target.ld` file from `i386.ld` and the startup-selected `.ldi` file. Both of these are essentially boilerplate code that can be copied and edited.

```
make {
    <PREFIX>/lib/vectors.o : <PACKAGE>/src/vectors.S
    $(CC) -Wp,-MD,vectors.tmp $(INCLUDE_PATH) $(CFLAGS) -c -o $@ $<
    @echo $@ ": \\" > $(notdir $@).deps
    @tail +2 vectors.tmp >> $(notdir $@).deps
    @echo >> $(notdir $@).deps
    @rm vectors.tmp
}

make {
    <PREFIX>/lib/target.ld: <PACKAGE>/src/i386.ld
    $(CC) -E -P -Wp,-MD,target.tmp -DEXTRAS=1 -xc $(INCLUDE_PATH) $(CFLAGS) -o $@ $<
    @echo $@ ": \\" > $(notdir $@).deps
    @tail +2 target.tmp >> $(notdir $@).deps
    @echo >> $(notdir $@).deps
    @rm target.tmp
}
```

The i386 is currently the only architecture that supports SMP. The following CDL simply enabled the HAL SMP support if required. Generally this will get enabled as a result of a `requires` statement in the kernel. The `requires` statement here turns off lazy FPU switching in the FPU support code, since it is inconsistent with SMP operation.


```

    cdl_component CYGPKG_HAL_SMP_SUPPORT {
display      "SMP support"
default_value 0
requires { CYGHWL_HAL_I386_FPU_SWITCH_LAZY == 0 }

    cdl_option CYGPKG_HAL_SMP_CPU_MAX {
        display      "Max number of CPUs supported"
        flavor        data
        default_value 2
    }
}

```

The i386 HAL has optional FPU support, which is enabled by default. It can be disabled to improve system performance. There are two FPU support options: either to save and restore the FPU state on every context switch, or to only switch the FPU state when necessary.

```

    cdl_component CYGHWL_HAL_I386_FPU {
display      "Enable I386 FPU support"
default_value 1
description  "This component enables support for the
              I386 floating point unit."

    cdl_option CYGHWL_HAL_I386_FPU_SWITCH_LAZY {
        display      "Use lazy FPU state switching"
        flavor        bool
        default_value 1

        description "
            This option enables lazy FPU state switching.
            The default behaviour for eCos is to save and
            restore FPU state on every thread switch, interrupt
            and exception. While simple and deterministic, this
            approach can be expensive if the FPU is not used by
            all threads. The alternative, enabled by this option,
            is to use hardware features that allow the FPU state
            of a thread to be left in the FPU after it has been
            descheduled, and to allow the state to be switched to
            a new thread only if it actually uses the FPU. Where
            only one or two threads use the FPU this can avoid a
            lot of unnecessary state switching."
        }
    }
}

```

The i386 HAL also has support for different classes of CPU. In particular, Pentium class CPUs have extra functional units, and some variants of GDB expect more registers to be reported. These options enable these features. Generally these are enabled by `requires` statements in variant or platform packages, or in `.ecm` files.

```

    cdl_component CYGHWL_HAL_I386_PENTIUM {
display      "Enable Pentium class CPU features"
default_value 0
description  "This component enables support for various
              features of Pentium class CPUs."

    cdl_option CYGHWL_HAL_I386_PENTIUM_SSE {
        display      "Save/Restore SSE registers on context switch"
        flavor        bool
        default_value 0
    }
}

```

```

        description "
            This option enables SSE state switching. The default
            behaviour for eCos is to ignore the SSE registers.
            Enabling this option adds SSE state information to
            every thread context."
    }

    cdl_option CYGHWR_HAL_I386_PENTIUM_GDB_REGS {
        display      "Support extra Pentium registers in GDB stub"
        flavor       bool
        default_value 0

        description "
            This option enables support for extra Pentium registers
            in the GDB stub. These are registers such as CR0-CR4, and
            all MSRs. Not all GDBs support these registers, so the
            default behaviour for eCos is to not include them in the
            GDB stub support code."
    }
}

```

In the i386 HALs, the linker script is provided by the architecture HAL. In other HALs, for example MIPS, it is provided in the variant HAL. The following option provides the name of the linker script to other elements in the configuration system.

```

    cdl_option CYGBLD_LINKER_SCRIPT {
        display "Linker script"
        flavor data
    no_define
        calculated { "src/i386.ld" }
    }

```

Finally, this interface indicates whether the platform supplied an implementation of the `hal_i386_mem_real_region_top()` function. If it does then it will contain a line of the form: `implements CYGINT_HAL_I386_MEM_REAL_REGION_TOP`. This allows packages such as RedBoot to detect the presence of this function so that they may call it.

```

    cdl_interface CYGINT_HAL_I386_MEM_REAL_REGION_TOP {
        display "Implementations of hal_i386_mem_real_region_top()"
    }
}

```

Chapter 7. Future developments

The HAL is not complete, and will evolve and increase over time. Among the intended developments are:

- Common macros for interpreting the contents of a saved machine context. These would allow portable code, such as debug stubs, to extract such values as the program counter and stack pointer from a state without having to interpret a `HAL_SavedRegisters` structure directly.
- Debugging support. Macros to set and clear hardware and software breakpoints. Access to other areas of machine state may also be supported.
- Static initialization support. The current HAL provides a dynamic interface to things like thread context initialization and ISR attachment. We also need to be able to define the system entirely statically so that it is ready to go on restart, without needing to run code. This will require extra macros to define these initializations. Such support may have a consequential effect on the current HAL specification.
- CPU state control. Many CPUs have both kernel and user states. Although it is not intended to run any code in user state for the foreseeable future, it is possible that this may happen eventually. If this is the case, then some minor changes may be needed to the current HAL API to accommodate this. These should mostly be extensions, but minor changes in semantics may also be required.
- Physical memory management. Many embedded systems have multiple memory areas with varying properties such as base address, size, speed, bus width, cacheability and persistence. An API is needed to support the discovery of this information about the machine's physical memory map.
- Memory management control. Some embedded processors have a memory management unit. In some cases this must be enabled to allow the cache to be controlled, particularly if different regions of memory must have different caching properties. For some purposes, in some systems, it will be useful to manipulate the MMU settings dynamically.
- Power management. Macros to access and control any power management mechanisms available on the CPU implementation. These would provide a substrate for a more general power management system that also involved device drivers and other hardware components.
- Generic serial line macros. Most serial line devices operate in the same way, the only real differences being exactly which bits in which registers perform the standard functions. It should be possible to develop a set of HAL macros that provide basic serial line services such as baud rate setting, enabling interrupts, polling for transmit or receive ready, transmitting and receiving data etc. Given these it should be possible to create a generic serial line device driver that will allow rapid bootstrapping on any new platform. It may be possible to extend this mechanism to other device types.

III. The ISO Standard C and Math Libraries

Chapter 8. C and math library overview

eCos provides compatibility with the ISO 9899:1990 specification for the standard C library, which is essentially the same as the better-known ANSI C3.159-1989 specification (C-89).

There are three aspects of this compatibility supplied by *eCos*. First there is a *C library* which implements the functions defined by the ISO standard, except for the mathematical functions. This is provided by the *eCos* C library packages.

Then *eCos* provides a math library, which implements the mathematical functions from the ISO C library. This distinction between C and math libraries is frequently drawn — most standard C library implementations provide separate linkable files for the two, and the math library contains all the functions from the `math.h` header file.

There is a third element to the ISO C library, which is the environment in which applications run when they use the standard C library. This environment is set up by the C library startup procedure ([the Section called *C library startup*](#)) and it provides (among other things) a `main()` entry point function, an `exit()` function that does the cleanup required by the standard (including handlers registered using the `atexit()` function), and an environment that can be read with `getenv()`.

The description in this manual focuses on the *eCos*-specific aspects of the C library (mostly related to *eCos*'s configurability) as well as mentioning the omissions from the standard in this release. We do not attempt to define the semantics of each function, since that information can be found in the ISO, ANSI, POSIX and IEEE standards, and the many good books that have been written about the standard C library, that cover usage of these functions in a more general and useful way.

Included non-ISO functions

The following functions from the POSIX specification are included for convenience:

`extern char **environ` variable (for setting up the environment for use with `getenv()`)

`_exit()`

`strtok_r()`

`rand_r()`

`asctime_r()`

`ctime_r()`

`localtime_r()`

`gmtime_r()`

eCos provides the following additional implementation-specific functions within the standard C library to adjust the date and time settings:

```
void cyg_libc_time_setdst(
    cyg_libc_time_dst state
);
```

This function sets the state of Daylight Savings Time. The values for state are:

<code>CYG_LIBC_TIME_DSTNA</code>	unknown
<code>CYG_LIBC_TIME_DSTOFF</code>	off
<code>CYG_LIBC_TIME_DSTON</code>	on

```
void cyg_libc_time_setzoneoffsets(
```

```
    time_t stdoffset, time_t dstoffset
);
```

This function sets the offsets from UTC used when Daylight Savings Time is enabled or disabled. The offsets are in `time_t`'s, which are seconds in the current implementation.

```
Cyg_libc_time_dst cyg_libc_time_getzoneoffsets(
    time_t *stdoffset, time_t *dstoffset
);
```

This function retrieves the current setting for Daylight Savings Time along with the offsets used for both STD and DST. The offsets are both in `time_t`'s, which are seconds in the current implementation.

```
cyg_bool cyg_libc_time_settime(
    time_t utctime
);
```

This function sets the current time for the system. The time is specified as a `time_t` in UTC. It returns non-zero on error.

Math library compatibility modes

This math library is capable of being operated in several different compatibility modes. These options deal solely with how errors are handled.

There are 4 compatibility modes: ANSI/POSIX 1003.1; IEEE-754; X/Open Portability Guide issue 3 (XPG3); and System V Interface Definition Edition 3.

In IEEE mode, the `matherr()` function (see below) is never called, no warning messages are printed on the `stderr` output stream, and `errno` is never set.

In ANSI/POSIX mode, `errno` is set correctly, but `matherr()` is never called and no warning messages are printed on the `stderr` output stream.

In X/Open mode, `errno` is set correctly, `matherr()` is called, but no warning messages are printed on the `stderr` output stream.

In SVID mode, functions which overflow return a value `HUGE` (defined in `math.h`), which is the maximum single precision floating point value (as opposed to `HUGE_VAL` which is meant to stand for infinity). `errno` is set correctly and `matherr()` is called. If `matherr()` returns 0, warning messages are printed on the `stderr` output stream for some errors.

The mode can be compiled-in as IEEE-only, or any one of the above methods settable at run-time.

Note: This math library assumes that the hardware (or software floating point emulation) supports IEEE-754 style arithmetic, 32-bit 2's complement integer arithmetic, doubles are in 64-bit IEEE-754 format.

`matherr()`

As mentioned above, in X/Open or SVID modes, the user can supply a function `matherr()` of the form:

```
int matherr( struct exception *e )
```

where `struct exception` is defined as:


```

struct exception {
    int type;
    char *name;
    double arg1, arg2, retval;
};

```

type is the exception type and is one of:

DOMAIN

argument domain exception

SING

argument singularity

OVERFLOW

overflow range exception

UNDERFLOW

underflow range exception

TLOSS

total loss of significance

PLOSS

partial loss of significance

name is a string containing the name of the function

arg1 and *arg2* are the arguments passed to the function

retval is the default value that will be returned by the function, and can be changed by `matherr()`

Note: `matherr` must have “C” linkage, not “C++” linkage.

If `matherr` returns zero, or the user doesn’t supply their own `matherr`, then the following *usually* happens in SVID mode:

Table 8-1. Behavior of math exception handling

Type	Behavior
DOMAIN	0.0 returned, <code>errno=EDOM</code> , and a message printed on <code>stderr</code>
SING	HUGE of appropriate sign is returned, <code>errno=EDOM</code> , and a message is printed on <code>stderr</code>
OVERFLOW	HUGE of appropriate sign is returned, and <code>errno=ERANGE</code>
UNDERFLOW	0.0 is returned and <code>errno=ERANGE</code>
TLOSS	0.0 is returned, <code>errno=ERANGE</code> , and a message is printed on <code>stderr</code>
PLOSS	The current implementation doesn’t return this type

X/Open mode is similar except that the message is not printed on stderr and HUGE_VAL is used in place of HUGE

Thread-safety and re-entrancy

With the appropriate configuration options set below, the math library is fully thread-safe if:

- Depending on the compatibility mode, the setting of the `errno` variable from the C library is thread-safe
- Depending on the compatibility mode, sending error messages to the stderr output stream using the C library `fputs()` function is thread-safe
- Depending on the compatibility mode, the user-supplied `matherr()` function and anything it depends on are thread-safe

In addition, with the exception of the `gamma*()` and `lgamma*()` functions, the math library is reentrant (and thus safe to use from interrupt handlers) if the Math library is always in IEEE mode.

Some implementation details

Here are some details about the implementation which might be interesting, although they do not affect the ISO-defined semantics of the library.

- It is possible to configure *eCos* to have the standard C library without the kernel. You might want to do this to use less memory.
- The opaque type returned by `clock()` is called `clock_t`, and is implemented as a 64 bit integer. The value returned by `clock()` is only correct if the kernel is configured with real-time clock support, as determined by the `CYGVAR_KERNEL_COUNTERS_CLOCK` configuration option in `kernel.h`.
- The `FILE` type is not implemented as a structure, but rather as a `CYG_ADDRESS`.
- The GNU C compiler will replace its own *built-in* implementations instead of calls to some C library functions. This can be turned off with the `-fno-builtin` option. But it is recommended for normal use to leave compiler builtins enabled. The functions affected by this are described in the documentation associated with the particular GNU compiler version you are using, but include at least: `abs()`, `cos()`, `fabs()`, `labs()`, `memcmp()`, `memcpy()`, `sin()`, `sqrt()`, `strcmp()`, `strcpy()`, and `strlen()`.
- `memcpy()` and `memset()` are located in the infrastructure package, not in the C library package. This is because the compiler calls these functions, and the kernel needs to resolve them even if the C library is not configured.
- Error codes such as `EDOM` and `ERANGE`, as well as `strerror()`, are implemented in the *error* package. The error package is separate from the rest of the C and math libraries so that the rest of *eCos* can use these error handling facilities even if the C library is not configured.
- The memory allocation package `CYGPKG_MEMALLOC` is responsible for providing the various heap management functions such as `malloc()`, `free()`, etc.
- Signals, as implemented by `<signal.h>`, are guaranteed to work correctly if raised using the `raise()` function from a normal working program context. Using signals from within an ISR or DSR context is not expected to work. Also, it is not guaranteed that if `CYGSEM_LIBC_SIGNALS_HWEXCEPTIONS` is set, that handling a signal using `signal()` will necessarily catch that form of exception. For example, it may be expected that a divide-by-zero error would be caught by handling `SIGFPE`. However it depends on the

underlying HAL implementation to implement the required hardware exception. And indeed the hardware itself may not be capable of detecting these exceptions so it may not be possible for the HAL implementer to do this in any case. Despite this lack of guarantees in this respect, the signals implementation is still ISO C compliant since ISO C does not offer any such guarantees either.

- If you include the POSIX compatibility layer in your configuration, by default it will present a conflict if the C library signals implementation is also present. Only one signals implementation may be present.
- The `getenv()` function is implemented (unless the `CYGPKG_LIBC_ENVIRONMENT` configuration option is turned off), but there is no shell or `putenv()` function to set the environment dynamically. The environment is set in a global variable `environ`, declared as:

```
extern char **environ; // Standard environment definition
```

The environment can be statically initialized at startup time using the `CYG-DAT_LIBC_DEFAULT_ENVIRONMENT` option. If so, remember that the final entry of the array initializer must be `NULL`.

Here is a minimal *eCos* program which demonstrates the use of environments (see also the test case in `language/c/libc/VERSION/tests/stdlib/getenv.c`):

```
#include <stdio.h>
#include <stdlib.h> // Main header for stdlib functions

extern char **environ; // Standard environment definition

int
main( int argc, char *argv[] )
{
    char *str;
    char *env[] = { "PATH=/usr/local/bin:/usr/bin",
        "HOME=/home/fred",
        "TEST=1234=5678",
        "home=hatstand",
        NULL };

    printf("Display the current PATH environment variable\n");

    environ = (char **)&env;

    str = getenv("PATH");

    if (str==NULL) {
        printf("The current PATH is unset\n");
    } else {
        printf("The current PATH is \"%s\"\n", str);
    }
    return 0;
}
```

Thread safety

The ISO C library has configuration options that control thread safety, i.e. working behavior if multiple threads call the same function at the same time.

The following functionality has to be configured correctly, or used carefully in a multi-threaded environment:

- `mblen()`
- `mbtowc()`
- `wctomb()`
- `printf()` (and all standard I/O functions except for `sprintf()` and `sscanf()`)
- `strtok()`
- `rand()` and `srand()`
- `signal()` and `raise()`
- `asctime()`, `ctime()`, `gmtime()`, and `localtime()`
- the `errno` variable
- the `environ` variable
- date and time settings

In some cases, to make *eCos* development easier, functions are provided (as specified by POSIX 1003.1) that define re-entrant alternatives, i.e. `rand_r()`, `strtok_r()`, `asctime_r()`, `ctime_r()`, `gmtime_r()`, and `localtime_r()`. In other cases, configuration options are provided that control either locking of functions or their shared data, such as with standard I/O streams, or by using per-thread data, such as with the `errno` variable.

In some other cases, like the setting of date and time, no re-entrant or thread-safe alternative or configuration is provided as it is simply not a worthwhile addition (date and time should rarely need to be set.)

C library startup

The C library includes a function declared as:

```
void cyg_iso_c_start( void )
```

This function is used to start an environment in which an ISO C style program can run in the most compatible way.

What this function does is to create a thread which will invoke `main()` — normally considered a program's entry point. In particular, it can supply arguments to `main()` using the `CYGDAT_LIBC_ARGUMENTS` configuration option, and when returning from `main()`, or calling `exit()`, pending `stdio` file output is flushed and any functions registered with `atexit()` are invoked. This is all compliant with the ISO C standard in this respect.

This thread starts execution when the *eCos* scheduler is started. If the *eCos* kernel package is not available (and hence there is no scheduler), then `cyg_iso_c_start()` will invoke the `main()` function directly, i.e. it will not return until the `main()` function returns.

The `main()` function should be defined as the following, and if defined in a C++ file, should have "C" linkage:

```
extern int main(  
    int argc,  
    char *argv[ ] )
```

The thread that is started by `cyg_iso_c_start()` can be manipulated directly, if you wish. For example you can suspend it. The kernel C API needs a handle to do this, which is available by including the following in your source code.

```
extern cyg_handle_t cyg_libc_main_thread;
```

Then for example, you can suspend the thread with the line:

```
cyg_thread_suspend( cyg_libc_main_thread );
```

If you call `cyg_iso_c_start()` and do not provide your own `main()` function, the system will provide a `main()` for you which will simply return immediately.

In the default configuration, `cyg_iso_c_start()` is invoked automatically by the `cyg_package_start()` function in the infrastructure configuration. This means that in the simplest case, your program can indeed consist of simply:

```
int main( int argc, char *argv[] )
{
    printf("Hello eCos\n");
}
```

If you override `cyg_package_start()` or `cyg_start()`, or disable the infrastructure configuration option `CYGSEM_START_ISO_C_COMPATIBILITY` then you must ensure that you call `cyg_iso_c_start()` yourself if you want to be able to have your program start at the entry point of `main()` automatically.

IV. I/O Package (Device Drivers)

Chapter 9. Introduction

The I/O package is designed as a general purpose framework for supporting device drivers. This includes all classes of drivers from simple serial to networking stacks and beyond.

Components of the I/O package, such as device drivers, are configured into the system just like all other components. Additionally, end users may add their own drivers to this set.

While the set of drivers (and the devices they represent) may be considered static, they must be accessed via an opaque “handle”. Each device in the system has a unique name and the `cyg_io_lookup()` function is used to map that name onto the handle for the device. This “hiding” of the device implementation allows for generic, named devices, as well as more flexibility. Also, the `cyg_io_lookup()` function provides drivers the opportunity to initialize the device when usage actually starts.

All devices have a name. The standard provided devices use names such as `"/dev/console"` and `"/dev/serial0"`, where the `"/dev/"` prefix indicates that this is the name of a device.

The entire I/O package API, as well as the standard set of provided drivers, is written in C.

Basic functions are provided to send data to and receive data from a device. The details of how this is done is left to the device [class] itself. For example, writing data to a block device like a disk drive may have different semantics than writing to a serial port.

Additional functions are provided to manipulate the state of the driver and/or the actual device. These functions are, by design, quite specific to the actual driver.

This driver model supports layering; in other words, a device may actually be created “on top of” another device. For example, the “tty” (terminal-like) devices are built on top of simple serial devices. The upper layer then has the flexibility to add features and functions not found at the lower layers. In this case the “tty” device provides for line buffering and editing not available from the simple serial drivers.

Some drivers will support visibility of the layers they depend upon. The “tty” driver allows information about the actual serial device to be manipulated by passing get/set config calls that use a serial driver “key” down to the serial driver itself.

Chapter 10. User API

All functions, except `cyg_io_lookup()` require an I/O “handle”.

All functions return a value of the type `Cyg_ErrNo`. If an error condition is detected, this value will be negative and the absolute value indicates the actual error, as specified in `cyg/error/codes.h`. The only other legal return value will be `ENOERR`. All other function arguments are pointers (references). This allows the drivers to pass information efficiently, both into and out of the driver. The most striking example of this is the “length” value passed to the read and write functions. This parameter contains the desired length of data on input to the function and the actual transferred length on return.

```
// Lookup a device and return its handle
Cyg_ErrNo cyg_io_lookup(
    const char *name,
    cyg_io_handle_t *handle )
```

This function maps a device name onto an appropriate handle. If the named device is not in the system, then the error `-ENOENT` is returned. If the device is found, then the handle for the device is returned by way of the handle pointer `*handle`.

```
// Write data to a device
Cyg_ErrNo cyg_io_write(
    cyg_io_handle_t handle,
    const void *buf,
    cyg_uint32 *len )
```

This function sends data to a device. The size of data to send is contained in `*len` and the actual size sent will be returned in the same place.

```
// Read data from a device
Cyg_ErrNo cyg_io_read(
    cyg_io_handle_t handle,
    void *buf,
    cyg_uint32 *len )
```

This function receives data from a device. The desired size of data to receive is contained in `*len` and the actual size obtained will be returned in the same place.

```
// Get the configuration of a device
Cyg_ErrNo cyg_io_get_config(
    cyg_io_handle_t handle,
    cyg_uint32 key,
    void *buf,
    cyg_uint32 *len )
```

This function is used to obtain run-time configuration about a device. The type of information retrieved is specified by the `key`. The data will be returned in the given buffer. The value of `*len` should contain the amount of data requested, which must be at least as large as the size appropriate to the selected key. The actual size of data retrieved is placed in `*len`. The appropriate key values differ for each driver and are all listed in the file `<cyg/io/config_keys.h>`.

```
// Change the configuration of a device
Cyg_ErrNo cyg_io_set_config(
    cyg_io_handle_t handle,
    cyg_uint32 key,
```

```
const void *buf,  
cyg_uint32 *len )
```

This function is used to manipulate or change the run-time configuration of a device. The type of information is specified by the *key*. The data will be obtained from the given buffer. The value of **len* should contain the amount of data provided, which must match the size appropriate to the selected key. The appropriate key values differ for each driver and are all listed in the file `<cyg/io/config_keys.h>`.

Chapter 11. Serial driver details

Two different classes of serial drivers are provided as a standard part of the eCos system. These are described as “raw serial” (serial) and “tty-like” (tty).

Raw Serial Driver

Use the include file `<cyg/io/serialio.h>` for this driver.

The raw serial driver is capable of sending and receiving blocks of raw data to a serial device. Controls are provided to configure the actual hardware, but there is no manipulation of the data by this driver.

There may be many instances of this driver in a given system, one for each serial channel. Each channel corresponds to a physical device and there will typically be a device module created for this purpose. The device modules themselves are configurable, allowing specification of the actual hardware details, as well as such details as whether the channel should be buffered by the serial driver, etc.

Runtime Configuration

Runtime configuration is achieved by exchanging data structures with the driver via the `cyg_io_set_config()` and `cyg_io_get_config()` functions.

```
typedef struct {
    cyg_serial_baud_rate_t baud;
    cyg_serial_stop_bits_t stop;
    cyg_serial_parity_t parity;
    cyg_serial_word_length_t word_length;
    cyg_uint32 flags;
} cyg_serial_info_t;
```

The field `word_length` contains the number of data bits per word (character). This must be one of the values:

```
CYGNUM_SERIAL_WORD_LENGTH_5
CYGNUM_SERIAL_WORD_LENGTH_6
CYGNUM_SERIAL_WORD_LENGTH_7
CYGNUM_SERIAL_WORD_LENGTH_8
```

The field `baud` contains a baud rate selection. This must be one of the values:

```
CYGNUM_SERIAL_BAUD_50
CYGNUM_SERIAL_BAUD_75
CYGNUM_SERIAL_BAUD_110
CYGNUM_SERIAL_BAUD_134_5
CYGNUM_SERIAL_BAUD_150
CYGNUM_SERIAL_BAUD_200
CYGNUM_SERIAL_BAUD_300
CYGNUM_SERIAL_BAUD_600
CYGNUM_SERIAL_BAUD_1200
CYGNUM_SERIAL_BAUD_1800
CYGNUM_SERIAL_BAUD_2400
CYGNUM_SERIAL_BAUD_3600
```

```
CYGNUM_SERIAL_BAUD_4800
CYGNUM_SERIAL_BAUD_7200
CYGNUM_SERIAL_BAUD_9600
CYGNUM_SERIAL_BAUD_14400
CYGNUM_SERIAL_BAUD_19200
CYGNUM_SERIAL_BAUD_38400
CYGNUM_SERIAL_BAUD_57600
CYGNUM_SERIAL_BAUD_115200
CYGNUM_SERIAL_BAUD_234000
```

The field *stop* contains the number of stop bits. This must be one of the values:

```
CYGNUM_SERIAL_STOP_1
CYGNUM_SERIAL_STOP_1_5
CYGNUM_SERIAL_STOP_2
```

Note: On most hardware, a selection of 1.5 stop bits is only valid if the word (character) length is 5.

The field *parity* contains the parity mode. This must be one of the values:

```
CYGNUM_SERIAL_PARITY_NONE
CYGNUM_SERIAL_PARITY_EVEN
CYGNUM_SERIAL_PARITY_ODD
CYGNUM_SERIAL_PARITY_MARK
CYGNUM_SERIAL_PARITY_SPACE
```

The field *flags* is a bitmask which controls the behavior of the serial device driver. It should be built from the values `CYG_SERIAL_FLAGS_xxx` defined below:

```
#define CYG_SERIAL_FLAGS_RTSCS 0x0001
```

If this bit is set then the port is placed in “hardware handshake” mode. In this mode, the CTS and RTS pins control when data is allowed to be sent/received at the port. This bit is ignored if the hardware does not support this level of handshake.

```
typedef struct {
    cyg_int32 rx_bufsize;
    cyg_int32 rx_count;
    cyg_int32 tx_bufsize;
    cyg_int32 tx_count;
} cyg_serial_buf_info_t;
```

The field *rx_bufsize* contains the total size of the incoming data buffer. This is set to zero on devices that do not support buffering (i.e. polled devices).

The field *rx_count* contains the number of bytes currently occupied in the incoming data buffer. This is set to zero on devices that do not support buffering (i.e. polled devices).

The field *tx_bufsize* contains the total size of the transmit data buffer. This is set to zero on devices that do not support buffering (i.e. polled devices).

The field *tx_count* contains the number of bytes currently occupied in the transmit data buffer. This is set to zero on devices that do not support buffering (i.e. polled devices).

API Details

cyg_io_write

```
cyg_io_write(handle, buf, len)
```

Send the data from *buf* to the device. The driver maintains a buffer to hold the data. The size of the intermediate buffer is configurable within the interface module. The data is not modified at all while it is being buffered. On return, **len* contains the amount of characters actually consumed .

It is possible to configure the write call to be blocking (default) or non-blocking. Non-blocking mode requires both the configuration option `CYGOPT_IO_SERIAL_SUPPORT_NONBLOCKING` to be enabled, and the specific device to be set to non-blocking mode for writes (see `cyg_io_set_config()`).

In blocking mode, the call will not return until there is space in the buffer and the entire contents of *buf* have been consumed.

In non-blocking mode, as much as possible gets consumed from *buf*. If everything was consumed, the call returns `ENOERR`. If only part of the *buf* contents was consumed, `-EAGAIN` is returned and the caller must try again. On return, **len* contains the number of characters actually consumed .

The call can also return `-EINTR` if interrupted via the `cyg_io_get_config()/ABORT` key.

cyg_io_read

```
cyg_io_read(handle, buf, len)
```

Receive data into the buffer, *buf*, from the device. No manipulation of the data is performed before being transferred. An interrupt driven interface module will support data arriving when no read is pending by buffering the data in the serial driver. Again, this buffering is completely configurable. On return, **len* contains the number of characters actually received.

It is possible to configure the read call to be blocking (default) or non-blocking. Non-blocking mode requires both the configuration option `CYGOPT_IO_SERIAL_SUPPORT_NONBLOCKING` to be enabled, and the specific device to be set to non-blocking mode for reads (see `cyg_io_set_config()`).

In blocking mode, the call will not return until the requested amount of data has been read.

In non-blocking mode, data waiting in the device buffer is copied to *buf*, and the call returns immediately. If there was enough data in the buffer to fulfill the request, `ENOERR` is returned. If only part of the request could be fulfilled, `-EAGAIN` is returned and the caller must try again. On return, **len* contains the number of characters actually received.

The call can also return `-EINTR` if interrupted via the `cyg_io_get_config()/ABORT` key.

cyg_io_get_config

```
cyg_io_get_config(handle, key, buf, len)
```

This function returns current [runtime] information about the device and/or driver.

CYG_IO_GET_CONFIG_SERIAL_INFO

Buf type:

cyg_serial_info_t

Function:

This function retrieves the current state of the driver and hardware. This information contains fields for hardware baud rate, number of stop bits, and parity mode. It also includes a set of flags that control the port, such as hardware flow control.

CYG_IO_GET_CONFIG_SERIAL_BUFFER_INFO

Buf type:

cyg_serial_buf_info_t

Function:

This function retrieves the current state of the software buffers in the serial drivers. For both receive and transmit buffers it returns the total buffer size and the current number of bytes occupied in the buffer. It does not take into account any buffering such as FIFOs or holding registers that the serial device itself may have.

CYG_IO_GET_CONFIG_SERIAL_OUTPUT_DRAIN

Buf type:

void *

Function:

This function waits for any buffered output to complete. This function only completes when there is no more data remaining to be sent to the device.

CYG_IO_GET_CONFIG_SERIAL_OUTPUT_FLUSH

Buf type:

void *

Function:

This function discards any buffered output for the device.

CYG_IO_GET_CONFIG_SERIAL_INPUT_DRAIN

Buf type:

void *

Function:

This function discards any buffered input for the device.

CYG_IO_GET_CONFIG_SERIAL_ABORT

Buf type:

void*

Function:

This function will cause any pending read or write calls on this device to return with `-EABORT`.

CYG_IO_GET_CONFIG_SERIAL_READ_BLOCKING

Buf type:

cyg_uint32 (values 0 or 1)

Function:

This function will read back the blocking-mode setting for read calls on this device. This call is only available if the configuration option `CYGOPT_IO_SERIAL_SUPPORT_NONBLOCKING` is enabled.

CYG_IO_GET_CONFIG_SERIAL_WRITE_BLOCKING

Buf type:

cyg_uint32 (values 0 or 1)

Function:

This function will read back the blocking-mode setting for write calls on this device. This call is only available if the configuration option `CYGOPT_IO_SERIAL_SUPPORT_NONBLOCKING` is enabled.

cyg_io_set_config

```
cyg_io_set_config(handle, key, buf, len)
```

This function is used to update or change runtime configuration of a port.

CYG_IO_SET_CONFIG_SERIAL_INFO

Buf type:

cyg_serial_info_t

Function:

This function updates the information for the driver and hardware. The information contains fields for hardware baud rate, number of stop bits, and parity mode. It also includes a set of flags that control the port, such as hardware flow control.

CYG_IO_SET_CONFIG_SERIAL_READ_BLOCKING

Buf type:

cyg_uint32 (values 0 or 1)

Function:

This function will set the blocking-mode for read calls on this device. This call is only available if the configuration option CYGOPT_IO_SERIAL_SUPPORT_NONBLOCKING is enabled.

CYG_IO_SET_CONFIG_SERIAL_WRITE_BLOCKING

Buf type:

cyg_uint32 (values 0 or 1)

Function:

This function will set the blocking-mode for write calls on this device. This call is only available if the configuration option CYGOPT_IO_SERIAL_SUPPORT_NONBLOCKING is enabled.

TTY driver

Use the include file <cyg/io/ttyio.h> for this driver.

This driver is built on top of the simple serial driver and is typically used for a device that interfaces with humans such as a terminal. It provides some minimal formatting of data on output and allows for line-oriented editing on input.

Runtime configuration

Runtime configuration is achieved by exchanging data structures with the driver via the `cyg_io_set_config()` and `cyg_io_get_config()` functions.

```
typedef struct {
    cyg_uint32 tty_out_flags;
    cyg_uint32 tty_in_flags;
} cyg_tty_info_t;
```

The field `tty_out_flags` is used to control what happens to data as it is sent to the serial port. It contains a bitmap comprised of the bits as defined by the `CYG_TTY_OUT_FLAGS_XXX` values below.

```
#define CYG_TTY_OUT_FLAGS_CRLF 0x0001 // Map '\n' => '\r\n' on output
```

If this bit is set in `tty_out_flags`, any occurrence of the character `"\n"` will be replaced by the sequence `"\r\n"` before being sent to the device.

The field `tty_in_flags` is used to control how data is handled as it comes from the serial port. It contains a bitmap comprised of the bits as defined by the `CYG_TTY_IN_FLAGS_XXX` values below.

```
#define CYG_TTY_IN_FLAGS_CR 0x0001 // Map '\r' => '\n' on input
```

If this bit is set in `tty_in_flags`, the character `"\r"` (“return” or “enter” on most keyboards) will be mapped to `"\n"`.

```
#define CYG_TTY_IN_FLAGS_CRLF 0x0002 // Map '\r\n' => '\n' on input
```

If this bit is set in `tty_in_flags`, the character sequence `"\r\n"` (often sent by DOS/Windows based terminals) will be mapped to `"\n"`.

```
#define CYG_TTY_IN_FLAGS_ECHO 0x0004 // Echo characters as processed
```

If this bit is set in `tty_in_flags`, characters will be echoed back to the serial port as they are processed.

```
#define CYG_TTY_IN_FLAGS_BINARY 0x0008 // No input processing
```

If this bit is set in `tty_in_flags`, the input will not be manipulated in any way before being placed in the user’s buffer.

API details

```
cyg_io_read(handle, buf, len)
```

This function is used to read data from the device. In the default case, data is read until an end-of-line character (`"\n"` or `"\r"`) is read. Additionally, the characters are echoed back to the [terminal] device. Minimal editing of the input is also supported.

Note: When connecting to a remote target via GDB it is not possible to provide console input while GDB is connected. The GDB remote protocol does not support input. Users must disconnect from GDB if this functionality is required.

```
cyg_io_write(handle, buf, len)
```

This function is used to send data to the device. In the default case, the end-of-line character "\n" is replaced by the sequence "\r\n".

```
cyg_io_get_config(handle, key, buf, len)
```

This function is used to get information about the channel's configuration at runtime.

```
CYG_IO_GET_CONFIG_TTY_INFO
```

Buf type:

```
cyg_tty_info_t
```

Function:

This function retrieves the current state of the driver.

Serial driver keys (see above) may also be specified in which case the call is passed directly to the serial driver.

```
cyg_io_set_config(handle, key, buf, len)
```

This function is used to modify the channel's configuration at runtime.

```
CYG_IO_SET_CONFIG_TTY_INFO
```

Buf type:

```
cyg_tty_info_t
```

Function:

This function changes the current state of the driver.

Serial driver keys (see above) may also be specified in which case the call is passed directly to the serial driver.

Chapter 12. How to Write a Driver

A device driver is nothing more than a named entity that supports the basic I/O functions - read, write, get config, and set config. Typically a device driver also uses and manages interrupts from the device. While the interface is generic and device driver independent, the actual driver implementation is completely up to the device driver designer.

That said, the reason for using a device driver is to provide access to a device from application code in as general purpose a fashion as reasonable. Most driver writers are also concerned with making this access as simple as possible while being as efficient as possible.

Most device drivers are concerned with the movement of information, for example data bytes along a serial interface, or packets in a network. In order to make the most efficient use of system resources, interrupts are used. This will allow other application processing to take place while the data transfers are under way, with interrupts used to indicate when various events have occurred. For example, a serial port typically generates an interrupt after a character has been sent “down the wire” and the interface is ready for another. It makes sense to allow further application processing while the data is being sent since this can take quite a long time. The interrupt can be used to allow the driver to send a character as soon as the current one is complete, without any active participation by the application code.

The main building blocks for device drivers are found in the include file: `<cyg/io/devtab.h>`

All device drivers in *eCos* are described by a device table entry, using the `cyg_devtab_entry_t` type. The entry should be created using the `DEVTAB_ENTRY()` macro, like this:

```
DEVTAB_ENTRY(1, name, dep_name, handlers, init, lookup, priv)
```

Arguments

1

The "C" label for this device table entry.

name

The "C" string name for the device.

dep_name

For a layered device, the "C" string name of the device this device is built upon.

handlers

A pointer to the I/O function "handlers" (see below).

init

A function called when *eCos* is initialized. This function can query the device, setup hardware, etc.

lookup

A function called when `cyg_io_lookup()` is called for this device.

priv

A placeholder for any device specific data required by the driver.

The interface to the driver is through the *handlers* field. This is a pointer to a set of functions which implement the various `cyg_io_XXX()` routines. This table is defined by the macro:

```
DEVIO_TABLE(l, write, read, get_config, set_config)
```

Arguments

l

The "C" label for this table of handlers.

write

The function called as a result of `cyg_io_write()`.

read

The function called as a result of `cyg_io_read()`.

get_config

The function called as a result of `cyg_io_get_config()`.

set_config

The function called as a result of `cyg_io_set_config()`.

When *eCos* is initialized (sometimes called "boot" time), the `init()` function is called for all devices in the system. The `init()` function is allowed to return an error in which case the device will be placed "off line" and all I/O requests to that device will be considered in error.

The `lookup()` function is called whenever the `cyg_io_lookup()` function is called with this device name. The lookup function may cause the device to come "on line" which would then allow I/O operations to proceed. Future versions of the I/O system will allow for other states, including power saving modes, etc.

How to Write a Serial Hardware Interface Driver

The standard serial driver supplied with *eCos* is structured as a hardware independent portion and a hardware dependent interface module. To add support for a new serial port, the user should be able to use the existing hardware independent portion and just add their own interface driver which handles the details of the actual device. The user should have no need to change the hardware independent portion.

The interfaces used by the serial driver and serial implementation modules are contained in the file `<cyg/io/serial.h>`

Note: In the sections below we use the notation `<<xx>>` to mean a module specific value, referred to as "xx" below.

DevTab Entry

The interface module contains the devtab entry (or entries if a single module supports more than one interface). This entry should have the form:

```
DEVTAB_ENTRY(<<module_name>>,
              <<device_name>>,
```

```

    0,
    &serial_devio,
    <<module_init>>,
    <<module_lookup>>,
    &<<serial_channel>>
);

```

Arguments

module_name

The "C" label for this devtab entry

device_name

The "C" string for the device. E.g. /dev/serial0.

serial_devio

The table of I/O functions. This set is defined in the hardware independent serial driver and should be used.

module_init

The module initialization function.

module_lookup

The device lookup function. This function typically sets up the device for actual use, turning on interrupts, configuring the port, etc.

serial_channel

This table (defined below) contains the interface between the interface module and the serial driver proper.

Serial Channel Structure

Each serial device must have a "serial channel". This is a set of data which describes all operations on the device. It also contains buffers, etc., if the device is to be buffered. The serial channel is created by the macro:

```

SERIAL_CHANNEL_USING_INTERRUPTS(l, funs, dev_priv, baud, stop, parity, word_length,
                                flags, out_buf, out_buflen, in_buf, in_buflen)

```

Arguments

l

The "C" label for this structure.

funs

The set of interface functions (see below).

dev_priv

A placeholder for any device specific data for this channel.

baud

The initial baud rate value (`cyg_serial_baud_t`).

stop

The initial stop bits value (`cyg_serial_stop_bits_t`).

parity

The initial parity mode value (`cyg_serial_parity_t`).

word_length

The initial word length value (`cyg_serial_word_length_t`).

flags

The initial driver flags value.

out_buf

Pointer to the output buffer. `NULL` if none required.

out_buf_len

The length of the output buffer.

in_buf

pointer to the input buffer. `NULL` if none required.

in_buf_len

The length of the input buffer.

If either buffer length is zero, no buffering will take place in that direction and only polled mode functions will be used.

The interface from the hardware independent driver into the hardware interface module is contained in the *funcs* table. This is defined by the macro:

Serial Functions Structure

```
SERIAL_FUNS(l, putc, getc, set_config, start_xmit, stop_xmit)
```

Arguments

l

The "C" label for this structure.

putc

```
bool (*putc)(serial_channel *priv, unsigned char c)
```

This function sends one character to the interface. It should return `true` if the character is actually consumed. It should return `false` if there is no space in the interface

getc

```
unsigned char (*getc)(serial_channel *priv)
```

This function fetches one character from the interface. It will be only called in a non-interrupt driven mode, thus it should wait for a character by polling the device until ready.

set_config

```
bool (*set_config)(serial_channel *priv, cyg_serial_info_t *config)
```

This function is used to configure the port. It should return `true` if the hardware is updated to match the desired configuration. It should return `false` if the port cannot support some parameter specified by the given configuration. E.g. selecting 1.5 stop bits and 8 data bits is invalid for most serial devices and should not be allowed.

start_xmit

```
void (*start_xmit)(serial_channel *priv)
```

In interrupt mode, turn on the transmitter and allow for transmit interrupts.

stop_xmit

```
void (*stop_xmit)(serial_channel *priv)
```

In interrupt mode, turn off the transmitter.

Callbacks

The device interface module can execute functions in the hardware independent driver via `chan->callbacks`. These functions are available:

```
void (*serial_init)( serial_channel *chan )
```

This function is used to initialize the serial channel. It is only required if the channel is being used in interrupt mode.

```
void (*xmt_char)( serial_channel *chan )
```

This function would be called from an interrupt handler after a transmit interrupt indicating that additional characters may be sent. The upper driver will call the `putc` function as appropriate to send more data to the device.

```
void (*rcv_char)( serial_channel *chan, unsigned char c )
```

This function is used to tell the driver that a character has arrived at the interface. This function is typically called from the interrupt handler.

Furthermore, if the device has a FIFO it should require the hardware independent driver to provide block transfer functionality (driver CDL should include "implements CYGINT_IO_SERIAL_BLOCK_TRANSFER"). In that case, the following functions are available as well:

```
bool (*data_xmt_req)(serial_channel *chan,
```

```
        int space,  
        int* chars_avail,  
        unsigned char** chars)  
void (*data_xmt_done)(serial_channel *chan)
```

Instead of calling `xmt_char()` to get a single character for transmission at a time, the driver should call `data_xmt_req()` in a loop, requesting character blocks for transfer. Call with a *space* argument of how much space there is available in the FIFO.

If the call returns `true`, the driver can read *chars_avail* characters from *chars* and copy them into the FIFO.

If the call returns `false`, there are no more buffered characters and the driver should continue without filling up the FIFO.

When all data has been unloaded, the driver must call `data_xmt_done()`.

```
bool (*data_rcv_req)(serial_channel *chan,  
                    int avail,  
                    int* space_avail,  
                    unsigned char** space)  
void (*data_rcv_done)(serial_channel *chan)
```

Instead of calling `rcv_char()` with a single character at a time, the driver should call `data_rcv_req()` in a loop, requesting space to unload the FIFO to. *avail* is the number of characters the driver wishes to unload.

If the call returns `true`, the driver can copy *space_avail* characters to *space*.

If the call returns `false`, the input buffer is full. It is up to the driver to decide what to do in that case (callback functions for registering overflow are being planned for later versions of the serial driver).

When all data has been unloaded, the driver must call `data_rcv_done()`.

Serial testing with `ser_filter`

Rationale

Since some targets only have one serial connection, a serial testing harness needs to be able to share the connection with GDB (however, the test and GDB can also run on separate lines).

The *serial filter* (`ser_filter`) sits between the serial port and GDB and monitors the exchange of data between GDB and the target. Normally, no changes are made to the data.

When a test request packet is sent from the test on the target, it is intercepted by the filter.

The filter and target then enter a loop, exchanging protocol data between them which GDB never sees.

In the event of a timeout, or a crash on the target, the filter falls back into its pass-through mode. If this happens due to a crash it should be possible to start regular debugging with GDB. The filter will stay in the pass-through mode until GDB disconnects.

The Protocol

The protocol commands are prefixed with an "@" character which the serial filter is looking for. The protocol commands include:

PING

Allows the test on the target to probe for the filter. The filter responds with `OK`, while GDB would just ignore the command. This allows the tests to do nothing if they require the filter and it is not present.

CONFIG

Requests a change of serial line configuration. Arguments to the command specify baud rate, data bits, stop bits, and parity. [This command is not fully implemented yet - there is no attempt made to recover if the new configuration turns out to cause loss of data.]

BINARY

Requests data to be sent from the filter to the target. The data is checksummed, allowing errors in the transfer to be detected. Sub-options of this command control how the data transfer is made:

NO_ECHO

(serial driver receive test) Just send data from the filter to the target. The test verifies the checksum and PASS/FAIL depending on the result.

EOP_ECHO

(serial driver half-duplex receive and send test) As `NO_ECHO` but the test echoes back the data to the filter. The filter does a checksum on the received data and sends the result to the target. The test PASS/FAIL depending on the result of both checksum verifications.

DUPLEX_ECHO

(serial driver duplex receive and send test) Smaller packets of data are sent back and forth in a pattern that ensures that the serial driver will be both sending and receiving at the same time. Again, checksums are computed and verified resulting in PASS/FAIL.

TEXT

This is a test of the text translations in the TTY layer. Requests a transfer of text data from the target to the filter and possibly back again. The filter treats this as a binary transfer, while the target may be doing translations on the data. The target provides the filter with checksums for what it should expect to see. This test is not implemented yet.

The above commands may be extended, and new commands added, as required to test (new) parts of the serial drivers in eCos.

The Serial Tests

The serial tests are built as any other eCos test. After running the **make tests** command, the tests can be found in `install/tests/io_serial/`

serial1

A simple API test.

serial2

A simple serial send test. It writes out two strings, one raw and one encoded as a GDB O-packet

`serial13` [requires the serial filter]

This tests the half-duplex send and receive capabilities of the serial driver.

`serial14` [requires the serial filter]

This test attempts to use a few different serial configurations, testing the driver's configuration/setup functionality.

`serial15` [requires the serial filter]

This tests the duplex send and receive capabilities of the serial driver.

All tests should complete in less than 30 seconds.

Serial Filter Usage

Running the `ser_filter` program with no (or wrong) arguments results in the following output:

```
Usage: ser_filter [-t -S] TcpIPport SerialPort BaudRate
or: ser_filter -n [-t -S] SerialPort BaudRate
-t: Enable tracing.
-S: Output data read from serial line.
-c: Output data on console instead of via GDB.
-n: No GDB.
```

The normal way to use it with GDB is to start the filter:

```
$ ser_filter -t 9000 com1 38400
```

In this case, the filter will be listening on port 9000 and connect to the target via the serial port `COM1` at 38400 baud. On a UNIX host, replace "`COM1`" with a device such as "`/dev/ttyS0`".

The `-t` option enables tracing which will cause the filter to describe its actions on the console.

Now start GDB with one of the tests as an argument:

```
$ mips-tx39-elf-gdb -nw install/tests/io_serial/serial13
```

Then connect to the filter:

```
(gdb) target remote localhost:9000
```

This should result in a connection in exactly the same way as if you had connected directly to the target on the serial line.

```
(gdb) c
```

Which should result in output similar to the below:

```
Continuing.
INFO: <BINARY:16:1!>
PASS: <Binary test completed>
INFO: <BINARY:128:1!>
PASS: <Binary test completed>
INFO: <BINARY:256:1!>
PASS: <Binary test completed>
INFO: <BINARY:1024:1!>
PASS: <Binary test completed>
INFO: <BINARY:512:0!>
PASS: <Binary test completed>
```

```
...
PASS: <Binary test completed>
INFO: <BINARY:16384:0!>
PASS: <Binary test completed>
PASS: <serial13 test OK>
EXIT: <done>
```

If any of the individual tests fail the testing will terminate with a `FAIL`.

With tracing enabled, you would also see the filter's status output:

The `PING` command sent from the target to determine the presence of the filter:

```
[400 11:35:16] Dispatching command PING
[400 11:35:16] Responding with status OK
```

Each of the binary commands result in output similar to:

```
[400 11:35:16] Dispatching command BINARY
[400 11:35:16] Binary data (Size:16, Flags:1).
[400 11:35:16] Sending CRC: '170231!', len: 7.
[400 11:35:16] Reading 16 bytes from target.
[400 11:35:16] Done. in_crc 170231, out_crc 170231.
[400 11:35:16] Responding with status OK
[400 11:35:16] Received DONE from target.
```

This tracing output is normally sent as O-packets to GDB which will display the tracing text. By using the `-c` option, the tracing text can be redirected to the console from which `ser_filter` was started.

A Note on Failures

A serial connection (especially when driven at a high baud rate) can garble the transmitted data because of noise from the environment. It is not the job of the serial driver to ensure data integrity - that is the job of protocols layering on top of the serial driver.

In the current implementation the serial tests and the serial filter are not resilient to such data errors. This means that the test may crash or hang (possibly without reporting a `FAIL`). It also means that you should be aware of random errors - a `FAIL` is not necessarily caused by a bug in the serial driver.

Ideally, the serial testing infrastructure should be able to distinguish random errors from consistent errors - the former are most likely due to noise in the transfer medium, while the latter are more likely to be caused by faulty drivers. The current implementation of the infrastructure does not have this capability.

Debugging

If a test fails, the serial filter's output may provide some hints about what the problem is. If the option `-s` is used when starting the filter, data received from the target is printed out:

```
[400 11:35:16] 0000 50 41 53 53 3a 3c 42 69 'PASS:<Bi'
[400 11:35:16] 0008 6e 61 72 79 20 74 65 73 'nary.tes'
[400 11:35:16] 0010 74 20 63 6f 6d 70 6c 65 't.comple'
[400 11:35:16] 0018 74 65 64 3e 0d 0a 49 4e 'ted>..IN'
[400 11:35:16] 0020 46 4f 3a 3c 42 49 4e 41 'FO:<BINA'
[400 11:35:16] 0028 52 59 3a 31 32 38 3a 31 'RY:128:1'
[400 11:35:16] 0030 21 3e 0d 0a 40 42 49 4e '!..@BIN'
[400 11:35:16] 0038 41 52 59 3a 31 32 38 3a 'ARY:128:'
[400 11:35:16] 0040 31 21 .. .. .. .. '!!'
```

In the case of an error during a testing command the data received by the filter will be printed out, as will the data that was expected. This allows the two data sets to be compared which may give some idea of what the problem is.

Chapter 13. Device Driver Interface to the Kernel

This chapter describes the API that device drivers may use to interact with the kernel and HAL. It is primarily concerned with the control and management of interrupts and the synchronization of ISRs, DSRs and threads.

The same API will be present in configurations where the kernel is not present. In this case the functions will be supplied by code acting directly on the HAL.

Interrupt Model

eCos presents a three level interrupt model to device drivers. This consists of Interrupt Service Routines (ISRs) that are invoked in response to a hardware interrupt; Deferred Service Routines (DSRs) that are invoked in response to a request by an ISR; and threads that are the clients of the driver.

Hardware interrupts are delivered with minimal intervention to an ISR. The HAL decodes the hardware source of the interrupt and calls the ISR of the attached interrupt object. This ISR may manipulate the hardware but is only allowed to make a restricted set of calls on the driver API. When it returns, an ISR may request that its DSR should be scheduled to run.

A DSR will be run when it is safe to do so without interfering with the scheduler. Most of the time the DSR will run immediately after the ISR, but if the current thread is in the scheduler, it will be delayed until the thread is finished. A DSR is allowed to make a larger set of driver API calls, including, in particular, being able to call `cyg_drv_cond_signal()` to wake up waiting threads.

Finally, threads are able to make all API calls and in particular are allowed to wait on mutexes and condition variables.

For a device driver to receive interrupts it must first define ISR and DSR routines as shown below, and then call `cyg_drv_interrupt_create()`. Using the handle returned, the driver must then call `cyg_drv_interrupt_attach()` to actually attach the interrupt to the hardware vector.

Synchronization

There are three levels of synchronization supported:

1. Synchronization with ISRs. This normally means disabling interrupts to prevent the ISR running during a critical section. In an SMP environment, this will also require the use of a spinlock to synchronize with ISRs, DSRs or threads running on other CPUs. This is implemented by the `cyg_drv_isr_lock()` and `cyg_drv_isr_unlock()` functions. This mechanism should be used sparingly and for short periods only. For finer grained synchronization, individual spinlocks are also supplied.
2. Synchronization with DSRs. This will be implemented in the kernel by taking the scheduler lock to prevent DSRs running during critical sections. In non-kernel configurations it will be implemented by non-kernel code. This is implemented by the `cyg_drv_dsr_lock()` and `cyg_drv_dsr_unlock()` functions. As with ISR synchronization, this mechanism should be used sparingly. Only DSRs and threads may use this synchronization mechanism, ISRs are not allowed to do this.
3. Synchronization with threads. This is implemented with mutexes and condition variables. Only threads may lock the mutexes and wait on the condition variables, although DSRs may signal condition variables.

Any data that is accessed from more than one level must be protected against concurrent access. Data that is accessed by ISRs must be protected with the ISR lock, or a spinlock at all times, *even in ISRs*. Data that is shared between DSRs and threads should be protected with the DSR lock. Data that is only accessed by threads must be protected with mutexes.

SMP Support

Some eCos targets contain support for Symmetric Multi-Processing (SMP) configurations, where more than one CPU may be present. This option has a number of ramifications for the way in which device drivers must be written if they are to be SMP-compatible.

Since it is possible for the ISR, DSR and thread components of a device driver to execute on different CPUs, it is important that SMP-compatible device drivers use the driver API routines correctly.

Synchronization between threads and DSRs continues to require that the thread-side code use `cyg_drv_dsr_lock()` and `cyg_drv_dsr_unlock()` to protect access to shared data. While it is not strictly necessary for DSR code to claim the DSR lock, since DSRs are run with it claimed already, it is good practice to do so.

Synchronization between ISRs and DSRs or threads requires that access to sensitive data be protected, in all places, by calls to `cyg_drv_isr_lock()` and `cyg_drv_isr_unlock()`. Disabling or masking interrupts is not adequate, since the thread or DSR may be running on a different CPU and interrupt enable/disable only work on the current CPU.

The ISR lock, for SMP systems, not only disables local interrupts, but also acquires a spinlock to protect against concurrent access from other CPUs. This is necessary because ISRs are not run with the scheduler lock claimed. Hence they can run in parallel with the other components of the device driver.

The ISR lock provided by the driver API is just a shared spinlock that is available for use by all drivers. If a driver needs to implement a finer grain of locking, it can use private spinlocks, accessed via the `cyg_drv_spinlock_*` functions.

Device Driver Models

There are several ways in which device drivers may be built. The exact model chosen will depend on the properties of the device and the behavior desired. There are three basic models that may be adopted.

The first model is to do all device processing in the ISR. When it is invoked the ISR programs the device hardware directly and accesses data to be transferred directly in memory. The ISR should also call `cyg_drv_interrupt_acknowledge()`. When it is finished it may optionally request that its DSR be invoked. The DSR does nothing but call `cyg_drv_cond_signal()` to cause a thread to be woken up. Thread level code must call `cyg_drv_isr_lock()`, or `cyg_drv_interrupt_mask()` to prevent ISRs running while it manipulates shared memory.

The second model is to defer device processing to the DSR. The ISR simply prevents further delivery of interrupts by either programming the device, or by calling `cyg_drv_interrupt_mask()`. It must then call `cyg_drv_interrupt_acknowledge()` to allow other interrupts to be delivered and then request that its DSR be called. When the DSR runs it does the majority of the device handling, optionally signals a condition variable to wake a thread, and finishes by calling `cyg_drv_interrupt_unmask()` to re-allow device interrupts. Thread level code uses `cyg_drv_dsr_lock()` to prevent DSRs running while it manipulates shared memory. The eCos serial device drivers use this approach.

The third model is to defer device processing even further to a thread. The ISR behaves exactly as in the previous model and simply blocks and acknowledges the interrupt before request that the DSR run. The DSR itself only calls `cyg_drv_cond_signal()` to wake the thread. When the thread awakens it performs all device processing, and has full access to all kernel facilities while it does so. It should finish by calling `cyg_drv_interrupt_unmask()` to re-allow device interrupts. The eCos ethernet device drivers are written to this model.

The first model is good for devices that need immediate processing and interact infrequently with thread level. The second model trades a little latency in dealing with the device for a less intrusive synchronization mechanism. The last model allows device processing to be scheduled with other threads and permits more complex device handling.

Synchronization Levels

Since it would be dangerous for an ISR or DSR to make a call that might reschedule the current thread (by trying to lock a mutex for example) all functions in this API have an associated synchronization level. These levels are:

Thread

This function may only be called from within threads. This is usually the client code that makes calls into the device driver. In a non-kernel configuration, this will be code running at the default non-interrupt level.

DSR

This function may be called by either DSR or thread code.

ISR

This function may be called from ISR, DSR or thread code.

The following table shows, for each API function, the levels at which is may be called:

Function	Callable from:		
	ISR	DSR	Thread

<code>cyg_drv_isr_lock</code>	X	X	X
<code>cyg_drv_isr_unlock</code>	X	X	X
<code>cyg_drv_spinlock_init</code>			X
<code>cyg_drv_spinlock_destroy</code>			X
<code>cyg_drv_spinlock_spin</code>	X	X	X
<code>cyg_drv_spinlock_clear</code>	X	X	X
<code>cyg_drv_spinlock_try</code>	X	X	X
<code>cyg_drv_spinlock_test</code>	X	X	X
<code>cyg_drv_spinlock_spin_intsave</code>	X	X	X
<code>cyg_drv_spinlock_clear_intsave</code>	X	X	X
<code>cyg_drv_dsr_lock</code>		X	X
<code>cyg_drv_dsr_unlock</code>		X	X
<code>cyg_drv_mutex_init</code>			X
<code>cyg_drv_mutex_destroy</code>			X
<code>cyg_drv_mutex_lock</code>			X
<code>cyg_drv_mutex_trylock</code>			X
<code>cyg_drv_mutex_unlock</code>			X
<code>cyg_drv_mutex_release</code>			X
<code>cyg_drv_cond_init</code>			X

cyg_drv_cond_destroy			X
cyg_drv_cond_wait			X
cyg_drv_cond_signal		X	X
cyg_drv_cond_broadcast		X	X
cyg_drv_interrupt_create			X
cyg_drv_interrupt_delete			X
cyg_drv_interrupt_attach	X	X	X
cyg_drv_interrupt_detach	X	X	X
cyg_drv_interrupt_mask	X	X	X
cyg_drv_interrupt_unmask	X	X	X
cyg_drv_interrupt_acknowledge	X	X	X
cyg_drv_interrupt_configure	X	X	X
cyg_drv_interrupt_level	X	X	X
cyg_drv_interrupt_set_cpu	X	X	X
cyg_drv_interrupt_get_cpu	X	X	X

The API

This section details the Driver Kernel Interface. Note that most of these functions are identical to Kernel C API calls, and will in most configurations be wrappers for them. In non-kernel configurations they will be supported directly by the HAL, or by code to emulate the required behavior.

This API is defined in the header file `<cyg/hal/drv_api.h>`.

cyg_drv_isr_lock

Function:

```
void cyg_drv_isr_lock()
```

Arguments:

None

Result:

None

Level:

ISR

Description:

Disables delivery of interrupts, preventing all ISRs running. This function maintains a counter of the number of times it is called.

cyg_drv_isr_unlock

Function:

```
void cyg_drv_isr_unlock()
```

Arguments:

None

Result:

None

Level:

ISR

Description:

Re-enables delivery of interrupts, allowing ISRs to run. This function decrements the counter maintained by `cyg_drv_isr_lock()`, and only re-allows interrupts when it goes to zero.

cyg_drv_spinlock_init

Function:

```
void cyg_drv_spinlock_init(cyg_spinlock_t *lock, cyg_bool_t locked )
```

Arguments:

lock - pointer to spinlock to initialize

locked - initial state of lock

Result:

None

Level:

Thread

Description:

Initialize a spinlock. The *locked* argument indicates how the spinlock should be initialized: TRUE for locked or FALSE for unlocked state.

cyg_drv_spinlock_destroy

Function:

```
void cyg_drv_spinlock_destroy(cyg_spinlock_t *lock )
```

Arguments:

lock - pointer to spinlock destroy

Result:

None

Level:

Thread

Description:

Destroy a spinlock that is no longer of use. There should be no CPUs attempting to claim the lock at the time this function is called, otherwise the behavior is undefined.

cyg_drv_spinlock_spin

Function:

```
void cyg_drv_spinlock_spin(cyg_spinlock_t *lock )
```

Arguments:

lock - pointer to spinlock to claim

Result:

None

Level:

ISR

Description:

Claim a spinlock, waiting in a busy loop until it is available. Wherever this is called from, this operation effectively pauses the CPU until it succeeds. This operations should therefore be used sparingly, and in situations where deadlocks/livelocks cannot occur. Also see `cyg_drv_spinlock_spin_intsave()`.

cyg_drv_spinlock_clear

Function:

```
void cyg_drv_spinlock_clear(cyg_spinlock_t *lock )
```

Arguments:

lock - pointer to spinlock to clear

Result:

None

Level:

ISR

Description:

Clear a spinlock. This clears the spinlock and allows another CPU to claim it. If there is more than one CPU waiting in `cyg_drv_spinlock_spin()` then just one of them will be allowed to proceed.

cyg_drv_spinlock_try

Function:

```
cyg_bool_t cyg_drv_spinlock_try(cyg_spinlock_t *lock )
```

Arguments:

lock - pointer to spinlock to try

Result:

TRUE if the spinlock was claimed, FALSE otherwise.

Level:

ISR

Description:

Try to claim the spinlock without waiting. If the spinlock could be claimed immediately then TRUE is returned. If the spinlock is already claimed then the result is FALSE.

cyg_drv_spinlock_test

Function:

```
cyg_bool_t cyg_drv_spinlock_test(cyg_spinlock_t *lock )
```

Arguments:

lock - pointer to spinlock to test

Result:

TRUE if the spinlock is available, FALSE otherwise.

Level:

ISR

Description:

Inspect the state of the spinlock. If the spinlock is not locked then the result is TRUE. If it is locked then the result will be FALSE.

cyg_drv_spinlock_spin_intsave

Function:

```
void cyg_drv_spinlock_spin_intsave(cyg_spinlock_t *lock,
                                     cyg_addrword_t *istate )
```

Arguments:

lock - pointer to spinlock to claim

istate - pointer to interrupt state save location

Result:

None

Level:

ISR

Description:

This function behaves exactly like `cyg_drv_spinlock_spin()` except that it also disables interrupts before attempting to claim the lock. The current interrupt enable state is saved in **istate*. Interrupts remain disabled once the spinlock had been claimed and must be restored by calling `cyg_drv_spinlock_clear_intsave()`.

In general, device drivers should use this function to claim and release spinlocks rather than the non-`_intsave()` variants, to ensure proper exclusion with code running on both other CPUs and this CPU.

cyg_drv_spinlock_clear_intsave

Function:

```
void cyg_drv_spinlock_clear_intsave( cyg_spinlock_t *lock,
                                     cyg_addrword_t istate )
```

Arguments:

lock - pointer to spinlock to clear

istate - interrupt state to restore

Result:

None

Level:

ISR

Description:

This function behaves exactly like `cyg_drv_spinlock_clear()` except that it also restores an interrupt state saved by `cyg_drv_spinlock_spin_intsave()`. The *istate* argument must have been initialized by a previous call to `cyg_drv_spinlock_spin_intsave()`.

cyg_drv_dsr_lock

Function:

```
void cyg_drv_dsr_lock()
```

Arguments:

None

Result:

None

Level:

DSR

Description:

Disables scheduling of DSRs. This function maintains a counter of the number of times it has been called.

cyg_drv_dsr_unlock

Function:

```
void cyg_drv_dsr_unlock()
```

Arguments:

None

Result:

None

Level:

DSR

Description:

Re-enables scheduling of DSRs. This function decrements the counter incremented by `cyg_drv_dsr_lock()`. DSRs are only allowed to be delivered when the counter goes to zero.

cyg_drv_mutex_init

Function:

```
void cyg_drv_mutex_init(cyg_drv_mutex_t *mutex)
```

Arguments:

mutex - pointer to mutex to initialize

Result:

None

Level:

Thread

Description:

Initialize the mutex pointed to by the `mutex` argument.

cyg_drv_mutex_destroy

Function:

```
void cyg_drv_mutex_destroy( cyg_drv_mutex_t *mutex )
```

Arguments:

mutex - pointer to mutex to destroy

Result:

None

Level:

Thread

Description:

Destroy the mutex pointed to by the *mutex* argument. The mutex should be unlocked and there should be no threads waiting to lock it when this call is made.

cyg_drv_mutex_lock

Function:

```
cyg_bool cyg_drv_mutex_lock( cyg_drv_mutex_t *mutex )
```

Arguments:

mutex - pointer to mutex to lock

Result:

TRUE if the thread has claimed the lock, FALSE otherwise.

Level:

Thread

Description:

Attempt to lock the mutex pointed to by the *mutex* argument. If the mutex is already locked by another thread then this thread will wait until that thread is finished. If the result from this function is FALSE then the thread was broken out of its wait by some other thread. In this case the mutex will not have been locked.

cyg_drv_mutex_trylock

Function:

```
cyg_bool cyg_drv_mutex_trylock( cyg_drv_mutex_t *mutex )
```

Arguments:

mutex - pointer to mutex to lock

Result:

TRUE if the mutex has been locked, FALSE otherwise.

Level:

Thread

Description:

Attempt to lock the mutex pointed to by the *mutex* argument without waiting. If the mutex is already locked by some other thread then this function returns FALSE. If the function can lock the mutex without waiting, then TRUE is returned.

cyg_drv_mutex_unlock

Function:

```
void cyg_drv_mutex_unlock( cyg_drv_mutex_t *mutex )
```

Arguments:

mutex - pointer to mutex to unlock

Result:

None

Level:

Thread

Description:

Unlock the mutex pointed to by the *mutex* argument. If there are any threads waiting to claim the lock, one of them is woken up to try and claim it.

cyg_drv_mutex_release

Function:

```
void cyg_drv_mutex_release( cyg_drv_mutex_t *mutex )
```

Arguments:

mutex - pointer to mutex to release

Result:

None

Level:

Thread

Description:

Release all threads waiting on the mutex pointed to by the *mutex* argument. These threads will return from `cyg_drv_mutex_lock()` with a `FALSE` result and will not have claimed the mutex. This function has no effect on any thread that may have the mutex claimed.

cyg_drv_cond_init

Function:

```
void cyg_drv_cond_init( cyg_drv_cond_t *cond, cyg_drv_mutex_t *mutex )
```

Arguments:

cond - condition variable to initialize

mutex - mutex to associate with this condition variable

Result:

None

Level:

Thread

Description:

Initialize the condition variable pointed to by the *cond* argument. The *mutex* argument must point to a mutex with which this condition variable is associated. A thread may only wait on this condition variable when it has already locked the associated mutex. Waiting will cause the mutex to be unlocked, and when the thread is reawakened, it will automatically claim the mutex before continuing.

cyg_drv_cond_destroy

Function:

```
void cyg_drv_cond_destroy( cyg_drv_cond_t *cond )
```

Arguments:

cond - condition variable to destroy

Result:

None

Level:

Thread

Description:

Destroy the condition variable pointed to by the *cond* argument.

cyg_drv_cond_wait

Function:

```
void cyg_drv_cond_wait( cyg_drv_cond_t *cond )
```

Arguments:

cond - condition variable to wait on

Result:

None

Level:

Thread

Description:

Wait for a signal on the condition variable pointed to by the *cond* argument. The thread must have locked the associated mutex, supplied in *cyg_drv_cond_init()*, before waiting on this condition variable. While the thread waits, the mutex will be unlocked, and will be re-locked before this function returns. It is possible for threads waiting on a condition variable to occasionally wake up spuriously. For this reason it is necessary to use this function in a loop that re-tests the condition each time it returns. Note that this function performs an implicit scheduler unlock/relock sequence, so that it may be used within an explicit *cyg_drv_dsr_lock()*...*cyg_drv_dsr_unlock()* structure.

cyg_drv_cond_signal

Function:

```
void cyg_drv_cond_signal( cyg_drv_cond_t *cond )
```

Arguments:

cond - condition variable to signal

Result:

None

Level:

DSR

Description:

Signal the condition variable pointed to by the *cond* argument. If there are any threads waiting on this variable at least one of them will be awakened. Note that in some configurations there may not be any difference between this function and `cyg_drv_cond_broadcast()`.

cyg_drv_cond_broadcast

Function:

```
void cyg_drv_cond_broadcast( cyg_drv_cond_t *cond )
```

Arguments:

cond - condition variable to broadcast to

Result:

None

Level:

DSR

Description:

Signal the condition variable pointed to by the *cond* argument. If there are any threads waiting on this variable they will all be awakened.

cyg_drv_interrupt_create

Function:

```
void cyg_drv_interrupt_create( cyg_vector_t vector,
                               cyg_priority_t priority,
                               cyg_addrword_t data,
                               cyg_ISR_t *isr,
                               cyg_DSR_t *dsr,
                               cyg_handle_t *handle,
                               cyg_interrupt *intr
                               )
```

Arguments:

vector - vector to attach to

priority - queuing priority

data - data pointer

isr - interrupt service routine

dsr - deferred service routine

handle - returned handle

intr - put interrupt object here

Result:

None

Level:

Thread

Description:

Create an interrupt object and returns a handle to it. The object contains information about which interrupt vector to use and the ISR and DSR that will be called after the interrupt object is attached to the vector. The interrupt object will be allocated in the memory passed in the *intr* parameter. The interrupt object is not immediately attached; it must be attached with the `cyg_interrupt_attach()` call.

cyg_drv_interrupt_delete

Function:

```
void cyg_drv_interrupt_delete( cyg_handle_t interrupt )
```

Arguments:

interrupt - interrupt to delete

Result:

None

Level:

Thread

Description:

Detach the interrupt from the vector and free the memory passed in the *intr* argument to `cyg_drv_interrupt_create()` for reuse.

cyg_drv_interrupt_attach

Function:

```
void cyg_drv_interrupt_attach( cyg_handle_t interrupt )
```

Arguments:

interrupt - interrupt to attach

Result:

None

Level:

ISR

Description:

Attach the interrupt to the vector so that interrupts will be delivered to the ISR when the interrupt occurs.

cyg_drv_interrupt_detach

Function:

```
void cyg_drv_interrupt_detach( cyg_handle_t interrupt )
```

Arguments:

interrupt - interrupt to detach

Result:

None

Level:

ISR

Description:

Detach the interrupt from the vector so that interrupts will no longer be delivered to the ISR.

cyg_drv_interrupt_mask

Function:

```
void cyg_drv_interrupt_mask(cyg_vector_t vector )
```

Arguments:

vector - vector to mask

Result:

None

Level:

ISR

Description:

Program the interrupt controller to stop delivery of interrupts on the given vector. On architectures which implement interrupt priority levels this may also disable all lower priority interrupts.

cyg_drv_interrupt_mask_intunsafe

Function:

```
void cyg_drv_interrupt_mask_intunsafe(cyg_vector_t vector )
```

Arguments:*vector* - vector to mask**Result:**

None

Level:

ISR

Description:

Program the interrupt controller to stop delivery of interrupts on the given vector. On architectures which implement interrupt priority levels this may also disable all lower priority interrupts. This version differs from `cyg_drv_interrupt_mask()` in not being interrupt safe. So in situations where, for example, interrupts are already known to be disabled, this may be called to avoid the extra overhead.

cyg_drv_interrupt_unmask**Function:**

```
void cyg_drv_interrupt_unmask(cyg_vector_t vector )
```

Arguments:*vector* - vector to unmask**Result:**

None

Level:

ISR

Description:

Program the interrupt controller to re-allow delivery of interrupts on the given *vector*.

cyg_drv_interrupt_unmask_intunsafe**Function:**

```
void cyg_drv_interrupt_unmask_intunsafe(cyg_vector_t vector )
```

Arguments:*vector* - vector to unmask**Result:**

None

Level:

ISR

Description:

Program the interrupt controller to re-allow delivery of interrupts on the given *vector*. This version differs from `cyg_drv_interrupt_unmask()` in not being interrupt safe.

cyg_drv_interrupt_acknowledge

Function:

```
void cyg_drv_interrupt_acknowledge( cyg_vector_t vector )
```

Arguments:

vector - vector to acknowledge

Result:

None

Level:

ISR

Description:

Perform any processing required at the interrupt controller and in the CPU to cancel the current interrupt request on the *vector*. An ISR may also need to program the hardware of the device to prevent an immediate re-triggering of the interrupt.

cyg_drv_interrupt_configure

Function:

```
void cyg_drv_interrupt_configure( cyg_vector_t vector,  
                                cyg_bool_t level,  
                                cyg_bool_t up  
                                )
```

Arguments:

vector - vector to configure

level - level or edge triggered

up - rising/falling edge, high/low level

Result:

None

Level:

ISR

Description:

Program the interrupt controller with the characteristics of the interrupt source. The *level* argument chooses between level- or edge-triggered interrupts. The *up* argument chooses between high and low level for level triggered interrupts or rising and falling edges for edge triggered interrupts. This function only works with interrupt controllers that can control these parameters.

cyg_drv_interrupt_level

Function:

```
void cyg_drv_interrupt_level( cyg_vector_t vector,
                             cyg_priority_t level
                           )
```

Arguments:

vector - vector to configure

level - level to set

Result:

None

Level:

ISR

Description:

Program the interrupt controller to deliver the given interrupt at the supplied priority level. This function only works with interrupt controllers that can control this parameter.

cyg_drv_interrupt_set_cpu

Function:

```
void cyg_drv_interrupt_set_cpu( cyg_vector_t vector,
                                cyg_cpu_t cpu
                              )
```

Arguments:

vector - interrupt vector to route

cpu - destination CPU

Result:

None

Level:

ISR

Description:

This function causes all interrupts on the given vector to be routed to the specified CPU. Subsequently, all such interrupts will be handled by that CPU. This only works if the underlying hardware is capable of performing this kind of routing. This function does nothing on a single CPU system.

cyg_drv_interrupt_get_cpu

Function:

```
cyg_cpu_t cyg_drv_interrupt_set_cpu( cyg_vector_t vector )
```

Arguments:

vector - interrupt vector to query

Result:

The CPU to which this vector is routed

Level:

ISR

Description:

In multi-processor systems this function returns the id of the CPU to which interrupts on the given vector are current being delivered. In single CPU systems this function returns zero.

cyg_ISR_t

Type:

```
typedef cyg_uint32 cyg_ISR_t( cyg_vector_t vector,  
                             cyg_addrword_t data  
                             )
```

Fields:

vector - vector being delivered

data - data value supplied by client

Result:

Bit mask indicating whether interrupt was handled and whether the DSR should be called.

Description:

Interrupt Service Routine definition. A pointer to a function with this prototype is passed to `cyg_interrupt_create()` when an interrupt object is created. When an interrupt is delivered the function will be called with the vector number and the data value that was passed to `cyg_interrupt_create()`.

The return value is a bit mask containing one or both of the following bits:

CYG_ISR_HANDLED

indicates that the interrupt was handled by this ISR. It is a configuration option whether this will prevent further ISR being run.

CYG_ISR_CALL_DSR

causes the DSR that was passed to `cyg_interrupt_create()` to be scheduled to be called.

cyg_DSR_t

Type:

```
typedef void cyg_DSR_t( cyg_vector_t vector,
                        cyg_ucount32 count,
                        cyg_addrword_t data
                      )
```

Fields:

vector - vector being delivered

count - number of times DSR has been scheduled

data - data value supplied by client

Result:

None

Description:

Deferred Service Routine prototype. A pointer to a function with this prototype is passed to `cyg_interrupt_create()` when an interrupt object is created. When the ISR requests the scheduling of its DSR, this function will be called at some later point. In addition to the *vector* and *data* arguments, which will be the same as those passed to the ISR, this routine is also passed a *count* of the number of times the ISR has requested that this DSR be scheduled. This counter is zeroed each time the DSR actually runs, so it indicates how many interrupts have occurred since it last ran.

V. File System Support Infrastructure

Chapter 14. Introduction

This document describes the filesystem infrastructure provided in eCos. This is implemented by the FILEIO package and provides POSIX compliant file and IO operations together with the BSD socket API. These APIs are described in the relevant standards and original documentation and will not be described here. See the Posix Standard Support documentation for details of which parts of the POSIX standard are supported.

This document is concerned with the interfaces presented to client filesystems and network protocol stacks.

The FILEIO infrastructure consist mainly of a set of tables containing pointers to the primary interface functions of a file system. This approach avoids problems of namespace pollution (for example several filesystems can have a function called `read()`, so long as they are static). The system is also structured to eliminate the need for dynamic memory allocation.

New filesystems can be written directly to the interfaces described here. Existing filesystems can be ported very easily by the introduction of a thin veneer porting layer that translates FILEIO calls into native filesystem calls.

The term filesystem should be read fairly loosely in this document. Object accessed through these interfaces could equally be network protocol sockets, device drivers, fifos, message queues or any other object that can present a file-like interface.

Chapter 15. File System Table

The filesystem table is an array of entries that describe each filesystem implementation that is part of the system image. Each resident filesystem should export an entry to this table using the `FSTAB_ENTRY()` macro.

Note: At present we do not support dynamic addition or removal of table entries. However, an API similar to `mount()` would allow new entries to be added to the table.

The table entries are described by the following structure:

```
struct cyg_fstab_entry
{
    const char          *name;           // filesystem name
    CYG_ADDRWORD        data;           // private data value
    cyg_uint32          syncmode;       // synchronization mode

    int (*mount)        ( cyg_fstab_entry *fste, cyg_mtab_entry *mte );
    int (*umount)       ( cyg_mtab_entry *mte, cyg_bool force );
    int (*open)         ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                          int mode, cyg_file *fte );
    int (*unlink)       ( cyg_mtab_entry *mte, cyg_dir dir, const char *name );
    int (*mkdir)        ( cyg_mtab_entry *mte, cyg_dir dir, const char *name );
    int (*rmdir)        ( cyg_mtab_entry *mte, cyg_dir dir, const char *name );
    int (*rename)       ( cyg_mtab_entry *mte, cyg_dir dirl, const char *name1,
                          cyg_dir dir2, const char *name2 );
    int (*link)         ( cyg_mtab_entry *mte, cyg_dir dirl, const char *name1,
                          cyg_dir dir2, const char *name2, int type );
    int (*opendir)      ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                          cyg_file *fte );
    int (*chdir)        ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                          cyg_dir *dir_out );
    int (*stat)         ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                          struct stat *buf );
    int (*getinfo)      ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                          int key, char *buf, int len );
    int (*setinfo)      ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                          int key, char *buf, int len );
};
```

The *name* field points to a string that identifies this filesystem implementation. Typical values might be "romfs", "fatfs", "ext2" etc.

The *data* field contains any private data that the filesystem needs, perhaps the root of its data structures.

The *syncmode* field contains a description of the locking protocol to be used when accessing this filesystem. It will be described in more detail in [Chapter 19](#).

The remaining fields are pointers to functions that implement filesystem operations that apply to files and directories as whole objects. The operation implemented by each function should be obvious from the names, with a few exceptions:

The `opendir()` function pointer opens a directory for reading. See [Chapter 18](#) for details.

The `getinfo()` and `setinfo()` function pointers provide support for various minor control and information functions such as `pathconf()` and `access()`.

With the exception of the `mount()` and `umount()` functions, all of these functions take three standard arguments, a pointer to a mount table entry (see later) a directory pointer (also see later) and a file name relative to the directory. These should be used by the filesystem to locate the object of interest.

Chapter 16. Mount Table

The mount table records the filesystems that are actually active. These can be seen as being analogous to mount points in Unix systems.

There are two sources of mount table entries. Filesystems (or other components) may export static entries to the table using the `MTAB_ENTRY()` macro. Alternatively, new entries may be installed at run time using the `mount()` function. Both types of entry may be unmounted with the `umount()` function.

A mount table entry has the following structure:

```
struct cyg_mtab_entry
{
    const char      *name;           // name of mount point
    const char      *fsname;         // name of implementing filesystem
    const char      *devname;        // name of hardware device
    const char      *options;        // mount option string
    CYG_ADDRWORD    data;            // private data value
    cyg_bool         valid;           // Valid entry?
    cyg_fstab_entry *fs;             // pointer to fstab entry
    cyg_dir          root;           // root directory pointer
};
```

The *name* field identifies the mount point. This is used to direct rooted filenames (filenames that begin with `"/"`) to the correct filesystem. When a file name that begins with `"/"` is submitted, it is matched against the *name* fields of all valid mount table entries. The entry that yields the longest match terminating before a `"/"`, or end of string, wins and the appropriate function from the filesystem table entry is then passed the remainder of the file name together with a pointer to the table entry and the value of the *root* field as the directory pointer.

For example, consider a mount table that contains the following entries:

```
{ "/",      "fatfs", "/dev/hd0", ... }
{ "/fd",    "fatfs", "/dev/fd0", ... }
{ "/rom",    "romfs", "", ... }
{ "/tmp",    "ramfs", "", ... }
{ "/dev",    "devfs", "", ... }
```

An attempt to open `"/tmp/foo"` would be directed to the RAM filesystem while an open of `"/bar/bundy"` would be directed to the hard disc FATFS filesystem. Opening `"/dev/tty0"` would be directed to the device management filesystem for lookup in the device table.

Unrooted file names (those that do not begin with a `'/'`) are passed straight to the filesystem that contains the current directory. The current directory is represented by a pair consisting of a mount table entry and a directory pointer.

The *fsname* field points to a string that should match the *name* field of the implementing filesystem. During initialization the mount table is scanned and the *fsname* entries looked up in the filesystem table. For each match, the filesystem's `_mount_` function is called and if successful the mount table entry is marked as valid and the *fs* pointer installed.

The *devname* field contains the name of the device that this filesystem is to use. This may match an entry in the device table (see later) or may be a string that is specific to the filesystem if it has its own internal device drivers.

The *data* field is a private data value. This may be installed either statically when the table entry is defined, or may be installed during the `mount()` operation.

The *valid* field indicates whether this mount point has actually been mounted successfully. Entries with a false *valid* field are ignored when searching for a name match.

The *fs* field is installed after a successful `mount()` operation to point to the implementing filesystem.

The *root* field contains a directory pointer value that the filesystem can interpret as the root of its directory tree. This is passed as the *dir* argument of filesystem functions that operate on rooted filenames. This field must be initialized by the filesystem's `mount()` function.

Chapter 17. File Table

Once a file has been opened it is represented by an open file object. These are allocated from an array of available file objects. User code accesses these open file objects via a second array of pointers which is indexed by small integer offsets. This gives the usual Unix file descriptor functionality, complete with the various duplication mechanisms.

A file table entry has the following structure:

```
struct CYG_FILE_TAG
{
    cyg_uint32          f_flag; /* file state */
    cyg_uint16          f_ccount; /* use count */
    cyg_uint16          f_type; /* descriptor type */
    cyg_uint32          f_syncmode; /* synchronization protocol */
    struct CYG_FILEOPS_TAG *f_ops; /* file operations */
    off_t               f_offset; /* current offset */
    CYG_ADDRWORD         f_data; /* file or socket */
    CYG_ADDRWORD         f_xops; /* extra type specific ops */
    cyg_mtab_entry       *f_mte; /* mount table entry */
};
```

The *f_flag* field contains some FILEIO control bits and some bits propagated from the *flags* argument of the `open()` call (defined by `CYG_FILE_MODE_MASK`).

The *f_ccount* field contains a use count that controls when a file will be closed. Each duplicate in the file descriptor array counts for one reference here. It is also incremented around each I/O operation to ensure that the file cannot be closed while it has current I/O operations.

The *f_type* field indicates the type of the underlying file object. Some of the possible values here are `CYG_FILE_TYPE_FILE`, `CYG_FILE_TYPE_SOCKET` or `CYG_FILE_TYPE_DEVICE`.

The *f_syncmode* field is copied from the *syncmode* field of the implementing filesystem. Its use is described in [Chapter 19](#).

The *f_offset* field records the current file position. It is the responsibility of the file operation functions to keep this field up to date.

The *f_data* field contains private data placed here by the underlying filesystem. Normally this will be a pointer to, or handle on, the filesystem object that implements this file.

The *f_xops* field contains a pointer to any extra type specific operation functions. For example, the socket I/O system installs a pointer to a table of functions that implement the standard socket operations.

The *f_mte* field contains a pointer to the parent mount table entry for this file. It is used mainly to implement the synchronization protocol. This may contain a pointer to some other data structure in file objects not derived from a filesystem.

The *f_ops* field contains a pointer to a table of file I/O operations. This has the following structure:

```
struct CYG_FILEOPS_TAG
{
    int (*fo_read)      (struct CYG_FILE_TAG *fp, struct CYG_UIO_TAG *uio);
    int (*fo_write)     (struct CYG_FILE_TAG *fp, struct CYG_UIO_TAG *uio);
    int  (*fo_lseek)    (struct CYG_FILE_TAG *fp, off_t *pos, int whence);
    int (*fo_ioctl)     (struct CYG_FILE_TAG *fp, CYG_ADDRWORD com,
                        CYG_ADDRWORD data);
};
```

```

int (*fo_select)      (struct CYG_FILE_TAG *fp, int which, CYG_ADDRWORD info);
int  (*fo_fsync)      (struct CYG_FILE_TAG *fp, int mode );
int  (*fo_close)      (struct CYG_FILE_TAG *fp);
int  (*fo_fstat)      (struct CYG_FILE_TAG *fp, struct stat *buf );
int  (*fo_getinfo)    (struct CYG_FILE_TAG *fp, int key, char *buf, int len );
int  (*fo_setinfo)    (struct CYG_FILE_TAG *fp, int key, char *buf, int len );
};

```

It should be obvious from the names of most of these functions what their responsibilities are. The `fo_getinfo()` and `fo_setinfo()` function pointers, like their counterparts in the filesystem structure, implement minor control and info functions such as `fpathconf()`.

The second argument to the `fo_read()` and `fo_write()` function pointers is a pointer to a UIO structure:

```

struct CYG_UIO_TAG
{
    struct CYG_IOVEC_TAG *uio_iov; /* pointer to array of iovecs */
    int      uio_iovcnt; /* number of iovecs in array */
    off_t    uio_offset; /* offset into file this uio corresponds to */
    ssize_t  uio_resid; /* residual i/o count */
    enum cyg_uio_seg  uio_segflg; /* see above */
    enum cyg_uio_rw   uio_rw;    /* see above */
};

struct CYG_IOVEC_TAG
{
    void      *iov_base; /* Base address. */
    ssize_t   iov_len;   /* Length. */
};

```

This structure encapsulates the parameters of any data transfer operation. It provides support for scatter/gather operations and records the progress of any data transfer. It is also compatible with the I/O operations of any BSD-derived network stacks and filesystems.

When a file is opened (or a file object created by some other means, such as `socket()` or `accept()`) it is the responsibility of the filesystem open operation to initialize all the fields of the object except the `f_ucount`, `f_syncmode` and `f_mte` fields. Since the `f_flag` field will already contain bits belonging to the FILEIO infrastructure, any changes to it must be made with the appropriate logical operations.

Chapter 18. Directories

Filesystem operations all take a directory pointer as one of their arguments. A directory pointer is an opaque handle managed by the filesystem. It should encapsulate a reference to a specific directory within the filesystem. For example, it may be a pointer to the data structure that represents that directory (such as an inode), or a pointer to a pathname for the directory.

The `chdir()` filesystem function pointer has two modes of use. When passed a pointer in the `dir_out` argument, it should locate the named directory and place a directory pointer there. If the `dir_out` argument is NULL then the `dir` argument is a previously generated directory pointer that can now be disposed of. When the infrastructure is implementing the `chdir()` function it makes two calls to filesystem `chdir()` functions. The first is to get a directory pointer for the new current directory. If this succeeds the second is to dispose of the old current directory pointer.

The `opendir()` function is used to open a directory for reading. This results in an open file object that can be read to return a sequence of struct dirent objects. The only operations that are allowed on this file are `read`, `lseek` and `close`. Each read operation on this file should return a single struct dirent object. When the end of the directory is reached, zero should be returned. The only seek operation allowed is a rewind to the start of the directory, by supplying an offset of zero and a *whence* specifier of `SEEK_SET`.

Most of these considerations are invisible to clients of a filesystem since they will access directories via the POSIX `opendir()`, `readdir()` and `closedir()` functions. The struct dirent object returned by `readdir()` will always contain `d_name` as required by POSIX. When `CYGPKG_FILEIO_DIRENT_DTYPE` is enabled it will also contain `d_type`, which is not part of POSIX, but often implemented by OSes. Currently only the FATFS, RAMFS, ROMFS and JFFS2 filesystem sets this value. For other filesystems a value of 0 will be returned in the member.

Support for the `getcwd()` function is provided by three mechanisms. The first is to use the `FS_INFO_GETCWD` getinfo key on the filesystem to use any internal support that it has for this. If that fails it falls back on one of the two other mechanisms. If `CYGPKG_IO_FILEIO_TRACK_CWD` is set then the current directory is tracked textually in `chdir()` and the result of that is reported in `getcwd()`. Otherwise an attempt is made to traverse the directory tree to its root using `".."` entries.

This last option is complicated and expensive, and relies on the filesystem supporting `"."` and `".."` entries. This is not always the case, particularly if the filesystem has been ported from a non-UNIX-compatible source. Tracking the pathname textually will usually work, but might not produce optimum results when symbolic links are being used.

Chapter 19. Synchronization

The FILEIO infrastructure provides a synchronization mechanism for controlling concurrent access to filesystems. This allows existing filesystems to be ported to eCos, even if they do not have their own synchronization mechanisms. It also allows new filesystems to be implemented easily without having to consider the synchronization issues.

The infrastructure maintains a mutex for each entry in each of the main tables: filesystem table, mount table and file table. For each class of operation each of these mutexes may be locked before the corresponding filesystem operation is invoked.

The synchronization protocol required by a filesystem is described by the *syncmode* field of the filesystem table entry. This is a combination of the following flags:

CYG_SYNCMODE_FILE_FILESYSTEM

Lock the filesystem table entry mutex during all filesystem level operations.

CYG_SYNCMODE_FILE_MOUNTPOINT

Lock the mount table entry mutex during all filesystem level operations.

CYG_SYNCMODE_IO_FILE

Lock the file table entry mutex during all I/O operations.

CYG_SYNCMODE_IO_FILESYSTEM

Lock the filesystem table entry mutex during all I/O operations.

CYG_SYNCMODE_IO_MOUNTPOINT

Lock the mount table entry mutex during all I/O operations.

CYG_SYNCMODE_SOCKET_FILE

Lock the file table entry mutex during all socket operations.

CYG_SYNCMODE_SOCKET_NETSTACK

Lock the network stack table entry mutex during all socket operations.

CYG_SYNCMODE_NONE

Perform no locking at all during any operations.

The value of the *syncmode* field in the filesystem table entry will be copied by the infrastructure to the open file object after a successful `open()` operation.

Chapter 20. Initialization and Mounting

As mentioned previously, mount table entries can be sourced from two places. Static entries may be defined by using the `MTAB_ENTRY()` macro. Such entries will be automatically mounted on system startup. For each entry in the mount table that has a non-null *name* field the filesystem table is searched for a match with the *fsname* field. If a match is found the filesystem's *mount* entry is called and if successful the mount table entry is marked valid and the *fs* field initialized. The `mount()` function is responsible for initializing the *root* field.

The size of the mount table is defined by the configuration value `CYGNUM_FILEIO_MTAB_MAX`. Any entries that have not been statically defined are available for use by dynamic mounts.

A filesystem may be mounted dynamically by calling `mount()`. This function has the following prototype:

```
int mount( const char *devname,
           const char *dir,
           const char *fsname);
```

The *devname* argument identifies a device that will be used by this filesystem and will be assigned to the *devname* field of the mount table entry.

The *dir* argument is the mount point name, it will be assigned to the *name* field of the mount table entry.

The *fsname* argument is the name of the implementing filesystem, it will be assigned to the *fsname* entry of the mount table entry. This argument may also contain options that control the mode in which the filesystem is mounted.

Since these three arguments are assigned directly to the mount table entry, the memory pointed to by these arguments must not change for the duration of the mount. This means they must be allocated from memory that will persist unchanged until unmounting, such as constant strings, dynamically allocated memory, or static or automatic variables that do not pass out of scope or get their values changed before unmounting.

The options attached to the *fsname* argument consist of a comma separated list of single keywords or keyword=value pairs separated from the filesystem name by a colon. For example, to mount the FAT filesystem with write-through cache synchronization the string would be: `"fatfs:sync=write"` and to mount it read-only: `"fatfs:readonly"`.

The process of mounting a filesystem dynamically is as follows. First a search is made of the mount table for an entry with a NULL *name* field to be used for the new mount point. The filesystem table is then searched for an entry whose name matches *fsname*. If this is successful then the mount table entry is initialized and the filesystem's `mount()` operation called. If this is successful, the mount table entry is marked valid and the *fs* field initialized.

Mounting a filesystem dynamically at the current working directory name, does not in fact change the current directory to one on the newly mounted filesystem. Instead the current working directory remains on the previous filesystem (or no filesystem in the case of `'/'` with no filesystems previously mounted). This is in line with usual POSIX/UNIX behaviour. To change to the new filesystem, a `chdir()` call must be made, even if it is to the current directory name as given by `getcwd()`. This is especially relevant when mounting a filesystem on `'/'` as the current working directory is usually also `'/'`.

It should also be noted that there is no requirement for there to be a directory entry for a filesystem mount point if mounted within another filesystem. So for example, there need not be a directory named `"/dev"` in the directory list of `"/"` even though there is a filesystem mounted on `"/dev"`.

Unmounting a filesystem is done by the `umount()` function. This can unmount filesystems whether they were mounted statically or dynamically.

The `umount()` function has the following prototype:

```
int umount( const char *name );
```

The mount table is searched for a match between the *name* argument and the entry *name* field. When a match is found the filesystem's `umount()` operation, with the *force* argument set to `false` is called and if successful, the mount table entry is invalidated by setting its *valid* field `false` and the *name* field to `NULL`.

There is also an `umount_force()` function with the following prototype:

```
int umount( const char *name );
```

The main difference between this and the standard `umount()` function is that it forces the filesystem to be unmounted. In the `FILEIO` package this means that all open files will be forced to close, the current directory will be moved away from the filesystem if it points to it and any threads waiting for access to the filesystem will be forced to return. When the filesystem's `umount()` function is called, the *force* argument will be set `true`, and the filesystem should take steps to free all resources and detach from the underlying device.

Care must be taken if mounting a filesystem on `"/` as it will not be possible to unmount the filesystem later if it is in use as the current working directory. Instead it will be necessary to change directory to a different filesystem before unmounting.

Chapter 21. Automounter

Where removable media is supported by the filesystem and the hardware device driver (currently only the FAT filesystem and the JUNG0 USB mass storage device driver have this support) it is possible to configure an automounter which will automatically mount any filesystems found on any device that is inserted. It will also automatically unmount the filesystem when the device is removed.

The automounter is controlled by a number of configuration options:

CYGPKG_IO_FILEIO_AUTOMOUNT

This option enables the eCos automounter. It is only active if there are device drivers present that are capable of dealing with removable media.

Default value: 0

CYGDAT_IO_FILEIO_AUTOMOUNT_ROOT

Any automounted filesystems will be mounted under this root directory.

Default value: "/auto"

CYGDAT_IO_FILEIO_AUTOMOUNT_DEVICES

This option is a list of device names of the devices that will be monitored by the automounter. Each entry is two strings within braces, with separate entries separated by commas. The first string gives the device name, the second the stub for making the mount point name under the automount root. The name of the filesystem root will be manufactured by appending the disk number and partition number to the name stub, separated by underscores. For example with the default values typical filesystem root names might be: "/auto/usb_0_1" or "/auto/usb_1_2".

Default value: { "/dev/usbmass/", "usb" }

The Automounter also defines a callback that may be used by applications to receive notifications that new filesystems have been mounted or unmounted. The `fileio.h` header contains the following definitions if the automounter is enabled:

```
typedef void cyg_automount_handler( int event, char *mountpoint, CYG_ADDRWORD data );
#define CYG_AUTOMOUNT_MOUNT      1
#define CYG_AUTOMOUNT_UMOUNT     2

__externC int cyg_automount_register_handler( char *devname, cyg_automount_handler *handler, CYG_ADDRWORD data );
```

The function `cyg_automount_register_handler()` causes the callback handler to be registered. The *devname* identifies the device to which the callback will be attached, it should match one of the device names defined in `CYGDAT_IO_FILEIO_AUTOMOUNT_DEVICES`. The *handler* argument is the callback function and *data* is a user defined data value.

When the handler is called, the *event* argument indicates the event being notified, `CYG_AUTOMOUNT_MOUNT` or `CYG_AUTOMOUNT_UMOUNT`. The *mountpoint* argument is the name of the root of the filesystem being notified, it will be composed as described above from `CYGDAT_IO_FILEIO_AUTOMOUNT_ROOT` and the stub part of the

relevant `CYGDAT_IO_FILEIO_AUTOMOUNT_DEVICES` entry. The *data* argument is the data value passed in from `cyg_automount_register_handler()`.

The handler will be called by the automounter just after the filesystem has been mounted, or just before it is unmounted. Application code should avoid running too much code in the handler and offload long running tasks to another thread. This is because the handler is called directly from the automounter thread and while it is executing, no other automount operations can be run.

Chapter 22. Sockets

If a network stack is present, then the FILEIO infrastructure also provides access to the standard BSD socket calls.

The netstack table contains entries which describe the network protocol stacks that are in the system image. Each resident stack should export an entry to this table using the `NSTAB_ENTRY()` macro.

Each table entry has the following structure:

```
struct cyg_nstab_entry
{
    cyg_bool          valid;           // true if stack initialized
    cyg_uint32        syncmode;        // synchronization protocol
    char              *name;           // stack name
    char              *devname;        // hardware device name
    CYG_ADDRWORD      data;           // private data value

    int               (*init)( cyg_nstab_entry *nste );
    int               (*socket)( cyg_nstab_entry *nste, int domain, int type,
                                int protocol, cyg_file *file );
};
```

This table is analogous to a combination of the filesystem and mount tables.

The *valid* field is set true if the stack's `init()` function returned successfully and the *syncmode* field contains the `CYG_SYNCMODE_SOCKET_*` bits described above.

The *name* field contains the name of the protocol stack.

The *devname* field names the device that the stack is using. This may reference a device under `"/dev"`, or may be a name that is only meaningful to the stack itself.

The `init()` function pointer is called during system initialization to start the protocol stack running. If it returns non-zero the *valid* field is set false and the stack will be ignored subsequently.

The `socket()` function is called to attempt to create a socket in the stack. When the `socket()` API function is called the netstack table is scanned and for each valid entry the `socket()` function pointer is called. If this returns non-zero then the scan continues to the next valid stack, or terminates with an error if the end of the table is reached.

The result of a successful socket call is an initialized file object with the *f_xops* field pointing to the following structure:

```
struct cyg_sock_ops
{
    int (*bind)      ( cyg_file *fp, const sockaddr *sa, socklen_t len );
    int (*connect)   ( cyg_file *fp, const sockaddr *sa, socklen_t len );
    int (*accept)    ( cyg_file *fp, cyg_file *new_fp,
                      struct sockaddr *name, socklen_t *anamelen );
    int (*listen)    ( cyg_file *fp, int len );
    int (*getname)   ( cyg_file *fp, sockaddr *sa, socklen_t *len, int peer );
    int (*shutdown)  ( cyg_file *fp, int flags );
    int (*getsockopt)( cyg_file *fp, int level, int optname,
                      void *optval, socklen_t *optlen);
    int (*setsockopt)( cyg_file *fp, int level, int optname,
                      const void *optval, socklen_t optlen);
};
```

```
int (*sendmsg)    ( cyg_file *fp, const struct msghdr *m,
                    int flags, ssize_t *retsize );
int (*recvmsg)    ( cyg_file *fp, struct msghdr *m,
                    socklen_t *namelen, ssize_t *retsize );
};
```

It should be obvious from the names of these functions which API calls they provide support for. The `getname()` function pointer provides support for both `getsockname()` and `getpeername()` while the `sendmsg()` and `recvmsg()` function pointers provide support for `send()`, `sendto()`, `sendmsg()`, `recv()`, `recvfrom()` and `recvmsg()` as appropriate.

Chapter 23. Select

The infrastructure provides support for implementing a select mechanism. This is modeled on the mechanism in the BSD kernel, but has been modified to make it implementation independent.

The main part of the mechanism is the `select()` API call. This processes its arguments and calls the `fo_select()` function pointer on all file objects referenced by the file descriptor sets passed to it. If the same descriptor appears in more than one descriptor set, the `fo_select()` function will be called separately for each appearance.

The *which* argument of the `fo_select()` function will either be `CYG_FREAD` to test for read conditions, `CYG_FWRITE` to test for write conditions or zero to test for exceptions. For each of these options the function should test whether the condition is satisfied and if so return true. If it is not satisfied then it should call `cyg_selrecord()` with the *info* argument that was passed to the function and a pointer to a `cyg_selinfo` structure.

The `cyg_selinfo` structure is used to record information about current select operations. Any object that needs to support select must contain an instance of this structure. Separate `cyg_selinfo` structures should be kept for each of the options that the object can select on - read, write or exception.

If none of the file objects report that the select condition is satisfied, then the `select()` API function puts the calling thread to sleep waiting either for a condition to become satisfied, or for the optional timeout to expire.

A selectable object must have some asynchronous activity that may cause a select condition to become true - either via interrupts or the activities of other threads. Whenever a selectable condition is satisfied, the object should call `cyg_selwakeup()` with a pointer to the appropriate `cyg_selinfo` structure. If the thread is still waiting, this will cause it to wake up and repeat its poll of the file descriptors. This time around, the object that caused the wakeup should indicate that the select condition is satisfied, and the `select()` API call will return.

Note that `select()` does not exhibit real time behaviour: the iterative poll of the descriptors, and the wakeup mechanism mitigate against this. If real time response to device or socket I/O is required then separate threads should be devoted to each device of interest and should use blocking calls to wait for a condition to become ready.

Chapter 24. Devices

Devices are accessed by means of a pseudo-filesystem, "devfs", that is mounted on "/dev". Open operations are translated into calls to `cyg_io_lookup()` and if successful result in a file object whose *`f_ops`* functions translate filesystem API functions into calls into the device API.

Chapter 25. Writing a New Filesystem

To create a new filesystem it is necessary to define the fstab entry and the file IO operations. The easiest way to do this is to copy an existing filesystem: either the test filesystem in the FILEIO package, or the RAM or ROM filesystem packages.

To make this clearer, the following is a brief tour of the FILEIO relevant parts of the RAM filesystem.

First, it is necessary to provide forward definitions of the functions that constitute the filesystem interface:

```
//=====
// Forward definitions

// Filesystem operations
static int ramfs_mount      ( cyg_fstab_entry *fste, cyg_mtab_entry *mte );
static int ramfs_umount    ( cyg_mtab_entry *mte, cyg_bool force );
static int ramfs_open      ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                             int mode, cyg_file *fte );
static int ramfs_unlink    ( cyg_mtab_entry *mte, cyg_dir dir, const char *name );
static int ramfs_mkdir    ( cyg_mtab_entry *mte, cyg_dir dir, const char *name );
static int ramfs_rmdir    ( cyg_mtab_entry *mte, cyg_dir dir, const char *name );
static int ramfs_rename    ( cyg_mtab_entry *mte, cyg_dir dir1, const char *name1,
                             cyg_dir dir2, const char *name2 );
static int ramfs_link      ( cyg_mtab_entry *mte, cyg_dir dir1, const char *name1,
                             cyg_dir dir2, const char *name2, int type );
static int ramfs_opendir   ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                             cyg_file *fte );
static int ramfs_chdir     ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                             cyg_dir *dir_out );
static int ramfs_stat      ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                             struct stat *buf );
static int ramfs_getinfo   ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                             int key, void *buf, int len );
static int ramfs_setinfo   ( cyg_mtab_entry *mte, cyg_dir dir, const char *name,
                             int key, void *buf, int len );

// File operations
static int ramfs_fo_read   (struct CYG_FILE_TAG *fp, struct CYG_UIO_TAG *uio);
static int ramfs_fo_write  (struct CYG_FILE_TAG *fp, struct CYG_UIO_TAG *uio);
static int ramfs_fo_lseek  (struct CYG_FILE_TAG *fp, off_t *pos, int whence );
static int ramfs_fo_ioctl  (struct CYG_FILE_TAG *fp, CYG_ADDRWORD com,
                             CYG_ADDRWORD data);
static int ramfs_fo_fsync  (struct CYG_FILE_TAG *fp, int mode );
static int ramfs_fo_close  (struct CYG_FILE_TAG *fp);
static int ramfs_fo_fstat  (struct CYG_FILE_TAG *fp, struct stat *buf );
static int ramfs_fo_getinfo (struct CYG_FILE_TAG *fp, int key, void *buf, int len );
static int ramfs_fo_setinfo (struct CYG_FILE_TAG *fp, int key, void *buf, int len );

// Directory operations
static int ramfs_fo_dirread (struct CYG_FILE_TAG *fp, struct CYG_UIO_TAG *uio);
static int ramfs_fo_dirlseek (struct CYG_FILE_TAG *fp, off_t *pos, int whence );
```

We define all of the fstab entries and all of the file IO operations. We also define alternatives for the *fo_read* and *fo_lseek* file IO operations.

We can now define the filesystem table entry. There is a macro, *FSTAB_ENTRY* to do this:

```
//=====
// Filesystem table entries

// -----
// Fstab entry.
// This defines the entry in the filesystem table.
// For simplicity we use _FILESYSTEM synchronization for all accesses since
// we should never block in any filesystem operations.

FSTAB_ENTRY( ramfs_fste, "ramfs", 0,
             CYG_SYNCMODE_FILE_FILESYSTEM|CYG_SYNCMODE_IO_FILESYSTEM,
             ramfs_mount,
             ramfs_umount,
             ramfs_open,
             ramfs_unlink,
             ramfs_mkdir,
             ramfs_rmdir,
             ramfs_rename,
             ramfs_link,
             ramfs_opendir,
             ramfs_chdir,
             ramfs_stat,
             ramfs_getinfo,
             ramfs_setinfo);
```

The first argument to this macro gives the fstab entry a name, the remainder are initializers for the field of the structure.

We must also define the file operations table that is installed in all open file table entries:

```
// -----
// File operations.
// This set of file operations are used for normal open files.

static cyg_fileops ramfs_fileops =
{
    ramfs_fo_read,
    ramfs_fo_write,
    ramfs_fo_lseek,
    ramfs_fo_ioctl,
    cyg_fileio_seltrue,
    ramfs_fo_fsync,
    ramfs_fo_close,
    ramfs_fo_fstat,
    ramfs_fo_getinfo,
    ramfs_fo_setinfo
};
```

These all point to functions supplied by the filesystem except the *fo_select* field which is filled with a pointer to *cyg_fileio_seltrue()*. This is provided by the FILEIO package and is a select function that always returns true to all operations.

Finally, we need to define a set of file operations for use when reading directories. This table only defines the *fo_read* and *fo_lseek* operations. The rest are filled with stub functions supplied by the FILEIO package that just return an error code.

```
// -----
// Directory file operations.
// This set of operations are used for open directories. Most entries
```

```
// point to error-returning stub functions. Only the read, lseek and
// close entries are functional.
```

```
static cyg_fileops ramfs_dirops =
{
    ramfs_fo_dirread,
    (cyg_fileop_write *)cyg_fileio_enosys,
    ramfs_fo_dirlseek,
    (cyg_fileop_ioctl *)cyg_fileio_enosys,
    cyg_fileio_seltrue,
    (cyg_fileop_fsync *)cyg_fileio_enosys,
    ramfs_fo_close,
    (cyg_fileop_fstat *)cyg_fileio_enosys,
    (cyg_fileop_getinfo *)cyg_fileio_enosys,
    (cyg_fileop_setinfo *)cyg_fileio_enosys
};
```

If the filesystem wants to have an instance automatically mounted on system startup, it must also define a mount table entry. This is done with the `MTAB_ENTRY` macro. This is an example from the test filesystem of how this is used:

```
MTAB_ENTRY( testfs_mtel,
            "/",
            "testfs",
            "",
            "",
            0);
```

The first argument provides a name for the table entry. The following arguments provide initialization for the *name*, *fsname*, *devname*, *options* and *data* fields respectively.

These definitions are adequate to let the new filesystem interact with the FILEIO package. The new filesystem now needs to be fleshed out with implementations of the functions defined above. Obviously, the exact form this takes will depend on what the filesystem is intended to do. Take a look at the RAM and ROM filesystems for examples of how this has been done.

VI. PCI Library

Chapter 26. The eCos PCI Library

The PCI library is an optional part of eCos, and is only applicable to some platforms.

PCI Library

The eCos PCI library provides the following functionality:

1. Scan the PCI bus for specific devices or devices of a certain class.
2. Read and change generic PCI information.
3. Read and change device-specific PCI information.
4. Allocate PCI memory and IO space to devices.
5. Translate a device's PCI interrupts to equivalent HAL vectors.

Example code fragments are from the pci1 test (see `io/pci/<release>/tests/pci1.c`).

All of the functions described below are declared in the header file `<cyg/io/pci.h>` which all clients of the PCI library should include.

PCI Overview

The PCI bus supports several address spaces: memory, IO, and configuration. All PCI devices must support mandatory configuration space registers. Some devices may also present IO mapped and/or memory mapped resources. Before devices on the bus can be used, they must be configured. Basically, configuration will assign PCI IO and/or memory address ranges to each device and then enable that device. All PCI devices have a unique address in configuration space. This address is comprised of a bus number, a device number, and a function number. Special devices called bridges are used to connect two PCI busses together. The PCI standard supports up to 255 busses with each bus having up to 32 devices and each device having up to 8 functions.

The environment in which a platform operates will dictate if and how eCos should configure devices on the PCI bus. If the platform acts as a host on a single PCI bus, then devices may be configured individually from the relevant device driver. If the platform is not the primary host, such as a PCI card plugged into a PC, configuration of PCI devices may be left to the PC BIOS. If PCI-PCI bridges are involved, configuration of all devices is best done all at once early in the boot process. This is because all devices on the secondary side of a bridge must be evaluated for their IO and memory space requirements before the bridge can be configured.

Initializing the bus

The PCI bus needs to be initialized before it can be used. This only needs to be done once - some HALs may do it as part of the platform initialization procedure, other HALs may leave it to the application or device drivers to do it. The following function will do the initialization only once, so it's safe to call from multiple drivers:

```
void cyg_pci_init( void );
```

Scanning for devices

After the bus has been initialized, it is possible to scan it for devices. This is done using the function:

```
cyg_bool cyg_pci_find_next(  cyg_pci_device_id cur_devid,
                             cyg_pci_device_id *next_devid );
```

It will scan the bus for devices starting at *cur_devid*. If a device is found, its devid is stored in *next_devid* and the function returns true.

The *pci1* test's outer loop looks like:

```
cyg_pci_init();
if (cyg_pci_find_next(CYG_PCI_NULL_DEVID, &devid)) {
    do {
        <use devid>
    } while (cyg_pci_find_next(devid, &devid));
}
```

What happens is that the bus gets initialized and a scan is started. *CYG_PCI_NULL_DEVID* causes *cyg_pci_find_next()* to restart its scan. If the bus does not contain any devices, the first call to *cyg_pci_find_next()* will return false.

If the call returns true, a loop is entered where the found devid is used. After devid processing has completed, the next device on the bus is searched for; *cyg_pci_find_next()* continues its scan from the current devid. The loop terminates when no more devices are found on the bus.

This is the generic way of scanning the bus, enumerating all the devices on the bus. But if the application is looking for a device of a given device class (e.g., a SCSI controller), or a specific vendor device, these functions simplify the task a bit:

```
cyg_bool cyg_pci_find_class(  cyg_uint32 dev_class,
                             cyg_pci_device_id *devid );
cyg_bool cyg_pci_find_device(  cyg_uint16 vendor, cyg_uint16 device,
                             cyg_pci_device_id *devid );
```

They work just like *cyg_pci_find_next()*, but only return true when the *dev_class* or *vendor/device* qualifiers match those of a device on the bus. The *devid* serves as both an input and an output operand: the scan starts at the given device, and if a device is found *devid* is updated with the value for the found device.

The *<cyg/io/pci_cfg.h>* header file (included by *pci.h*) contains definitions for PCI class, vendor and device codes which can be used as arguments to the find functions. The list of vendor and device codes is not complete: add new codes as necessary. If possible also register the codes at the PCI Database (<http://www.pcidatabase.com>) which is where the eCos definitions are generated from.

Generic config information

When a valid device ID (*devid*) is found using one of the above functions, the associated device can be queried and controlled using the functions:

```
void cyg_pci_get_device_info (  cyg_pci_device_id devid,
                               cyg_pci_device *dev_info );
void cyg_pci_set_device_info (  cyg_pci_device_id devid,
                               cyg_pci_device *dev_info );
```

The *cyg_pci_device* structure (defined in *pci.h*) primarily holds information as described by the PCI specification [1]. The *pci1* test prints out some of this information:

```
// Get device info
cyg_pci_get_device_info(devid, &dev_info);
diag_printf("\n Command    0x%04x, Status 0x%04x\n",
            dev_info.command, dev_info.status);
```

The command register can also be written to, controlling (among other things) whether the device responds to IO and memory access from the bus.

Specific config information

The above functions only allow access to generic PCI config registers. A device can have extra config registers not specified by the PCI specification. These can be accessed with these functions:

```
void cyg_pci_read_config_uint8(  cyg_pci_device_id devid,
                                cyg_uint8 offset, cyg_uint8 *val);
void cyg_pci_read_config_uint16( cyg_pci_device_id devid,
                                cyg_uint8 offset, cyg_uint16 *val);
void cyg_pci_read_config_uint32( cyg_pci_device_id devid,
                                cyg_uint8 offset, cyg_uint32 *val);
void cyg_pci_write_config_uint8( cyg_pci_device_id devid,
                                cyg_uint8 offset, cyg_uint8 val);
void cyg_pci_write_config_uint16( cyg_pci_device_id devid,
                                cyg_uint8 offset, cyg_uint16 val);
void cyg_pci_write_config_uint32( cyg_pci_device_id devid,
                                cyg_uint8 offset, cyg_uint32 val);
```

The write functions should only be used for device-specific config registers since using them on generic registers may invalidate the contents of a previously fetched `cyg_pci_device` structure.

Allocating memory

A PCI device ignores all IO and memory access from the PCI bus until it has been activated. Activation cannot happen until after device configuration. Configuration means telling the device where it should map its IO and memory resources. This is done with one of the following functions::

```
cyg_bool cyg_pci_configure_device( cyg_pci_device *dev_info );
cyg_bool cyg_pci_configure_bus(  cyg_uint8 bus, cyg_uint8 *next_bus );
```

The `cyg_pci_configure_device` handles all IO and memory regions that need configuration on non-bridge devices. On platforms with multiple busses connected by bridges, the `cyg_pci_configure_bus` function should be used. It will recursively configure all devices on the given *bus* and all subordinate busses. `cyg_pci_configure_bus` will use `cyg_pci_configure_device` to configure individual non-bridge devices.

Each region is represented in the PCI device's config space by BARs (Base Address Registers) and is handled individually according to type using these functions:

```
cyg_bool cyg_pci_allocate_memory( cyg_pci_device *dev_info,
                                cyg_uint32 bar,
                                CYG_PCI_ADDRESS64 *base );
cyg_bool cyg_pci_allocate_io(   cyg_pci_device *dev_info,
                                cyg_uint32 bar,
                                CYG_PCI_ADDRESS32 *base );
```

The memory bases (in two distinct address spaces) are increased as memory regions are allocated to devices. Allocation will fail (the function returns false) if the base exceeds the limits of the address space (IO is 1MB, memory is 2^{32} or 2^{64} bytes).

These functions can also be called directly by the application/driver if necessary, but this should not be necessary.

The bases are initialized with default values provided by the HAL. It is possible for an application to override these using the following functions:

```
void cyg_pci_set_memory_base( CYG_PCI_ADDRESS64 base );
void cyg_pci_set_io_base( CYG_PCI_ADDRESS32 base );
```

When a device has been configured, the `cyg_pci_device` structure will contain the physical address in the CPU's address space where the device's memory regions can be accessed.

This information is provided in `base_map[]` - there is a 32 bit word for each of the device's BARs. For 32 bit PCI memory regions, each 32 bit word will be an actual pointer that can be used immediately by the driver: the memory space will normally be linearly addressable by the CPU.

However, for 64 bit PCI memory regions, some (or all) of the region may be outside of the CPU's address space. In this case the driver will need to know how to access the region in segments. This functionality may be adopted by the eCos HAL if deemed useful in the future. The 2GB available on many systems should suffice though.

Interrupts

A device may generate interrupts. The HAL vector associated with a given device on the bus is platform specific. This function allows a driver to find the actual interrupt vector for a given device:

```
cyg_bool cyg_pci_translate_interrupt( cyg_pci_device *dev_info,
                                     CYG_ADDRWORD *vec );
```

If the function returns false, no interrupts will be generated by the device. If it returns true, the `CYG_ADDRWORD` pointed to by `vec` is updated with the HAL interrupt vector the device will be using. This is how the function is used in the `pci1` test:

```
if (cyg_pci_translate_interrupt(&dev_info, &irq))
    diag_printf(" Wired to HAL vector %d\n", irq);
else
    diag_printf(" Does not generate interrupts.\n");
```

The application/driver should attach an interrupt handler to a device's interrupt before activating the device.

Activating a device

When the device has been allocated memory space it can be activated. This is not done by the library since a driver may have to initialize more state on the device before it can be safely activated.

Activating the device is done by enabling flags in its command word. As an example, see the `pci1` test which can be configured to enable the devices it finds. This allows these to be accessed from GDB (if a breakpoint is set on `cyg_test_exit`):

```
#ifdef ENABLE_PCI_DEVICES
{
    cyg_uint16 cmd;

    // Don't use cyg_pci_set_device_info since it clears
    // some of the fields we want to print out below.
    cyg_pci_read_config_uint16(dev_info.devid,
                              CYG_PCI_CFG_COMMAND, &cmd);
    cmd |= CYG_PCI_CFG_COMMAND_IO | CYG_PCI_CFG_COMMAND_MEMORY;
    cyg_pci_write_config_uint16(dev_info.devid,
```

```

CYG_PCI_CFG_COMMAND, cmd);
}
diag_printf(" **** Device IO and MEM access enabled\n");
#endif

```

Note: The best way to activate a device is actually through `cyg_pci_set_device_info()`, but in this particular case the `cyg_pci_device` structure contents from before the activation is required for printout further down in the code.

Links

See these links for more information about PCI:

1. <http://www.pcisig.com/> - information on the PCI specifications
2. <http://www.yourvote.com/pci/> - list of vendor and device IDs
3. <http://www.picmg.org/> - PCI Industrial Computer Manufacturers Group

PCI Library reference

This document defines the PCI Support Library for eCos.

The PCI support library provides a set of routines for accessing the PCI bus configuration space in a portable manner. This is provided by two APIs. The high level API is used by device drivers, or other code, to access the PCI configuration space portably. The low level API is used by the PCI library itself to access the hardware in a platform-specific manner, and may also be used by device drivers to access the PCI configuration space directly.

Underlying the low-level API is HAL support for the basic configuration space operations. These should not generally be used by any code other than the PCI library, and are present in the HAL to allow low level initialization of the PCI bus and devices to take place if necessary.

PCI Library API

The PCI library provides the following routines and types for accessing the PCI configuration space.

The API for the PCI library is found in the header file `<cyg/io/pci.h>`.

Definitions

The header file contains definitions for the common configuration structure offsets and specimen values for device, vendor and class code.

Types and data structures

The following types are defined:

```
typedef CYG_WORD32 cyg_pci_device_id;
```

This is comprised of the bus number, device number and functional unit numbers packed into a single word. The macro `CYG_PCI_DEV_MAKE_ID()`, in conjunction with the `CYG_PCI_DEV_MAKE_DEVFN()` macro, may be used to construct a device id from the bus, device and functional unit numbers. Similarly the macros `CYG_PCI_DEV_GET_BUS()`, `CYG_PCI_DEV_GET_DEVFN()`, `CYG_PCI_DEV_GET_DEV()`, and `CYG_PCI_DEV_GET_FN()` may be used to extract the constituent parts of a device id. It should not be necessary to use these macros under normal circumstances. The following code fragment demonstrates how these macros may be used:

```
// Create a packed representation of device 1, function 0
cyg_uint8 devfn = CYG_PCI_DEV_MAKE_DEVFN(1,0);

// Create a packed devid for that device on bus 2
cyg_pci_device_id devid = CYG_PCI_DEV_MAKE_ID(2, devfn);

diag_printf("bus %d, dev %d, func %d\n",
            CYG_PCI_DEV_GET_BUS(devid),
            CYG_PCI_DEV_GET_DEV(CYG_PCI_DEV_GET_DEVFN(devid)),
            CYG_PCI_DEV_GET_FN(CYG_PCI_DEV_GET_DEVFN(devid)));

typedef struct cyg_pci_device;
```

This structure is used to contain data read from a PCI device's configuration header by `cyg_pci_get_device_info()`. It is also used to record the resource allocations made to the device.

```
typedef CYG_WORD64 CYG_PCI_ADDRESS64;
typedef CYG_WORD32 CYG_PCI_ADDRESS32;
```

Pointers in the PCI address space are 32 bit (IO space) or 32/64 bit (memory space). In most platform and device configurations all of PCI memory will be linearly addressable using only 32 bit pointers as read from `base_map[]`.

The 64 bit type is used to allow handling 64 bit devices in the future, should it be necessary, without changing the library's API.

Functions

```
void cyg_pci_init(void);
```

Initialize the PCI library and establish contact with the hardware. This function is idempotent and can be called either by all drivers in the system, or just from an application initialization function.

```
cyg_bool cyg_pci_find_device( cyg_uint16 vendor,
                             cyg_uint16 device,
                             cyg_pci_device_id *devid );
```

Searches the PCI bus configuration space for a device with the given *vendor* and *device* ids. The search starts at the device pointed to by *devid*, or at the first slot if it contains `CYG_PCI_NULL_DEVID`. **devid* will be updated with the ID of the next device found. Returns `true` if one is found and `false` if not.

```
cyg_bool cyg_pci_find_class( cyg_uint32 dev_class,
                             cyg_pci_device_id *devid );
```


Searches the PCI bus configuration space for a device with the given *dev_class* class code. The search starts at the device pointed to by *dev_id*, or at the first slot if it contains CYG_PCI_NULL_DEVID.

**dev_id* will be updated with the ID of the next device found. Returns *true* if one is found and *false* if not.

```
cyg_bool cyg_pci_find_next( cyg_pci_device_id cur_dev_id,
                           cyg_pci_device_id *next_dev_id );
```

Searches the PCI configuration space for the next valid device after *cur_dev_id*. If *cur_dev_id* is given the value CYG_PCI_NULL_DEVID, then the search starts at the first slot. It is permitted for *next_dev_id* to point to *cur_dev_id*. Returns *true* if another device is found and *false* if not.

```
cyg_bool cyg_pci_find_matching( cyg_pci_match_func *matchp,
                               void * match_callback_data,
                               cyg_pci_device_id *dev_id );
```

Searches the PCI bus configuration space for a device whose properties match those required by the caller supplied *cyg_pci_match_func*. The search starts at the device pointed to by *dev_id*, or at the first slot if it contains CYG_PCI_NULL_DEVID. The *dev_id* will be updated with the ID of the next device found. This function returns *true* if a matching device is found and *false* if not.

The *match_func* has a type declared as:

```
typedef cyg_bool (cyg_pci_match_func)( cyg_uint16 vendor,
                                       cyg_uint16 device,
                                       cyg_uint32 class,
                                       void *      user_data);
```

The *vendor*, *device*, and *class* are from the device configuration space. The *user_data* is the callback data passed to *cyg_pci_find_matching*.

```
void cyg_pci_get_device_info ( cyg_pci_device_id dev_id,
                              cyg_pci_device *dev_info );
```

This function gets the PCI configuration information for the device indicated in *dev_id*. The common fields of the *cyg_pci_device* structure, and the appropriate fields of the relevant header union member are filled in from the device's configuration space. If the device has not been enabled, then this function will also fetch the size and type information from the base address registers and place it in the *base_size[]* array.

```
void cyg_pci_set_device_info ( cyg_pci_device_id dev_id,
                              cyg_pci_device *dev_info );
```

This function sets the PCI configuration information for the device indicated in *dev_id*. Only the configuration space registers that are writable are actually written. Once all the fields have been written, the device info will be read back into **dev_info*, so that it reflects the true state of the hardware.

```
void cyg_pci_read_config_uint8( cyg_pci_device_id dev_id,
                               cyg_uint8 offset, cyg_uint8 *val );
void cyg_pci_read_config_uint16( cyg_pci_device_id dev_id,
                                 cyg_uint8 offset, cyg_uint16 *val );
void cyg_pci_read_config_uint32( cyg_pci_device_id dev_id,
                                 cyg_uint8 offset, cyg_uint32 *val );
```

These functions read registers of the appropriate size from the configuration space of the given device. They should mainly be used to access registers that are device specific. General PCI registers are best accessed through *cyg_pci_get_device_info()*.

```
void cyg_pci_write_config_uint8( cyg_pci_device_id dev_id,
                                 cyg_uint8 offset, cyg_uint8 val );
```

```
void cyg_pci_write_config_uint16( cyg_pci_device_id devid,
    cyg_uint8 offset, cyg_uint16 val );
void cyg_pci_write_config_uint32( cyg_pci_device_id devid,
    cyg_uint8 offset, cyg_uint32 val );
```

These functions write registers of the appropriate size to the configuration space of the given device. They should mainly be used to access registers that are device specific. General PCI registers are best accessed through `cyg_pci_get_device_info()`. Writing the general registers this way may render the contents of a `cyg_pci_device` structure invalid.

Resource allocation

These routines allocate memory and I/O space to PCI devices.

```
cyg_bool cyg_pci_configure_device( cyg_pci_device *dev_info )
```

Allocate memory and IO space to all base address registers using the current memory and IO base addresses in the library. The allocated base addresses, translated into directly usable values, will be put into the matching `base_map[]` entries in `*dev_info`. If `*dev_info` does not contain valid `base_size[]` entries, then the result is `false`. This function will also call `cyg_pci_translate_interrupt()` to put the interrupt vector into the HAL vector entry.

```
cyg_bool cyg_pci_configure_bus( cyg_uint8 bus, cyg_uint8 *next_bus )
```

Allocate memory and IO space to all base address registers on all devices on the given bus and all subordinate busses. If a PCI-PCI bridge is found on `bus`, this function will call itself recursively in order to configure the bus on the other side of the bridge. Because of the nature of bridge devices, all devices on the secondary side of a bridge must be allocated memory and IO space before the memory and IO windows on the bridge device can be properly configured. The `next_bus` argument points to the bus number to assign to the next subordinate bus found. The number will be incremented as new busses are discovered. If successful, `true` is returned. Otherwise, `false` is returned.

```
cyg_bool cyg_pci_translate_interrupt( cyg_pci_device *dev_info,
    CYG_ADDRWORD *vec );
```

Translate the device's PCI interrupt (INTA#-INTD#) to the associated HAL vector. This may also depend on which slot the device occupies. If the device may generate interrupts, the translated vector number will be stored in `vec` and the result is `true`. Otherwise the result is `false`.

```
cyg_bool cyg_pci_allocate_memory( cyg_pci_device *dev_info,
    cyg_uint32 bar,
    CYG_PCI_ADDRESS64 *base );
cyg_bool cyg_pci_allocate_io( cyg_pci_device *dev_info,
    cyg_uint32 bar,
    CYG_PCI_ADDRESS32 *base );
```

These routines allocate memory or I/O space to the base address register indicated by `bar`. The base address in `*base` will be correctly aligned and the address of the next free location will be written back into it if the allocation succeeds. If the base address register is of the wrong type for this allocation, or `dev_info` does not contain valid `base_size[]` entries, the result is `false`. These functions allow a device driver to set up its own mappings if it wants. Most devices should probably use `cyg_pci_configure_device()`.

```
void cyg_pci_set_memory_base( CYG_PCI_ADDRESS64 base );
void cyg_pci_set_io_base( CYG_PCI_ADDRESS32 base );
```

These routines set the base addresses for memory and I/O mappings to be used by the memory allocation routines. Normally these base addresses will be set to default values based on the platform. These routines allow these to be changed by application code if necessary.

PCI Library Hardware API

This API is used by the PCI library to access the PCI bus configuration space. Although it should not normally be necessary, this API may also be used by device driver or application code to perform PCI bus operations not supported by the PCI library.

```
void cyg_pcihw_init(void);
```

Initialize the PCI hardware so that the configuration space may be accessed.

```
void cyg_pcihw_read_config_uint8(  cyg_uint8 bus,
                                   cyg_uint8 devfn, cyg_uint8 offset, cyg_uint8 *val);
void cyg_pcihw_read_config_uint16( cyg_uint8 bus,
                                   cyg_uint8 devfn, cyg_uint8 offset, cyg_uint16 *val);
void cyg_pcihw_read_config_uint32( cyg_uint8 bus,
                                   cyg_uint8 devfn, cyg_uint8 offset, cyg_uint32 *val);
```

These functions read a register of the appropriate size from the PCI configuration space at an address composed from the *bus*, *devfn* and *offset* arguments.

```
void cyg_pcihw_write_config_uint8(  cyg_uint8 bus,
                                   cyg_uint8 devfn, cyg_uint8 offset, cyg_uint8 val);
void cyg_pcihw_write_config_uint16( cyg_uint8 bus,
                                   cyg_uint8 devfn, cyg_uint8 offset, cyg_uint16 val);
void cyg_pcihw_write_config_uint32( cyg_uint8 bus,
                                   cyg_uint8 devfn, cyg_uint8 offset, cyg_uint32 val);
```

These functions write a register of the appropriate size to the PCI configuration space at an address composed from the *bus*, *devfn* and *offset* arguments.

```
cyg_bool cyg_pcihw_translate_interrupt( cyg_uint8 bus,
                                        cyg_uint8 devfn,
                                        CYG_ADDRWORD *vec);
```

This function interrogates the device and determines which HAL interrupt vector it is connected to.

HAL PCI support

HAL support consists of a set of C macros that provide the implementation of the low level PCI API.

```
HAL_PCI_INIT()
```

Initialize the PCI bus.

```
HAL_PCI_READ_UINT8( bus, devfn, offset, val )
HAL_PCI_READ_UINT16( bus, devfn, offset, val )
HAL_PCI_READ_UINT32( bus, devfn, offset, val )
```

Read a value from the PCI configuration space of the appropriate size at an address composed from the *bus*, *devfn* and *offset*.

```
HAL_PCI_WRITE_UINT8( bus, devfn, offset, val )
```

```
HAL_PCI_WRITE_UINT16( bus, devfn, offset, val )
HAL_PCI_WRITE_UINT32( bus, devfn, offset, val )
```

Write a value to the PCI configuration space of the appropriate size at an address composed from the *bus*, *devfn* and *offset*.

```
HAL_PCI_TRANSLATE_INTERRUPT( bus, devfn, *vec, valid )
```

Translate the device's interrupt line into a HAL interrupt vector.

```
HAL_PCI_ALLOC_BASE_MEMORY
HAL_PCI_ALLOC_BASE_IO
```

These macros define the default base addresses used to initialize the memory and I/O allocation pointers.

```
HAL_PCI_PHYSICAL_MEMORY_BASE
HAL_PCI_PHYSICAL_IO_BASE
```

PCI memory and IO range do not always correspond directly to physical memory or IO addresses. Frequently the PCI address spaces are windowed into the processor's address range at some offset. These macros define offsets to be added to the PCI base addresses to translate PCI bus addresses into physical memory addresses that can be used to access the allocated memory or IO space.

Note: The chunk of PCI memory space directly addressable through the window by the CPU may be smaller than the amount of PCI memory actually provided. In that case drivers will have to access PCI memory space in segments. Doing this will be platform specific and is currently beyond the scope of the HAL.

```
HAL_PCI_IGNORE_DEVICE( bus, dev, fn )
```

This macro, if defined, may be used to limit the devices which are found by the bus scanning functions. This is sometimes necessary for devices which need special handling. If this macro evaluates to `true`, the given device will not be found by `cyg_pci_find_next` or other bus scanning functions.

```
HAL_PCI_IGNORE_BAR( dev_info, bar_num )
```

This macro, if defined, may be used to limit which BARs are discovered and configured. This is sometimes necessary for platforms with limited PCI windows. If this macro evaluates to `true`, the given BAR will not be discovered by `cyg_pci_get_device_info` and therefore not configured by `cyg_pci_configure_device`.

VII. FLASH Library

Chapter 27. The eCos FLASH Library

The FLASH library is an optional part of eCos, and is only applicable to some platforms.

The eCos FLASH library provides the following functionality:

1. Identifying installed device of a FLASH family.
2. Read, erasing and writing to FLASH blocks.
3. Validating an address is within the FLASH.
4. Determining the number and size of FLASH blocks.

There are two APIs with the flash library. The old API is retained for backwards compatibility reasons, but should slowly be replaced with the new API which is much more flexible and does not pollute the name space as much.

Notes on using the FLASH library

FLASH devices cannot be read from when an erase or write operation is active. This means it is not possible to execute code from flash while an erase or write operation is active. It is possible to use the library when the executable image is resident in FLASH. The low level drivers are written such that the linker places the functions that actually manipulate the flash into RAM. However the library may not be interrupt safe. An interrupt must not cause execution of code that is resident in FLASH. This may be the image itself, or RedBoot. In some configurations of eCos, ^C on the serial port or debugging via Ethernet may cause an interrupt handler to call RedBoot. If RedBoot is resident in FLASH this will cause a crash. Similarly, if another thread invokes a virtual vector function to access RedBoot, eg to perform a `diag_printf()` a crash could result.

Thus with a ROM based image or a ROM based Redboot it is recommended to disable interrupts while erasing or programming flash. Using both a ROMRAM or RAM images and a ROMRAM or RAM RedBoot are safe and there is no need to disable interrupts.

Danger, Will Robinson! Danger!

Unlike nearly every other aspect of embedded system programming, getting it wrong with FLASH devices can render your target system useless. Most targets have a boot loader in the FLASH. Without this boot loader the target will obviously not boot. So before starting to play with this library its worth investigating a few things. How do you recover your target if you delete the boot loader? Do you have the necessary JTAG cable? Or is specialist hardware needed? Is it even possible to recover the target boards or must it be thrown into the rubbish bin? How does killing the board affect your project schedule?

Chapter 28. The Version 2 eCos FLASH API

There are two APIs described here. The first is the application API which programs should use. The second API is that between the FLASH IO library and the device drivers.

FLASH user API

All of the functions described below are declared in the header file `<cyg/io/flash.h>` which all users of the FLASH library should include.

Initializing the FLASH library

The FLASH library needs to be initialized before other FLASH operations can be performed. This only needs to be done once. The following function will only do the initialization once so it's safe to call multiple times:

```
__externC int cyg_flash_init(cyg_flash_printf *pf);
```

The parameter *pf* must always be set to NULL. It exists solely for backward compatibility and other settings are deprecated and obsolete. Past use of this parameter has now been replaced with use of the `cyg_flash_set_global_printf` function.

Retrieving information about FLASH devices

The following five functions return information about the FLASH.

```
__externC int cyg_flash_get_info(cyg_uint32 devno, cyg_flash_info_t * info);
__externC int cyg_flash_get_info_addr(cyg_flashaddr_t flash_base, cyg_flash_info_t * info);
__externC int cyg_flash_verify_addr(const flashaddr_t address);
__extern size_t cyg_flash_block_size(const cyg_flashaddr_t flash_base);

typedef struct cyg_flash_block_info
{
    size_t          block_size;
    cyg_uint32      blocks;
} cyg_flash_block_info_t;

typedef struct {
    cyg_flashaddr_t start;          // First address
    cyg_flashaddr_t end;            // Last address
    cyg_uint32      num_block_infos; // Number of entries
    const cyg_flash_block_info_t *blocks_info; // Info about one block size
} cyg_flash_info_t;
```

`cyg_flash_get_info()` is the main function to get information about installed flash devices. Parameter *devno* is used to iterate over the available flash devices, starting from 0. If the *devno*'th device exists, the structure pointed to by *info* is filled in and `CYG_FLASH_ERR_OK` is returned, otherwise `CYG_FLASH_ERR_INVALID`. `cyg_flash_get_info_addr()` is similar, but returns the information about the flash device at the given address. `cyg_flash_block_size()` returns the size of the block at the given address. `cyg_flash_verify_addr()` tests if the target addresses is within one of the FLASH devices, returning `CYG_FLASH_ERR_OK` if so.

Reading from FLASH

There are two methods for reading from FLASH. The first is to use the following function.

```
__externC int cyg_flash_read(cyg_flashaddr_t flash_base, void *ram_base, size_t len, cyg_flashaddr_t
```

flash_base is where in the flash to read from. *ram_base* indicates where the data read from flash should be placed into RAM. *len* is the number of bytes to be read from the FLASH and *err_address* is used to return the location in FLASH that any error occurred while reading.

The second method is to simply `memcpy()` directly from the FLASH. This is not recommended since some types of device cannot be read in this way, eg NAND FLASH. Using the FLASH library function to read the FLASH will always work so making it easy to port code from one FLASH device to another.

Erasing areas of FLASH

Blocks of FLASH can be erased using the following function:

```
__externC int cyg_flash_erase(cyg_flashaddr_t flash_base, size_t len, cyg_flashaddr_t *err_address
```

flash_base is where in the flash to erase from. *len* is the minimum number of bytes to erase in the FLASH and *err_address* is used to return the location in FLASH that any error occurred while erasing. It should be noted that FLASH devices are block oriented when erasing. It is not possible to erase a few bytes within a block, the whole block will be erased. *flash_base* may be anywhere within the first block to be erased and *flash_base+len* may be anywhere in the last block to be erased.

Programming the FLASH

Programming of the flash is achieved using the following function.

```
__externC int cyg_flash_program(cyg_flashaddr_t flash_base, void *ram_base, size_t len, cyg_flasha
```

flash_base is where in the flash to program from. *ram_base* indicates where the data to be programmed into FLASH should be read from in RAM. *len* is the number of bytes to be program into the FLASH and *err_address* is used to return the location in FLASH that any error occurred while programming.

Locking and unlocking blocks

Some flash devices have the ability to lock and unlock blocks. A locked block cannot be erased or programmed without it first being unlocked. For devices which support this feature and when CYGHWI_IO_FLASH_BLOCK_LOCKING is enabled then the following two functions are available:

```
__externC int cyg_flash_lock(const cyg_flashaddr_t flash_base, size_t len, cyg_flashaddr_t *err_ad
__externC int cyg_flash_unlock(const cyg_flashaddr_t flash_base, size_t len, cyg_flashaddr_t *err_
```

Locking FLASH mutexes

When the eCos kernel package is included in the eCos configuration, the FLASH IO library will perform mutex locking on FLASH operations. This makes the API defined here thread safe. However applications may wish to directly access the contents of the FLASH. In order for this to be thread safe it is necessary for the application

to use the following two functions to inform the FLASH IO library that the FLASH devices are being used and other API calls should be blocked.

```
__externC int cyg_flash_mutex_lock(const cyg_flashaddr_t from, size_t len);
__externC int cyg_flash_mutex_unlock(const cyg_flashaddr_t from, size_t len);
```

Configuring diagnostic output

Each FLASH device can have an associated function which is called to perform diagnostic output. The function to be used can be configured with the following functions:

```
__externC int cyg_flash_set_printf(const cyg_flashaddr_t flash_base,
                                   cyg_flash_printf *pf);
__externC void cyg_flash_set_global_printf(cyg_flash_printf *pf);
typedef int cyg_flash_printf(const char *fmt, ...);
```

The parameter *pf* is a pointer to a function which is to be used for diagnostic output. Typically the function `diag_printf()` will be passed. Normally this function is not used by the higher layer of the library unless `CYGSEM_IO_FLASH_CHATTER` is enabled. Passing a *NULL* causes diagnostic output from lower level drivers to be discarded.

`cyg_flash_set_printf` is used to set a diagnostic output function which will be used specifically when diagnostic output is attempted from the FLASH device driver associated with the base address of *flash_base*. An error will be returned if no FLASH device is found for this address, or the FLASH subsystem has not yet been initialised with `cyg_flash_init`.

`cyg_flash_set_global_printf` sets a diagnostic output function for all available FLASH devices. Any previous setting of a diagnostic output function (including with `cyg_flash_set_printf`) will be discarded. This function may be called prior to `cyg_flash_init`.

Return values and errors

All the functions above return one of the following return values.

CYG_FLASH_ERR_OK	No error - operation complete
CYG_FLASH_ERR_INVALID	Invalid FLASH address
CYG_FLASH_ERR_ERASE	Error trying to erase
CYG_FLASH_ERR_LOCK	Error trying to lock/unlock
CYG_FLASH_ERR_PROGRAM	Error trying to program
CYG_FLASH_ERR_PROTOCOL	Generic error
CYG_FLASH_ERR_PROTECT	Device/region is write-protected
CYG_FLASH_ERR_NOT_INIT	FLASH info not yet initialized
CYG_FLASH_ERR_HWR	Hardware (configuration?) problem
CYG_FLASH_ERR_ERASE_SUSPEND	Device is in erase suspend mode
CYG_FLASH_ERR_PROGRAM_SUSPEND	Device is in program suspend mode
CYG_FLASH_ERR_DRV_VERIFY	Driver failed to verify data
CYG_FLASH_ERR_DRV_TIMEOUT	Driver timed out waiting for device
CYG_FLASH_ERR_DRV_WRONG_PART	Driver does not support device
CYG_FLASH_ERR_LOW_VOLTAGE	Not enough juice to complete job

To turn an error code into a human readable string the following function can be used:

```
__externC const char *cyg_flash_errmsg(const int err);
```

FLASH device API

This section describes the API between the FLASH IO library the FLASH device drivers.

The FLASH device Structure

This structure keeps all the information about a single driver.

```
struct cyg_flash_dev {
    const struct cyg_flash_dev_funs *funs;           // Function pointers
    cyg_uint32 flags;                                // Device characteristics
    cyg_flashaddr_t start;                           // First address
    cyg_flashaddr_t end;                             // Last address
    cyg_uint32 num_block_infos;                      // Number of entries
    const cyg_flash_block_info_t *block_info;        // Info about one block size

    const void *priv;                                // Devices private data

    // The following are only written to by the FLASH IO layer.
    cyg_flash_printf *pf;                            // Pointer to diagnostic printf
    bool init;                                        // Device has been initialised
#ifdef CYGPKG_KERNEL
    cyg_mutex_t mutex;                               // Mutex for thread safeness
#endif
    if (CYGHWI_IO_FLASH_DEVICE > 1)
        struct cyg_flash_dev *next;                 // Pointer to next device
    endif
};

struct cyg_flash_dev_funs {
    int (*flash_init) (struct cyg_flash_dev *dev);
    size_t (*flash_query) (struct cyg_flash_dev *dev, void * data, size_t len);
    int (*flash_erase_block) (struct cyg_flash_dev *dev, cyg_flashaddr_t block_base);
    int (*flash_program) (struct cyg_flash_dev *dev, cyg_flashaddr_t base, const void* data, size_t len);
    int (*flash_read) (struct cyg_flash_dev *dev, const cyg_flashaddr_t base, void* data, size_t len);
#ifdef CYGHWI_IO_FLASH_BLOCK_LOCKING
    int (*flash_block_lock) (struct cyg_flash_dev *dev, const cyg_flashaddr_t block_base);
    int (*flash_block_unlock) (struct cyg_flash_dev *dev, const cyg_flashaddr_t block_base);
#endif
};
```

The FLASH IO layer will only pass requests for operations on a single block.

Chapter 29. The legacy Version 1 eCos FLASH API

The library has a number of limitations:

1. Only one family of FLASH device may be supported at once.
2. Multiple devices of one family are supported, but they must be contiguous in memory.
3. The library is not thread or interrupt safe under some conditions.
4. The library currently does not use the eCos naming convention for its functions. This may change in the future but backward compatibility is likely to be kept.

There are two APIs described here. The first is the application API which programs should use. The second API is that between the FLASH io library and the device drivers.

FLASH user API

All of the functions described below are declared in the header file `<cyg/io/flash.h>` which all users of the FLASH library should include.

Initializing the FLASH library

The FLASH library needs to be initialized before other FLASH operations can be performed. This only needs to be done once. The following function will only do the initialization once so it's safe to call multiple times:

```
externC int flash_init( _printf *pf );
typedef int _printf(const char *fmt, ...);
```

The parameter *pf* is a pointer to a function which is to be used for diagnostic output. Typically the function `diag_printf()` will be passed. Normally this function is not used by the higher layer of the library unless `CYGSEM_IO_FLASH_CHATTER` is enabled. Passing a `NULL` is not recommended, even when `CYGSEM_IO_FLASH_CHATTER` is disabled. The lower layers of the library may unconditionally call this function, especially when errors occur, probably resulting in a more serious error/crash!.

Retrieving information about the FLASH

The following four functions return information about the FLASH.

```
externC int flash_get_block_info(int *block_size, int *blocks);
externC int flash_get_limits(void *target, void **start, void **end);
externC int flash_verify_addr(void *target);
externC bool flash_code_overlaps(void *start, void *end);
```

The function `flash_get_block_info()` returns the size and number of blocks. When the device has a mixture of block sizes, the size of the "normal" block will be returned. Please read the source code to determine exactly what this means. `flash_get_limits()` returns the lower and upper memory address the FLASH occupies. The

target parameter is current unused. `flash_verify_addr()` tests if the target addresses is within the flash, returning `FLASH_ERR_OK` if so. Lastly, `flash_code_overlaps()` checks if the executing code is resident in the section of flash indicated by *start* and *end*. If this function returns true, erase and program operations within this range are very likely to cause the target to crash and burn horribly. Note the FLASH library does allow you to shoot yourself in the foot in this way.

Reading from FLASH

There are two methods for reading from FLASH. The first is to use the following function.

```
externC int flash_read(void *flash_base, void *ram_base, int len, void **err_address);
```

flash_base is where in the flash to read from. *ram_base* indicates where the data read from flash should be placed into RAM. *len* is the number of bytes to be read from the FLASH and *err_address* is used to return the location in FLASH that any error occurred while reading.

The second method is to simply `memcpy()` directly from the FLASH. This is not recommended since some types of device cannot be read in this way, eg NAND FLASH. Using the FLASH library function to read the FLASH will always work so making it easy to port code from one FLASH device to another.

Erasing areas of FLASH

Blocks of FLASH can be erased using the following function:

```
externC int flash_erase(void *flash_base, int len, void **err_address);
```

flash_base is where in the flash to erase from. *len* is the minimum number of bytes to erase in the FLASH and *err_address* is used to return the location in FLASH that any error occurred while erasing. It should be noted that FLASH devices are block oriented when erasing. It is not possible to erase a few bytes within a block, the whole block will be erased. *flash_base* may be anywhere within the first block to be erased and *flash_base+len* may be anywhere in the last block to be erased.

Programming the FLASH

Programming of the flash is achieved using the following function.

```
externC int flash_program(void *flash_base, void *ram_base, int len, void **err_address);
```

flash_base is where in the flash to program from. *ram_base* indicates where the data to be programmed into FLASH should be read from in RAM. *len* is the number of bytes to be program into the FLASH and *err_address* is used to return the location in FLASH that any error occurred while programming.

Locking and unlocking blocks

Some flash devices have the ability to lock and unlock blocks. A locked block cannot be erased or programmed without it first being unlocked. For devices which support this feature and when `CYGHWR_IO_FLASH_BLOCK_LOCKING` is enabled then the following two functions are available:

```
externC int flash_lock(void *flash_base, int len, void **err_address);  
externC int flash_unlock(void *flash_base, int len, void **err_address);
```

Return values and errors

All the functions above, except `flash_code_overlaps()` return one of the following return values.

<code>FLASH_ERR_OK</code>	No error - operation complete
<code>FLASH_ERR_INVALID</code>	Invalid FLASH address
<code>FLASH_ERR_ERASE</code>	Error trying to erase
<code>FLASH_ERR_LOCK</code>	Error trying to lock/unlock
<code>FLASH_ERR_PROGRAM</code>	Error trying to program
<code>FLASH_ERR_PROTOCOL</code>	Generic error
<code>FLASH_ERR_PROTECT</code>	Device/region is write-protected
<code>FLASH_ERR_NOT_INIT</code>	FLASH info not yet initialized
<code>FLASH_ERR_HW</code>	Hardware (configuration?) problem
<code>FLASH_ERR_ERASE_SUSPEND</code>	Device is in erase suspend mode
<code>FLASH_ERR_PROGRAM_SUSPEND</code>	Device is in program suspend mode
<code>FLASH_ERR_DRV_VERIFY</code>	Driver failed to verify data
<code>FLASH_ERR_DRV_TIMEOUT</code>	Driver timed out waiting for device
<code>FLASH_ERR_DRV_WRONG_PART</code>	Driver does not support device
<code>FLASH_ERR_LOW_VOLTAGE</code>	Not enough juice to complete job

To turn an error code into a human readable string the following function can be used:

```
externC char *flash_errmsg(int err);
```

Notes on using the FLASH library

The FLASH library evolved from the needs and environment of RedBoot rather than being a general purpose eCos component. This history explains some of the problems with the library.

The library is not thread safe. Multiple simultaneous calls to its library functions will likely fail and may cause a crash. It is the callers responsibility to use the necessary mutex's if needed.

FLASH device API

This section describes the API between the FLASH IO library the FLASH device drivers.

The flash_info structure

The `flash_info` structure is used by both the FLASH IO library and the device driver.

```
struct flash_info {
    int    block_size;    // Assuming fixed size "blocks"
    int    blocks;        // Number of blocks
    int    buffer_size;   // Size of write buffer (only defined for some devices)
    unsigned long block_mask;
    void *start, *end;    // Address range
    int    init;          // FLASH API initialised
    _printf *pf;          // printf like function for diagnostics
};
```

`block_mask` is used internally in the FLASH IO library. It contains a mask which can be used to turn an arbitrary address in flash to the base address of the block which contains the address.

There exists one global instance of this structure with the name *flash_info*. All calls into the device driver makes use of this global structure to maintain state.

Initializing the device driver

The FLASH IO library will call the following function to initialize the device driver:

```
externC int flash_hwr_init(void);
```

The device driver should probe the hardware to see if the FLASH devices exist. If it does it should fill in *start*, *end*, *blocks* and *block_size*. If the FLASH contains a write buffer the size of this should be placed in *buffer_size*. On successful probing the function should return `FLASH_ERR_OK`. When things go wrong it can be assumed that *pf* points to a printf like function for outputting error messages.

Querying the FLASH

FLASH devices can be queried to return there manufacture ID, size etc. This function allows this information to be returned.

```
int flash_query(unsigned char *data);
```

The caller must know the size of data to be returned and provide an appropriately sized buffer pointed to be parameter *data*. This function is generally used by `flash_hwr_init()`.

Erasing a block of FLASH

So that the FLASH IO layer can erase a block of FLASH the following function should be provided.

```
int flash_erase_block(volatile flash_t *block, unsigned int block_size);
```

Programming a region of FLASH

The following function must be provided so that data can be written into the FLASH.

```
int flash_program_buf(volatile flash_t *addr, flash_t *data, int len,  
                     unsigned long block_mask, int buffer_size);
```

The device will only be asked to program data in one block of the flash. The FLASH IO layer will break longer user requests into a smaller writes.

Reading a region from FLASH

Some FLASH devices are not memory mapped so it is not possible to read there contents directly. The following function read a region of FLASH.

```
int flash_read_buf(volatile flash_t* addr, flash_t* data, int len);
```

As with writing to the flash, the FLASH IO layer will break longer user requests for data into a number of reads which are at maximum one block in size.

A device which cannot be read directly should set `CYGSEM_IO_FLASH_READ_INDIRECT` so that the IO layer makes use of the `flash_read_buf()` function.

Locking and unlocking FLASH blocks

Some flash devices allow blocks to be locked so that they cannot be written to. The device driver should provide the following functions to manipulate these locks.

```
int flash_lock_block(volatile flash_t *block);
int flash_unlock_block(volatile flash_t *block, int block_size, int blocks);
```

These functions are only used if `CYGHWR_IO_FLASH_BLOCK_LOCKING`

Mapping FLASH error codes to FLASH IO error codes

The functions `flash_erase_block()`, `flash_program_buf()`, `flash_read_buf()`, `flash_lock_block()` and `flash_unlock_block()` return an error code which is specific to the flash device. To map this into a FLASH IO error code, the driver should provide the following function:

```
int flash_hwr_map_error(int err);
```

Determining if code is in FLASH

Although a general function, the device driver is expected to provide the implementation of the function `flash_code_overlaps()`.

Implementation Notes

The FLASH IO layer will manipulate the caches as required. The device drivers do not need to enable/disable caches when performing operations of the FLASH.

Device drivers should keep all chatter to a minimum when `CYGSEM_IO_FLASH_CHATTER` is not defined. All output should use the print function in the *pf* in *flash_info* and not `diag_printf()`

Device driver functions which manipulate the state of the flash so that it cannot be read from for program execute need to ensure their code is placed into RAM. The linker will do this if the appropriate attribute is added to the function. e.g:

```
int flash_program_buf(volatile flash_t *addr, flash_t *data, int len,
                    unsigned long block_mask, int buffer_size)
__attribute__((section (".2ram.flash_program_buf")));
```


Chapter 30. FLASH I/O devices

It can be useful to be able to access FLASH devices using the generic I/O infrastructure found in `CYGPKG_IO`, and the generic FLASH layer provides an optional ability to do so. This allows the use of functions like `cyg_io_lookup()`, `cyg_io_read()`, `cyg_io_write()` etc.

Additionally it means that, courtesy of the “devfs” pseudo-filesystem in the file I/O layer (`CYGPKG_IO_FILEIO`), functions like `open()`, `read()`, `write()` etc. can even be used directly on the FLASH devices.

Overview and CDL Configuration

This package implements support for FLASH as an I/O device by exporting it as if it is a block device. To enable this support, the CDL option titled “Provide /dev block devices”, also known as `CYGPKG_IO_FLASH_BLOCK_DEVICE`, must be enabled. (There is also a legacy format alternative which is now deprecated).

There are two methods of addressing FLASH as a block device:

1. Using the FLASH Information System (FIS) - this is a method of defining and naming FLASH partitions, usually in RedBoot. This option is only valid if RedBoot is resident and was used to boot the application. To reference FLASH partitions in this way, you would use a device name of the form `/dev/flash/fis/partition-name`, for example `/dev/flash/fis/jffs2` to reference a FIS partition named JFFS2.

The CDL option `CYGFUN_IO_FLASH_BLOCK_FROM_FIS` must be enabled for this support.

2. Referencing by device number, offset and length - this method extracts addressing information from the name itself. The form of the device would be `/dev/flash/device-number/offset[,length]`

device-number

This is a fixed number allocated to identify each FLASH region in the system. The first region is numbered 0, the second 1, and so on. If you have only one FLASH device, it will be numbered 0.

offset

This is the index into the FLASH region in bytes to use. It may be specified as decimal, or if prefixed with 0x, then hexadecimal.

length

This field is optional and defaults to the remainder of the FLASH region. Again it may be specified in decimal or hexadecimal.

Some examples:

`/dev/flash/0/0`

This defines a block device that uses the entirety of FLASH region 0.

```
/dev/flash/1/0x20000,65536
```

This defines a block device which points inside FLASH region 1, starting at offset 0x20000 (128Kb) and extending for 64Kb.

```
/dev/flash/0/65536
```

This defines a block device which points inside FLASH region 0, starting at offset 64Kb and continuing up to the end of the device.

Obviously great care is required when constructing the device names as using the wrong specification may subsequently overwrite important areas of FLASH, such as RedBoot. Using the alternative via FIS names is preferable as these are less error-prone to configure, and also allows for the FLASH region to be relocated without requiring program recompilation.

Using FLASH I/O devices

The FLASH I/O block devices can be accessed, read and written using the standard interface supplied by the generic I/O (CYGPKG_IO) package. These include the functions: `cyg_io_lookup()` to access the device and get a handle, `cyg_io_read()` and `cyg_io_write()` for sequential read and write operations, `cyg_io_bread()` and `cyg_io_bwrite()` for random access read and write operations, and `cyg_io_get_config()` and `cyg_io_setconfig()` for run-time configuration inspection and control.

However there are two aspects that differ from some other I/O devices accessed this way:

1. The first is that the lookup operation uses up resources which must be subsequently freed when the last user of the I/O handle is finished. The number of FLASH I/O devices that may be simultaneously opened is configured with the `CYGNUM_IO_FLASH_BLOCK_DEVICES` CDL option. After the last user is finished, the device may be closed using `cyg_io_setconfig()` with the `CYG_IO_SET_CONFIG_CLOSE` key. Reference counting to ensure that it is only the last user that causes a close, is left to higher layers.
2. The second is that write operations assume that the flash is already erased. Attempting to write to Flash that has already been written to may result in errors. Instead FLASH must be erased before it may be written.

FLASH block devices can also be read and written using the standard POSIX primitives, `open()`, `close()`, `read()`, `write()`, `lseek()`, and so on if the POSIX file I/O package (CYGPKG_FILEIO) is included in the configuration. As with the eCos generic I/O interface you must call `close()` to ensure resources are freed when the device is no longer used.

Other configuration keys are provided to perform FLASH erase operations, and to retrieve device sizes, and FLASH block sizes at a particular address. These operations are accessed with `cyg_io_get_config()` (or if using the POSIX file I/O API, `cyg_fs_getinfo()`) with the following keys:

```
CYG_IO_GET_CONFIG_FLASH_ERASE
```

This erases a region of FLASH. `cyg_io_get_config()` must be passed a structure defined as per the following, which is also supplied in `<cyg/io/flash.h>`:

```
typedef struct {
    CYG_ADDRESS offset;
    size_t len;
    int flasherr;
    cyg_flashaddr_t err_address;
```

```
} cyg_io_flash_getconfig_erase_t;
```

In this structure, *offset* specifies the offset within the block device to erase, *len* specifies the amount to address, *flasherr* is set on return to specify an error with the FLASH erase operation itself, and *err_address* is used if there was an error to specify at which address the error happened.

CYG_IO_GET_CONFIG_FLASH_LOCK

This protects a region of FLASH using the locking facilities available on the card, if provided by the underlying driver. `cyg_io_get_config()` must be passed a structure defined as per the following:

```
typedef struct {
    CYG_ADDRESS offset;
    size_t len;
    int flasherr;
    cyg_flashaddr_t err_address;
} cyg_io_flash_getconfig_lock_t;
```

In this structure, *offset* specifies the offset within the block device to lock, *len* specifies the amount to address, *flasherr* is set on return to specify an error with the FLASH lock operation itself, and *err_address* is used if there was an error to specify at which address the error happened. If locking support is not available -EINVAL will be returned from `cyg_io_get_config()`.

CYG_IO_GET_CONFIG_FLASH_UNLOCK

This disables protection for a region of FLASH using the unlocking facilities available on the card, if provided by the underlying driver. `cyg_io_get_config()` must be passed a structure defined as per the following:

```
typedef struct {
    CYG_ADDRESS offset;
    size_t len;
    int flasherr;
    cyg_flashaddr_t err_address;
} cyg_io_flash_getconfig_unlock_t;
```

In this structure, *offset* specifies the offset within the block device to unlock, *len* specifies the amount to address, *flasherr* is set on return to specify an error with the FLASH unlock operation itself, and *err_address* is used if there was an error to specify at which address the error happened. If unlocking support is not available -EINVAL will be returned from `cyg_io_get_config()`.

CYG_IO_GET_CONFIG_FLASH_DEVSZ

This returns the size of the FLASH block device. The `cyg_io_get_config()` function must be passed a structure defined as per the following, which is also supplied in `<cyg/io/flash.h>`:

```
typedef struct {
    size_t dev_size;
} cyg_io_flash_getconfig_devsize_t;
```

In this structure, *dev_size* is used to return the size of the FLASH device.

CYG_IO_GET_CONFIG_FLASH_DEVADDR

This returns the address in the virtual memory map that the generic flash layer has been informed that this FLASH device is mapped to. Note that some flash devices such as dataflash are not truly memory mapped, and so this function only returns useful information when used with a true memory mapped FLASH device. The `cyg_io_get_config()` function must be passed a structure defined as per the following, which is also supplied in `<cyg/io/flash.h>`:

```
typedef struct {
    cyg_flashaddr_t dev_addr;
} cyg_io_flash_getconfig_devaddr_t;
```

In this structure, *dev_addr* is used to return the address corresponding to the base of the FLASH device in the virtual memory map.

CYG_IO_GET_CONFIG_FLASH_BLOCKSIZE

This returns the size of a FLASH block at a supplied offset in the FLASH block device. The `cyg_io_get_config()` function must be passed a structure defined as per the following, which is also supplied in `<cyg/io/flash.h>`:

```
typedef struct {
    CYG_ADDRESS offset;
    size_t block_size;
} cyg_io_flash_getconfig_blocksize_t;
```

In this structure, *offset* specifies the address within the block device of which the FLASH block size is required - a single FLASH device may contain blocks of differing sizes. The *block_size* field is used to return the block size at the specified offset.

VIII. SPI Support

Overview

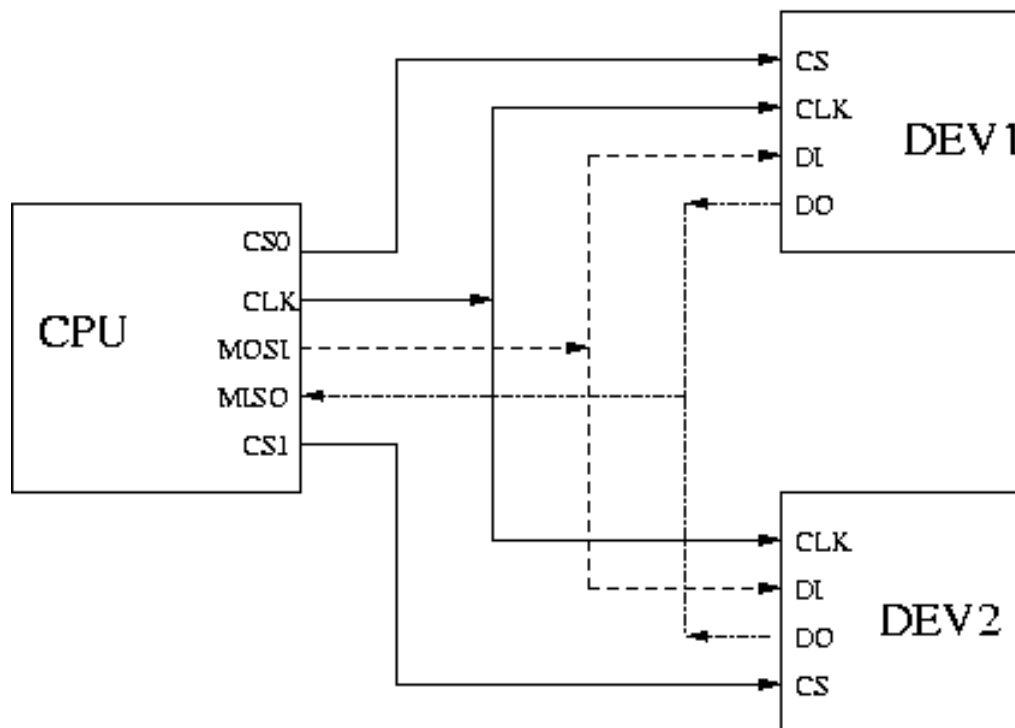
Name

Overview — eCos Support for SPI, the Serial Peripheral Interface

Description

The Serial Peripheral Interface (SPI) is one of a number of serial bus technologies. It can be used to connect a processor to one or more peripheral chips, for example analog-to-digital convertors or real time clocks, using only a small number of pins and PCB tracks. The technology was originally developed by Motorola but is now also supported by other vendors.

A typical SPI system might look like this:



At the start of a data transfer the master cpu asserts one of the chip select signals and then generates a clock signal. During each clock tick the cpu will output one bit on its master-out-slave-in line and read one bit on the master-in-slave-out line. Each device is connected to the clock line, the two data lines, and has its own chip select. If a device's chip select is not asserted then it will ignore any incoming data and will tristate its output. If a device's chip select is asserted then during each clock tick it will read one bit of data on its input pin and output one bit on its output pin.

The net effect is that the cpu can write an arbitrary amount of data to one of the attached devices at a time, and simultaneously read the same amount of data. Some devices are inherently uni-directional. For example an LED unit would only accept data from the cpu: it will not send anything meaningful back; the cpu will still sample its input every clock tick, but this should be discarded.

A useful feature of SPI is that there is no flow control from the device back to the cpu. If the cpu tries to communicate with a device that is not currently present, for example an MMC socket which does not contain

a card, then the I/O will still proceed. However the cpu will read random data. Typically software-level CRC checksums or similar techniques will be used to allow the cpu to detect this.

SPI communication is not fully standardized. Variations between devices include the following:

1. Many devices involve byte transfers, where the unit of data is 8 bits. Others use larger units, up to 16 bits.
2. Chip selects may be active-high or active-low. If the attached devices use a mixture of polarities then this can complicate things.
3. Clock rates can vary from 128KHz to 20MHz or greater. With some devices it is necessary to interrogate the device using a slow clock, then use the obtained information to select a faster clock for subsequent transfers.
4. The clock is inactive between data transfers. When inactive the clock's polarity can be high or low.
5. Devices depend on the phase of the clock. Data may be sampled on either the rising edge or the falling edge of the clock.
6. A device may need additional delays, for example between asserting the chip select and the first clock tick.
7. Some devices involve complicated transactions: perhaps a command from cpu to device; then an initial status response from the device; a data transfer; and a final status response. From the cpu's perspective these are separate stages and it may be necessary to abort the operation after the initial status response. However the device may require that the chip select remain asserted for the whole transaction. A side effect of this is that it is not possible to do a quick transfer with another device in the middle of the transaction.
8. Certain devices, for example MMC cards, depend on a clock signal after a transfer has completed and the chip select has dropped. This clock is used to finish some processing within the device.

Inside the cpu the clock and data signals are usually managed by dedicated hardware. Alternatively SPI can be implemented using bit-banging, but that approach is normally used for other serial bus technologies such as I2C. The chip selects may also be implemented by the dedicated SPI hardware, but often GPIO pins are used instead.

eCos Support for SPI

The eCos SPI support for any given platform is spread over a number of different packages:

- This package, `CYGPKG_IO_SPI`, exports an API for accessing devices attached to an SPI bus. This API handles issues such as locking between threads. The package does not contain any hardware-specific code, instead it will call into an SPI bus driver package.

In future this package may be extended with a bit-banging implementation of an SPI bus driver. This would depend on lower-level code for manipulating the GPIO pins used for the clock, data and chip select signals, but timing and framing could be handled by generic code.

- There will be a bus driver package for the specific SPI hardware on the target hardware, for example `CYGPKG_DEVS_SPI_MCF52xx_QSPI`. This is responsible for the actual I/O. A bus driver may be used on many different boards, all with the same SPI bus but with different devices attached to that bus. Details of the actual devices should be supplied by other code.
- The generic API depends on `cyg_spi_device` data structures. These contain the information needed by a bus driver, for example the appropriate clock rate and the chip select to use. Usually the data structures are provided by the platform HAL since it is that package which knows about all the devices on the board.

On some development boards the SPI pins are brought out to expansion connectors, allowing end users to add extra devices. In such cases the platform HAL may not know about all the devices on the board. Data structures for the additional devices can instead be supplied by application code.

- Some types of SPI devices may have their own driver package. For example one common use for SPI buses is to provide low-cost MultiMediaCard (MMC) support. An MMC is a non-trivial device so there is an eCos package specially for that, providing a block device interface for higher-level code such as file systems. Other SPI devices such as analog-to-digital converters are much simpler and come in many varieties. There are no dedicated packages to support each such device: the chances are low that another board would use the exact same device, so there are no opportunities for code re-use. Instead the devices may be accessed directly by application code or by extra functions in the platform HAL.

Typically all appropriate packages will be loaded automatically when you configure eCos for a given target. If the application does not use any of the SPI I/O facilities, directly or indirectly, then linker garbage collection should eliminate all unnecessary code and data. All necessary initialization should happen automatically. However the exact details may depend on the target, so the platform HAL documentation should be checked for further details.

There is one important exception to this: if the SPI devices are attached to an expansion connector then the platform HAL will not know about these devices. Instead more work will have to be done by application code.

SPI Interface

Name

SPI Functions — allow applications and other packages to access SPI devices

Synopsis

```
#include <cyg/io/spi.h>

void cyg_spi_transfer(cyg_spi_device* device, cyg_bool polled, cyg_uint32 count, const
cyg_uint8* tx_data, cyg_uint8* rx_data);
void cyg_spi_tick(cyg_spi_device* device, cyg_bool polled, cyg_uint32 count);
int cyg_spi_get_config(cyg_spi_device* device, cyg_uint32 key, void* buf, cyg_uint32*
len);
int cyg_spi_set_config(cyg_spi_device* device, cyg_uint32 key, const void* buf,
cyg_uint32* len);
void cyg_spi_transaction_begin(cyg_spi_device* device);
cyg_bool cyg_spi_transaction_begin_nb(cyg_spi_device* device);
void cyg_spi_transaction_transfer(cyg_spi_device* device, cyg_bool polled, cyg_uint32
count, const cyg_uint8* tx_data, cyg_uint8* rx_data, cyg_bool drop_cs);
void cyg_spi_transaction_tick(cyg_spi_device* device, cyg_bool polled, cyg_uint32
count);
void cyg_spi_transaction_end(cyg_spi_device* device);
```

Description

All SPI functions take a pointer to a `cyg_spi_device` structure as their first argument. This is an opaque data structure, usually provided by the platform HAL. It contains the information needed by the SPI bus driver to interact with the device, for example the required clock rate and polarity.

An SPI transfer involves the following stages:

1. Perform thread-level locking on the bus. Only one thread at a time is allowed to access an SPI bus. This eliminates the need to worry about locking at the bus driver level. If a platform involves multiple SPI buses then each one will have its own lock. Prepare the bus for transfers to the specified device, for example by making sure it will tick at the right clock rate.
2. Assert the chip select on the specified device, then transfer data to and from the device. There may be a single data transfer or a sequence. It may or may not be necessary to keep the chip select asserted throughout a sequence.
3. Optionally generate some number of clock ticks without asserting a chip select, for those devices which need this to complete an operation.
4. Return the bus to a quiescent state. Then unlock the bus, allowing other threads to perform SPI operations on devices attached to this bus.

The simple functions `cyg_spi_transfer` and `cyg_spi_tick` perform all these steps in a single call. These are suitable for simple I/O operations. The alternative transaction-oriented functions each perform just one of these steps. This makes it possible to perform multiple transfers while only locking and unlocking the bus once, as required for more complicated devices.

With the exception of `cyg_spi_transaction_begin_nb` all the functions will block until completion. There are no error conditions. An SPI transfer will always take a predictable amount of time, depending on the transfer size and the clock rate. The SPI bus does not receive any feedback from a device about possible errors, instead those have to be handled by software at a higher level. If a thread cannot afford the time it will take to perform a complete large transfer then a number of smaller transfers can be used instead.

SPI operations should always be performed at thread-level or during system initialization, and not inside an ISR or DSR. This greatly simplifies locking. Also a typical ISR or DSR should not perform a blocking operation such as an SPI transfer.

SPI transfers can happen in either polled or interrupt-driven mode. Typically polled mode should be used during system initialization, before the scheduler has been started and interrupts have been enabled. Polled mode should also be used in single-threaded applications such as RedBoot. A typical multi-threaded application should normally use interrupt-driven mode because this allows for more efficient use of cpu cycles. Polled mode may be used in a multi-threaded application but this is generally undesirable: the cpu will spin while waiting for a transfer to complete, wasting cycles; also the current thread may get preempted or timesliced, making the timing of an SPI transfer much less predictable. On some hardware interrupt-driven mode is impossible or would be very inefficient. In such cases the bus drivers will only support polled mode and will ignore the `polled` argument.

Simple Transfers

`cyg_spi_transfer` can be used for SPI operations to simple devices. It takes the following arguments:

`cyg_spi_device* device`

This identifies the SPI device that should be used.

`cyg_bool polled`

Polled mode should be used during system initialization and in a single-threaded application. Interrupt-driven mode should normally be used in a multi-threaded application.

`cyg_uint32 count`

This identifies the number of data items to be transferred. Usually each data item is a single byte, but some devices use a larger size up to 16 bits.

`const cyg_uint8* tx_data`

The data to be transferred to the device. If the device will only output data and ignore its input then a null pointer can be used. Otherwise the array should contain `count` data items, usually bytes. For devices where each data item is larger than one byte the argument will be interpreted as an array of shorts instead, and should be aligned to a 2-byte boundary. The bottom `n` bits of each short will be sent to the device. The buffer need not be aligned to a cache-line boundary, even for SPI devices which use DMA transfers, but some bus drivers may provide better performance if the buffer is suitably aligned. The buffer will not be modified by the transfer.

`cyg_uint8* rx_data`

A buffer for the data to be received from the device. If the device does not generate any output then a null pointer can be used. The same size and alignment rules apply as for `tx_data`.

`cyg_spi_transfer` performs all the stages of an SPI transfer: locking the bus; setting it up correctly for the specified device; asserting the chip select and transferring the data; dropping the chip select at the end of the transfer; returning the bus to a quiescent state; and unlocking the bus.

Additional Clock Ticks

Some devices require a number of clock ticks on the SPI bus between transfers so that they can complete some internal processing. These ticks must happen at the appropriate clock rate but no chip select should be asserted and no data transfer will happen. `cyg_spi_tick` provides this functionality. The `device` argument identifies the SPI bus, the required clock rate and the size of each data item. The `polled` argument has the usual meaning. The `count` argument specifies the number of data items that would be transferred, which in conjunction with the size of each data item determines the number of clock ticks.

Transactions

A transaction-oriented API is available for interacting with more complicated devices. This provides separate functions for each of the steps in an SPI transfer.

`cyg_spi_transaction_begin` must be used at the start of a transaction. This performs thread-level locking on the bus, blocking if it is currently in use by another thread. Then it prepares the bus for transfers to the specified device, for example by making sure it will tick at the right clock rate.

`cyg_spi_transaction_begin_nb` is a non-blocking variant, useful for threads which cannot afford to block for an indefinite period. If the bus is currently locked the function returns false immediately. If the bus is not locked then it acts as `cyg_spi_transaction_begin` and returns true.

Once the bus has been locked it is possible to perform one or more data transfers by calling `cyg_spi_transaction_transfer`. This takes the same arguments as `cyg_spi_transfer`, plus an additional one `drop_cs`. A non-zero value specifies that the device's chip select should be dropped at the end of the transfer, otherwise the chip select remains asserted. It is essential that the chip select be dropped in the final transfer of a transaction. If the protocol makes this difficult then `cyg_spi_transaction_tick` can be used to generate dummy ticks with all chip selects dropped.

If the device requires additional clock ticks in the middle of a transaction without being selected, `cyg_spi_transaction_tick` can be used. This will drop the device's chip select if necessary, then generate the appropriate number of ticks. The arguments are the same as for `cyg_spi_tick`.

`cyg_spi_transaction_end` should be called at the end of a transaction. It returns the SPI bus to a quiescent state, then unlocks it so that other threads can perform I/O.

A typical transaction might involve the following. First a command should be sent to the device, consisting of four bytes. The device will then respond with a single status byte, zero for failure, non-zero for success. If successful then the device can accept another `n` bytes of data, and will generate a 2-byte response including a checksum. The device's chip select should remain asserted throughout. The code for this would look something like:

```
#include <cyg/io/spi.h>
#include <cyg/hal/hal_io.h>    // Defines the SPI devices
...
cyg_spi_transaction_begin(&hal_spi_eprom);
// Interrupt-driven transfer, four bytes of command
cyg_spi_transaction_transfer(&hal_spi_eprom, 0, 4, command, NULL, 0);
// Read back the status
cyg_spi_transaction_transfer(&hal_spi_eprom, 0, 1, NULL, status, 0);
if (!status[0]) {
    // Command failed, generate some extra ticks to drop the chip select
    cyg_spi_transaction_tick(&hal_spi_eprom, 0, 1);
} else {
    // Transfer the data, then read back the final status. The
    // chip select should be dropped at the end of this.
    cyg_spi_transaction_transfer(&hal_spi_eprom, 0, n, data, NULL, 0);
}
```

```

        cyg_spi_transaction_transfer(&hal_spi_eprom, 0, 2, NULL, status, 1);
        // Code for checking the final status should go here
    }
    // Transaction complete so clean up
    cyg_spi_transaction_end(&hal_spi_eprom);

```

A number of variations are possible. For example the command and status could be packed into the beginning and end of two 5-byte arrays, allowing a single transfer.

Device Configuration

The functions `cyg_spi_get_config` and `cyg_spi_set_config` can be used to examine and change parameters associated with SPI transfers. The only keys that are defined for all devices are `CYG_IO_GET_CONFIG_SPI_CLOCKRATE` and `CYG_IO_SET_CONFIG_SPI_CLOCKRATE`. Some types of device, for example MMC cards, support a range of clock rates. The `cyg_spi_device` structure will be initialized with a low clock rate. During system initialization the device will be queried for the optimal clock rate, and the `cyg_spi_device` should then be updated. The argument should be a clock rate in Hertz. For example the following code switches communication to 1Mbit/s:

```

cyg_uint32    new_clock_rate = 1000000;
cyg_uint32    len            = sizeof(cyg_uint32);
if (cyg_spi_set_config(&hal_mmc_device,
                      CYG_IO_SET_CONFIG_SPI_CLOCKRATE,
                      (const void *)&new_clock_rate, &len)) {
    // Error recovery code
}

```

If an SPI bus driver does not support the exact clock rate specified it will normally use the nearest valid one. SPI bus drivers may define additional keys appropriate for specific hardware. This means that the valid keys are not known by the generic code, and theoretically it is possible to use a key that is not valid for the SPI bus to which the device is attached. It is also possible that the argument used with one of these keys is invalid. Hence both `cyg_spi_get_config` and `cyg_spi_set_config` can return error codes. The return value will be 0 for success, non-zero for failure. The SPI bus driver's documentation should be consulted for further details.

Both configuration functions will lock the bus, in the same way as `cyg_spi_transfer`. Changing the clock rate in the middle of a transfer or manipulating other parameters would have unexpected consequences.

Porting to New Hardware

Name

Porting — Adding SPI support to new hardware

Description

Adding SPI support to an eCos port can take two forms. If there is already an SPI bus driver for the target hardware then both that driver and this generic SPI package `CYGPKG_IO_SPI` should be included in the `ecos.db` target entry. Typically the platform HAL will need to supply some platform-specific information needed by the bus driver. In addition the platform HAL should provide `cyg_spi_device` structures for every device attached to the bus. The exact details of this depend on the bus driver so its documentation should be consulted for further details. If there is no suitable SPI bus driver yet then a new driver package will have to be written.

Adding a Device

The generic SPI package `CYGPKG_IO_SPI` defines a data structure `cyg_spi_device`. This contains the information needed by the generic package, but not the additional information needed by a bus driver to interact with the device. Each bus driver will define a larger data structure, for example `cyg_mcf52xx_qspi_device`, which contains a `cyg_spi_device` as its first field. This is analogous to C++ base and derived classes, but without any use of virtual functions. The bus driver package should be consulted for the details.

During initialization an SPI bus driver may need to know about all the devices attached to that bus. For example it may need to know which cpu pins should be configured as chip selects rather than GPIO pins. To achieve this all device definitions should specify the particular bus to which they are attached, for example:

```
struct cyg_mcf52xx_qspi_device hal_spi_atod CYG_SPI_DEVICE_ON_BUS(0) =
{
    .spi_common.spi_bus = &cyg_mcf52xx_qspi_bus,
    ...
};
```

The `CYG_SPI_DEVICE_ON_BUS` macro adds information to the structure which causes the linker to group all such structures in a single table. The bus driver's initialization code can then iterate over this table.

Adding Bus Support

An SPI bus driver usually involves a new hardware package. This needs to perform the following:

1. Define a device structure which contains a `cyg_spi_device` as its first element. This should contain all the information needed by the bus driver to interact with a device on that bus.
2. Provide functions for the following operations:

```
spi_transaction_begin
spi_transaction_transfer
spi_transaction_tick
spi_transaction_end
spi_get_config
spi_set_config
```

These correspond to the main API functions, but can assume that the bus is already locked so no other

thread will be manipulating the bus or any of the attached devices. Some of these operations may be no-ops.

3. Define a bus structure which contains a `cyg_spi_bus` as its first element. This should contain any additional information needed by the bus driver.
4. Optionally, instantiate the bus structure. The instance should have a well-known name since it needs to be referenced by the device structure initializers. For some drivers it may be best to create the bus inside the driver package. For other drivers it may be better to leave this to the platform HAL or the application. It depends on how much platform-specific knowledge is needed to fill in the bus structure.
5. Create a HAL table for the devices attached to this bus.
6. Arrange for the bus to be initialized early on during system initialization. Typically this will happen via a prioritized static constructor with priority `CYG_INIT_BUS_SPI`. As part of this initialization the bus driver should invoke the `CYG_SPI_BUS_COMMON_INIT` macro on its `cyg_spi_bus` field.
7. Provide the appropriate documentation, including details of how the SPI device structures should be initialized.

There are no standard SPI testcases. It is not possible to write SPI code without knowing about the devices attached to the bus, and those are inherently hardware-specific.

IX. I2C Support

Overview

Name

Overview — eCos Support for I2C, the Inter IC Bus

Description

The Inter IC Bus (I2C) is one of a number of serial bus technologies. It can be used to connect a processor to one or more peripheral chips, for example analog-to-digital convertors or real time clocks, using only a small number of pins and PCB tracks. The technology was originally developed by Philips Semiconductors but is supported by many other vendors. The bus specification is freely available.

In a typical I2C system the processor acts as the I2C bus master. The peripheral chips act as slaves. The bus consists of just two wires: SCL carries a clock signal generated by the master, and SDA is a bi-directional data line. The normal clock frequency is 100KHz. Each slave has a 7-bit address. With some chips the address is hard-wired, and it is impossible to have two of these chips on the same bus. With other chips it is possible to choose between one of a small number of addresses by connecting spare pins to either VDD or GND.

An I2C data transfer involves a number of stages:

1. The bus master generates a start condition, a high-to-low transition on the SDA line while SCL is kept high. This signalling cannot occur during data transfer.
2. The bus master clocks the 7-bit slave address onto the SDA line, followed by a direction bit to distinguish between reads and writes.
3. The addressed device acknowledges. If the master does not see an acknowledgement then this suggests it is using the wrong address for the slave device.
4. If the master is transmitting data to the slave then it will send this data one byte at a time. The slave acknowledges each byte. If the slave is unable to accept more data, for example because it has run out of buffer space, then it will generate a nack and the master should stop sending.
5. If the master is receiving data from the slave then the slave will send this data one byte at a time. The master should acknowledge each byte, until the last one. When the master has received all the data it wants it should generate a nack and the slave will stop sending. This nack is essential because it causes the slave to stop driving the SDA line, releasing it back to the master.
6. It is possible to switch direction in a single transfer, using what is known as a repeated start. This involves generating another start condition, sending the 7-bit address again, followed by a new direction bit.
7. At the end of a transfer the master should generate a stop condition, a low-to-high transition on the SDA line while SCL is kept high. Again this signalling does not occur at other times.

There are a number of extensions. The I2C bus supports multiple bus masters and there is an arbitration procedure to allow a master to claim the bus. Some devices can have 10-bit addresses rather than 7-bit addresses. There is a fast mode operating at 400KHz instead of the usual 100KHz, and a high-speed mode operating at 3.4MHz. Currently most I2C-based systems do not involve any of these extensions.

At the hardware level I2C bus master support can be implemented in one of two ways. Some processors provide a dedicated I2C device, with the hardware performing much of the work. On other processors the I2C device is implemented in software, by bit-banging some GPIO pins. The latter approach can consume a significant number of cpu cycles, but is often acceptable because only occasional access to the I2C devices is needed.

eCos Support for I2C

The eCos I2C support for any given platform is spread over a number of different packages:

- This package, `CYGPKG_IO_I2C`, exports a generic API for accessing devices attached to an I2C bus. This API handles issues such as locking between threads. The package does not contain any hardware-specific code. Instead it will use a separate I2C bus driver to handle the hardware, and it defines the interface that such bus drivers should provide. The package only provides support for a bus master, not for acting as a slave device.

`CYGPKG_IO_I2C` also provides the hardware-independent portion of a bit-banged bus implementation. This needs to be complemented by a hardware-specific function that actually manipulates the SDA and SCL lines.

- If the processor has a dedicated I2C device then there will be a bus driver package for that hardware. The processor may be used on many different platforms and the same bus driver can be used on each one. The actual I2C devices attached to the bus will vary from one platform to the next.
- The generic API depends on `cyg_i2c_device` data structures. These contain the information needed by a bus driver, for example the device address. Usually the data structures are provided by the platform HAL since it is that package which knows about all the devices on the platform.

On some development boards the I2C lines are brought out to expansion connectors, allowing end users to add extra devices. In such cases the platform HAL may not know about all the devices on the board. Data structures for the additional devices can instead be supplied by application code.

- If the board uses a bit-banged bus then typically the platform HAL will also instantiate the bus instance, providing the function that handles the low-level SDA and SCL manipulation. Usually this code cannot be shared because each board may use different GPIO pins for driving SCL and SDA, so the code belongs in the platform HAL rather than in a separate package.
- Some types of I2C devices may have their own driver package. For example a common type of I2C device is a battery-backed wallclock, and eCos defines how these devices should be supported. Such an I2C device will have its own wallclock device driver and the device will not be accessed directly by application code. For other types of device eCos does not define an API and there will not be separate device driver packages. Instead application code is expected to use the `cyg_i2c_device` structures directly to access the hardware.

Typically all appropriate packages will be loaded automatically when you configure eCos for a given platform. If the application does not use any of the I2C I/O facilities, directly or indirectly, then linker garbage collection should eliminate all unnecessary code and data. All necessary initialization should happen automatically. However the exact details may depend on the platform, so the platform HAL documentation should be checked for further details.

There is one important exception to this: if the I2C devices are attached to an expansion connector then the platform HAL will not know about these devices. Instead more work will have to be done by application code.

I2C Interface

Name

I2C Functions — allow applications and other packages to access I2C devices

Synopsis

```
#include <cyg/io/i2c.h>

cyg_uint32 cyg_i2c_tx(const cyg_i2c_device* device, const cyg_uint8* tx_data,
cyg_uint32 count);
cyg_uint32 cyg_i2c_rx(const cyg_i2c_device* device, cyg_uint8* rx_data, cyg_uint32
count);
void cyg_i2c_transaction_begin(const cyg_i2c_device* device);
cyg_bool cyg_i2c_transaction_begin_nb(const cyg_i2c_device* device);
cyg_uint32 cyg_i2c_transaction_tx(const cyg_i2c_device* device, cyg_bool send_start,
const cyg_uint8* tx_data, cyg_uint32 count, cyg_bool send_stop);
cyg_uint32 cyg_i2c_transaction_rx(const cyg_i2c_device* device, cyg_bool send_start,
cyg_uint8* rx_data, cyg_uint32 count, cyg_bool send_nack, cyg_bool send_stop);
void cyg_i2c_transaction_stop(const cyg_i2c_device* device);
void cyg_i2c_transaction_end(const cyg_i2c_device* device);
```

Description

All I2C functions take a pointer to a `cyg_i2c_device` structure as their first argument. These structures are usually provided by the platform HAL. They contain the information needed by the I2C bus driver to interact with the device, for example the device address.

An I2C transaction involves the following stages:

1. Perform thread-level locking on the bus. Only one thread at a time is allowed to access an I2C bus. This eliminates the need to worry about locking at the bus driver level. If a platform involves multiple I2C buses then each one will have its own lock.
2. Generate a start condition, send the address and direction bit, and wait for an acknowledgement from the addressed device.
3. Either transmit data to or receive data from the addressed device.
4. The previous two steps may be repeated several times, allowing data to move in both directions during a single transfer.
5. Generate a stop condition, ending the current data transfer. It is now possible to start another data transfer while the bus is still locked, if desired.
6. End the transaction by unlocking the bus, allowing other threads to access other devices on the bus.

The simple functions `cyg_i2c_tx` and `cyg_i2c_rx` perform all these steps in a single call, making them suitable for many I/O operations. The alternative transaction-oriented functions provide greater control when appropriate, for example if a repeated start is necessary for a bi-directional data transfer.

With the exception of `cyg_i2c_transaction_begin_nb` all the functions will block until completion. The tx routines will return 0 if the specified device does not respond to its address, or the number of bytes actually

transferred. This may be less than the number requested if the device sends an early nack, for example because it has run out of buffer space. The rx routines will return 0 or the number of bytes received. Usually this will be the same as the `count` parameter. A slave device has no way of indicating to the master that no more data is available, so the rx operation cannot complete early.

I2C operations should always be performed at thread-level or during system initialization, and not inside an ISR or DSR. This greatly simplifies locking. Also a typical ISR or DSR should not perform a blocking operation such as an I2C transfer.

Simple Transfers

`cyg_i2c_tx` and `cyg_i2c_rx` can be used for simple data transfers. They both go through the following steps: lock the bus, generate the start condition, send the device address and the direction bit, either send or receive the data, generate the stop condition, and unlock the bus. At the end of a transfer the bus is back in its idle state, ready for the next transfer.

`cyg_i2c_tx` returns the number of bytes actually transmitted. This may be 0 if the device does not respond when its address is sent out. It may be less than the number of bytes requested if the device generates an early nack, typically because it has run out of buffer space.

`cyg_i2c_rx` returns 0 if the device does not respond when its address is sent out, or the number of bytes actually received. Usually this will be the number of bytes requested because an I2C slave device has no way of aborting an rx operation early.

Transactions

To allow multiple threads to access devices on the I2C some locking is required. This is encapsulated inside transactions. The `cyg_i2c_tx` and `cyg_i2c_rx` functions implicitly use such transactions, but the functionality is also available directly to application code. Amongst other things transactions can be used for more complicated interactions with I2C devices, in particular ones involving repeated starts.

`cyg_i2c_transaction_begin` must be used at the start of a transaction. This performs thread-level locking on the bus, blocking if it is currently in use by another thread.

`cyg_i2c_transaction_begin_nb` is a non-blocking variant, useful for threads which cannot afford to block for an indefinite period. If the bus is currently locked the function returns false immediately. If the bus is not locked then it acts as `cyg_i2c_transaction_begin` and returns true.

Once the bus has been locked it is possible to perform one or more data transfers by calling `cyg_i2c_transaction_tx`, `cyg_i2c_transaction_rx` and `cyg_i2c_transaction_stop`. Code should ensure that a stop condition has been generated by the end of a transaction.

Once the transaction is complete `cyg_i2c_transaction_end` should be called. This unlocks the bus, allowing other threads to perform I2C I/O to devices on the same bus.

As an example consider reading the registers in an FS6377 programmable clock generator. The first step is to write a byte 0 to the device, setting the current register to 0. Then a repeated start condition should be generated and it is possible to read the 16 byte-wide registers, starting with the current one. Typical code for this might look like:

```
cyg_uint8  tx_data[1];
cyg_uint8  rx_data[16];

cyg_i2c_transaction_begin(&hal_alai2c_fs6377);
tx_data[0] = 0x00;
cyg_i2c_transaction_tx(&hal_alai2c_fs6377,
```



```

        true, tx_data, 1, false);
cyg_i2c_transaction_rx(&hal_alaiia_i2c_fs6377,
        true, rx_data, 16, true, true);
cyg_i2c_transaction_end(&hal_alaiia_i2c_fs6377);

```

Here `hal_alaiia_i2c_fs6377` is a `cyg_i2c_device` structure provided by the platform HAL. A transaction is begun, locking the bus. Then there is a transmit for a single byte. This transmit involves generating a start condition and sending the address and direction bit, but not a stop condition. Next there is a receive for 16 bytes. This also involves a start condition, which the device will interpret as a repeated start because it has not yet seen a stop. The start condition will be followed by the address and direction bit, and then the device will start transmitting the register contents. Once all 16 bytes have been received the rx routine will send a nack rather than an ack, halting the transfer, and then a stop condition is generated. Finally the transaction is ended, unlocking the bus.

The arguments to `cyg_i2c_transaction_tx` are as follows:

```
const cyg_i2c_device* device
```

This identifies the I2C device that should be used.

```
cyg_bool send_start
```

If true, generate a start condition and send the address and direction bit. If false, skip those steps and go straight to transmitting the actual data. The latter can be useful if the data to be transmitted is spread over several buffers. The first tx call will involve generating the start condition but subsequent tx calls can skip this and just continue from the previous one.

`send_start` must be true if the tx call is the first operation in a transaction, or if the previous call was an rx or stop.

```
const cyg_uint8* tx_data
cyg_uint32 count
```

These arguments specify the data to be transmitted to the device.

```
cyg_bool send_stop
```

If true, generate a stop condition at the end of the transmit. Usually this is done only if the transmit is the last operation in a transaction.

The arguments to `cyg_i2c_transaction_rx` are as follows:

```
const cyg_i2c_device* device
```

This identifies the I2C device that should be used.

```
cyg_bool send_start
```

If true, generate a start condition and send the address and direction bit. If false, skip those steps and go straight to receiving the actual data. The latter can be useful if the incoming data should be spread over several buffers. The first rx call will involve generating the start condition but subsequent rx calls can skip this and just continue from the previous one. Another use is for devices which can send variable length data, consisting of an initial length and then the actual data. The first rx will involve generating the start condition and reading the length, a subsequent rx will then just read the data.

`send_start` must be true if the rx call is the first operation in a transaction, if the previous call was a tx or stop, or if the previous call was an rx and the `send_nack` flag was set.

```
cyg_uint8* rx_data  
cyg_uint32 count
```

These arguments specify how much data should be received and where it should be placed.

```
cyg_bool send_nack
```

If true generate a nack instead of an ack for the last byte received. This causes the slave to end its transmit. The next operation should either involve a repeated start or a stop. `send_nack` should be set to false only if `send_stop` is also false, the next operation will be another rx, and that rx does not specify `send_start`.

```
cyg_bool send_stop
```

If true, generate a stop condition at the end of the transmit. Usually this is done only if the transmit is the last operation in a transaction.

The final transaction-oriented function is `cyg_i2c_transaction_stop`. This just generates a stop condition. It should be used if the previous operation was a tx or rx that, for some reason, did not set the `send_stop` flag. A stop condition must be generated before the transaction is ended.

Initialization

The generic package `CYGPKG_IO_I2C` arranges for all I2C bus devices to be initialized via a single prioritized C++ static constructor. This constructor will run early on during system startup, before any application code, with priority `CYG_INIT_BUS_I2C`. Other code should not try to access any of the I2C devices until after the buses have been initialized.

Porting to New Hardware

Name

Porting — Adding I2C support to new hardware

Description

Adding I2C support to an eCos port involves a number of steps. The generic I2C package `CYGPKG_IO_I2C` should be included in the appropriate `ecos.db` target entry or entries. Next `cyg_i2c_device` structures should be provided for every device on the bus. Usually this is the responsibility of the platform HAL. In the case of development boards where the I2C SDA and SCL lines are accessible via an expansion connector, more devices may have been added and it will be the application's responsibility to provide the structures. Finally there is a need for one or more `cyg_i2c_bus` structures. Amongst other things these structures provide functions for actually driving the bus. If the processor has dedicated I2C hardware then this structure will usually be provided by a device driver package. If the bus is implemented by bit-banging then the bus structure will usually be provided by the platform HAL.

Adding a Device

The eCos I2C API works in terms of `cyg_i2c_device` structures, and these provide the information needed to access the hardware. A `cyg_i2c_device` structure contains the following fields:

`cyg_i2c_bus* i2c_bus`

This specifies the bus which the slave device is connected to. Most boards will only have a single I2C bus, but multiple buses are possible.

`cyg_uint16 i2c_address`

For most devices this will be the 7-bit I2C address the device will respond to. There is room for future expansion, for example to support 10-bit addresses.

`cyg_uint16 i2c_flags`

This field is not used at present. It exists for future expansion, for example to allow for fast mode or high-speed mode, and incidentally pads the structure to a 32-bit boundary.

`cyg_uint32 i2c_delay`

This holds the clock period which should be used when interacting with the device, in nanoseconds. Usually this will be 10000 ns, corresponding to a 100KHz clock, and the header `cyg/io/i2c.h` provides a `#define CYG_I2C_DEFAULT_DELAY` for this. Sometimes it may be desirable to use a slower clock, for example to reduce noise problems.

The normal way to instantiate a `cyg_i2c_device` structure uses the `CYG_I2C_DEVICE` macro, also provided by `cyg/io/i2c.h`:

```
#include <cyg/io/i2c.h>
```

```
CYG_I2C_DEVICE(cyg_i2c_wallclock_ds1307,  
               &hal_aliaia_i2c_bus,  
               0x68,  
               0x00,
```

```

        CYG_I2C_DEFAULT_DELAY);

CYG_I2C_DEVICE(hal_alaia_i2c_fs6377,
               &hal_alaia_i2c_bus,
               0x58,
               0x00,
               CYG_I2C_DEFAULT_DELAY);

```

The arguments to the macro are the variable name, an I2C bus pointer, the device address, the flags field, and the delay field. The above code fragment defines two I2C device variables, `cyg_i2c_wallclock_ds1307` and `hal_alaia_i2c_fs6377`, which can be used for the first argument to the `cyg_i2c_` functions. Both devices are on the same bus. The device addresses are 0x68 and 0x58 respectively, and the devices do not have any special requirements.

When the platform HAL provides these structures it should also export them for use by the application and other packages. Usually this involves an entry in `cyg/hal/plf_io.h`, which gets included automatically via one of the main exported HAL header files `cyg/hal/hal_io.h`. Unfortunately exporting the structures directly can be problematical because of circular dependencies between the I2C header and the HAL headers. Instead the platform HAL should define a macro `HAL_I2C_EXPORTED_DEVICES`:

```

# define HAL_I2C_EXPORTED_DEVICES
extern cyg_i2c_bus          hal_alaia_i2c_bus;
extern cyg_i2c_device       cyg_i2c_wallclock_ds1307;
extern cyg_i2c_device       hal_alaia_i2c_fs6377;

```

This macro gets expanded automatically by `cyg/io/i2c.h` once the data structures themselves have been defined, so application code can just include that header and all the buses and devices will be properly exported and usable.

There is no single convention for naming the I2C devices. If the device will be used by some other package then typically that specifies the name that should be used. For example the DS1307 wallclock driver expects the I2C device to be called `cyg_i2c_wallclock_ds1307`, so failing to observe that convention will lead to compile-time and link-time errors. If the device will not be used by any other package then it is up to the platform HAL to select the name, and as long as reasonable care is taken to avoid name space pollution the exact name does not matter.

Bit-banged Bus

Some processors come with dedicated I2C hardware. On other hardware the I2C bus involves simply connecting some GPIO pins to the SCL and SDA lines and then using software to implement the I2C protocol. This is usually referred to as bit-banging the bus. The generic I2C package `CYGPKG_IO_I2C` provides the main code for a bit-banged implementation, requiring one platform-specific function that does the actual GPIO pin manipulation. This function is usually hardware-specific because different boards will use different pins for the I2C bus, so typically it is left to the platform HAL to provide this function and instantiate the I2C bus object. There is no point in creating a separate package for this because the code cannot be re-used for other platforms.

Instantiating a bit-banged I2C bus requires the following:

```

#include <cyg/io/i2c.h>

static cyg_bool
hal_alaia_i2c_bitbang(cyg_i2c_bus* bus, cyg_i2c_bitbang_op op)
{
    cyg_bool result = 0;

```

```

switch(op) {
    ...
}
return result;
}

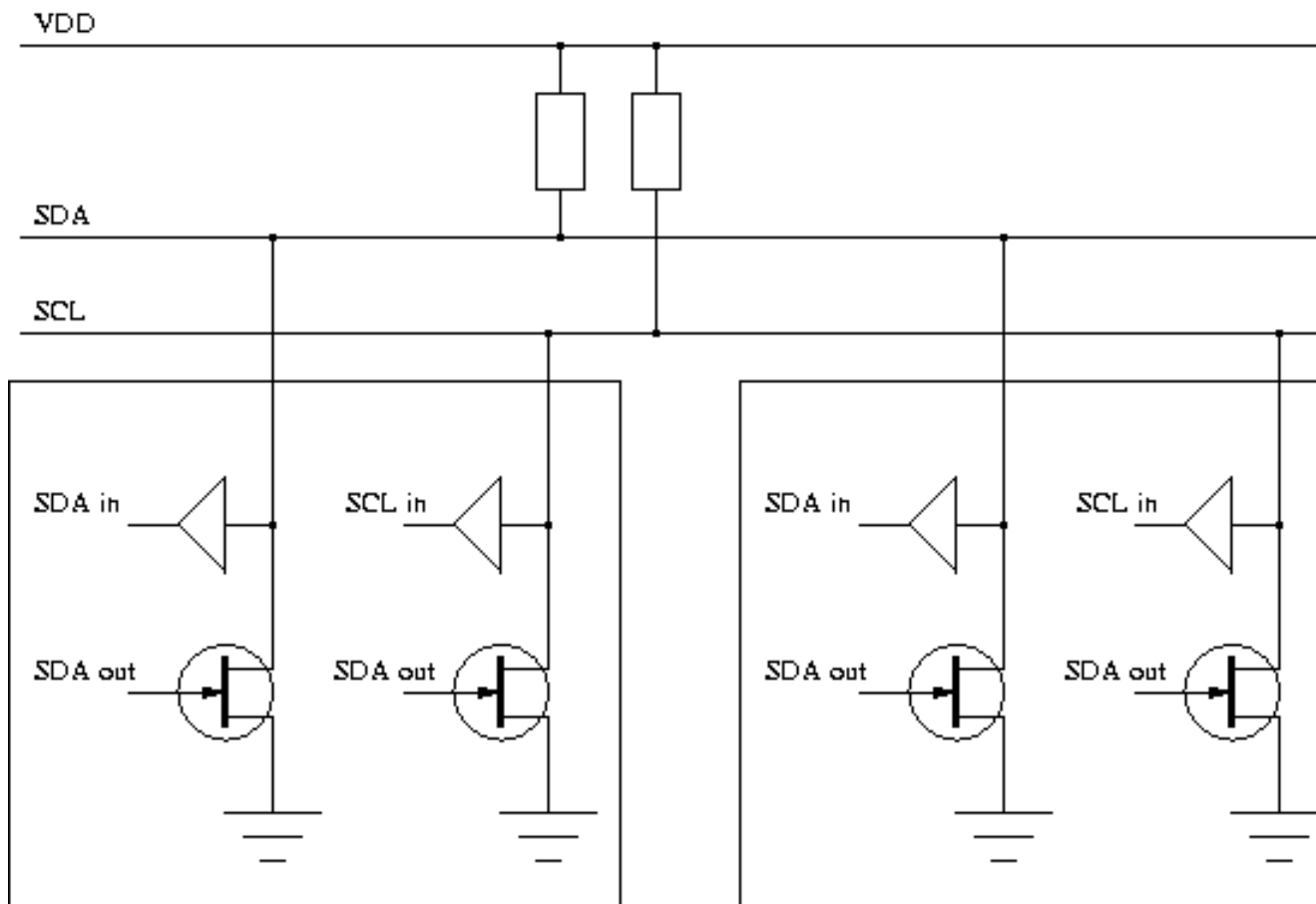
```

```

CYG_I2C_BITBANG_BUS(hal_alaiia_i2c_bus, &hal_alaiia_i2c_bitbang);

```

This gives a structure `hal_alaiia_i2c_bus` which can be used when defining the `cyg_i2c_device` structures. The second argument specifies the function which will do the actual bit-banging. It takes two arguments. The first identifies the bus, which can be useful if the hardware has multiple I2C buses. The second specifies the bit-bang operation that should be performed. To understand these operations consider how I2C devices should be wired up according to the specification:



Master and slave devices are interfaced to the bus in exactly the same way. The default state of the bus is to have both lines high via the pull-up resistors. Any device on the bus can lower either line, when allowed to do so by the protocol. Usually the SDA line only changes while SCL is low, but the start and stop conditions involve SDA changing while SCL is high. All devices have the ability to both read and write both lines. In reality not all bit-banged hardware works quite like this. Instead just two GPIO pins are used, and these are switched between input and output mode as required.

The bitbang function should support the following operations:

CYG_I2C_BITBANG_INIT

This will be called during system initialization, as a side effect of a prioritized C++ static constructor. The bitbang function should ensure that both SCL and SDA are driven high.

CYG_I2C_BITBANG_SCL_HIGH

CYG_I2C_BITBANG_SCL_LOW

CYG_I2C_BITBANG_SDA_HIGH

CYG_I2C_BITBANG_SDA_LOW

These operations simply set the appropriate lines high or low.

CYG_I2C_BITBANG_SCL_HIGH_CLOCKSTRETCH

In its simplest form this operation should simply set the SCL line high, indicating that the data on the SDA line is stable. However there is a complication: if a device is not ready yet then it can throttle back the master by keeping the SCL line low. This is known as clock-stretching. Hence for this operation the bitbang function should allow the SCL line to float high, then poll it until it really has become high. If a single pin is used for the SCL line then this pin should be turned back into a high output at the end of the call.

CYG_I2C_BITBANG_SCL_LOW_SDA_INPUT

This is used when there is a change of direction and the slave device is about to start driving the SDA line. This can be significant if a single pin is used to handle both input and output of SDA, to avoid a situation where both the master and the slave are driving the SDA line for an extended period of time. The operation combines dropping the SCL line and switching SDA to an input in an atomic or near-atomic operation.

CYG_I2C_BITBANG_SDA_READ

The SDA line is currently set as an input and the bitbang function should sample and return the current state.

The bitbang function returns a boolean. For most operations this return value is ignored. For CYG_I2C_BITBANG_SDA_READ it should be the current level of the SDA line.

Depending on the hardware some care may have to be taken when manipulating the GPIO pins. Although the I2C subsystem performs the required locking at the bus level, the device registers controlling the GPIO pins may get used by other subsystems or by the application. It is the responsibility of the bitbang function to perform appropriate locking, whether via a mutex or by briefly disabling interrupts around the register accesses.

Full Bus Driver

If the processor has dedicated I2C hardware then usually this will involve a separate device driver package in the `devs/i2c` hierarchy of the eCos component repository. That package should also be included in the appropriate `ecos.db` target entry or entries. The device driver may exist already, or it may have to be written from scratch.

A new I2C driver basically involves creating an `cyg_i2c_bus` structure. The device driver should supply the following fields:

`i2c_init_fn`

This function will be called during system initialization to set up the I2C hardware. The generic I2C code creates a static object with a prioritized constructor, and this constructor will invoke the init functions for the various I2C buses in the system.

```
i2c_tx_fn
i2c_rx_fn
i2c_stop_fn
```

These functions implement the core I2C functionality. The arguments and results are the same as for the transaction functions `cyg_i2c_transaction_tx`, `cyg_i2c_transaction_rx` and `cyg_i2c_transaction_stop`.

```
void* i2c_extra
```

This field holds any extra information that may be needed by the device driver. Typically it will be a pointer to some driver-specific data structure.

To assist with instantiating a `cyg_i2c_bus` object the header file `cyg/io/i2c.h` provides a macro. Typical usage would be:

```
struct xyzzy_data {
    ...
} xyzzy_object;

static void
xyzzy_i2c_init(struct cyg_i2c_bus* bus)
{
    ...
}

static cyg_uint32
xyzzy_i2c_tx(const cyg_i2c_device* dev,
             cyg_bool send_start,
             const cyg_uint8* tx_data, cyg_uint32 count,
             cyg_bool send_stop)
{
    ...
}

static cyg_uint32
xyzzy_i2c_rx(const cyg_i2c_device* dev,
             cyg_bool send_start,
             cyg_uint8* rx_data, cyg_uint32 count,
             cyg_bool send_nack, cyg_bool send_stop)
{
    ...
}

static void
xyzzy_i2c_stop(const cyg_i2c_device* dev)
{
    ...
}

CYG_I2C_BUS(cyg_i2c_xyzzy_bus,
            &xyzzy_i2c_init,
            &xyzzy_i2c_tx,
            &xyzzy_i2c_rx,
            &xyzzy_i2c_stop,
            (void*) &xyzzy_object);
```

Porting to New Hardware

The generic I2C code contains these functions for a bit-banged I2C bus device. It can be used as a starting point for new drivers. Note that the bit-bang code uses the `i2c_extra` field to hold the hardware-specific bitbang function rather than a pointer to some data structure.

X. ADC Support

Overview

Name

Overview — eCos Support for Analog/Digital Converters

Introduction

ADC support in eCos is based around the standard character device interface. Hence all device IO function, or file IO functions may be used to access ADC devices.

ADC devices are presented as read-only serial channels that generate samples at a given rate. The size of each sample is hardware specific and is defined by the `cyg_adc_sample_t` type. The sample rate may be set at runtime by the application. Most ADC devices support several channels which are all sampled at the same rate. Therefore setting the rate for one channel will usually change the rate for all channels on that device.

Examples

The use of the ADC devices is best shown by example. The following is a simple example of using the eCos device interface to access the ADC:

```
int res;
cyg_io_handle_t handle;

// Get a handle for ADC device 0 channel 0
res = cyg_io_lookup( "/dev/adc00", &handle );

if( res != ENOERR )
    handle_error(err);

for(;;)
{
    cyg_adc_sample_t sample;
    cyg_uint32 len = sizeof(sample);

    // read a sample from the channel
    res = cyg_io_read( handle, &sample, &len );

    if( res != ENOERR )
        handle_error(err);

    use_sample( sample );
}
```

In this example, the required channel is looked up and a handle on it acquired. Conventionally ADC devices are named `"/dev/adcXY"` where X is the device number and Y the channel within that device. Following this, samples are read from the device sequentially.

ADC devices may also be accessed using FILEIO operations. These allow more sophisticated usage. The following example shows `select()` being used to gather samples from several devices.

```
int fd1, fd2;

// open channels, non-blocking
fd1 = open( "/dev/adc01", O_RDONLY|O_NONBLOCK );
```

```

fd2 = open( "/dev/adc02", O_RDONLY|O_NONBLOCK );

if( fd1 < 0 || fd2 < 0 )
    handle_error( errno );

for(;;)
{
    fd_set rd;
    int maxfd = 0;
    int err;
    cyg_adc_sample_t samples[128];
    int len;

    FD_ZERO( &rd );

    FD_SET( fd1, &rd );
    FD_SET( fd2, &rd );
    maxfd = max(fd1,fd2);

    // select on available data on each channel.
    err = select( maxfd+1, &rd, NULL, NULL, NULL );

    if( err < 0 )
        handle_error(errno);

    // If channel 1 has data, handle it
    if( FD_ISSET( fd1, &rd ) )
    {
        len = read( fd1, &samples, sizeof(samples) );

        if( len > 0 )
            handle_samples_chan1( &samples, len/sizeof(sample[0]) );
    }

    // If channel 2 has data, handle it
    if( FD_ISSET( fd2, &rd ) )
    {
        len = read( fd2, &samples, sizeof(samples) );

        if( len > 0 )
            handle_samples_chan2( &samples, len/sizeof(sample[0]) );
    }
}

```

This test uses FILEIO operations to access ADC channels. It starts by opening two channels for reading only and with blocking disabled. It then falls into a loop using select to wake up whenever either channel has samples available.

Details

As indicated, the main interface to ADC devices is via the standard character device interface. However, there are a number of aspects that are ADC specific.

Sample Type

Samples can vary in size depending on the underlying hardware and is often a non-standard number of bits. The actual number of bits is defined by the hardware driver package, and the generic ADC package uses this to define a type `cyg_adc_sample_t` which can contain at least the required number of bits. All reads from an ADC channel should be expressed in multiples of this type, and actual bytes read will also always be a multiple.

Sample Rate

The sample rate of an ADC device can be varied by calling a `set_config` function, either at the device IO API level or at the FILEIO level. The following two functions show how this is done at each:

```
int set_rate_io( cyg_io_handle_t handle, int rate )
{
    cyg_adc_info_t info;
    cyg_uint32 len = sizeof(info);

    info.rate = rate;

    return cyg_io_set_config( handle,
                              CYG_IO_SET_CONFIG_ADC_RATE,
                              &info,
                              &len);
}

int set_rate_fileio( int fd, int rate )
{
    cyg_adc_info_t info;

    info.rate = rate;

    return cyg_fs_fsetinfo( fd,
                            CYG_IO_SET_CONFIG_ADC_RATE,
                            &info,
                            sizeof(info) );
}
```

Enabling a Channel

Channels are initialized in a disabled state and generate no samples. When a channel is first looked up or opened, then it is automatically enabled and samples start to accumulate. A channel may then be disabled or re-enabled via a `set_config` function:

```
int disable_io( cyg_io_handle_t handle )
{
    return cyg_io_set_config( handle,
                              CYG_IO_SET_CONFIG_ADC_DISABLE,
                              NULL,
                              NULL);
}

int enable_io( cyg_io_handle_t handle )
{
    return cyg_io_set_config( handle,
                              CYG_IO_SET_CONFIG_ADC_DISABLE,
                              NULL,
```

```

                                NULL) ;
}

```

Configuration

The ADC package defines a number of generic configuration options that apply to all ADC implementations:

cdl_component CYGPKG_IO_ADC_DEVICES

This option enables the hardware device drivers for the current platform. ADC devices will only be enabled if this option is itself enabled.

cdl_option CYGNUM_IO_ADC_SAMPLE_SIZE

This option defines the sample size for the ADC devices. Given in bits, it will be rounded up to 8, 16 or 32 to define the `cyg_adc_sample_t` type. This option is usually set by the hardware device driver.

cdl_option CYGPKG_IO_ADC_SELECT_SUPPORT

This option enables support for the `select()` API function on all ADC devices. This option can be disabled if the `select()` is not used, saving some code and data space.

In addition to the generic options, each hardware device driver defines some parameters for each device and channel. The exact names of the following option depends on the hardware device driver, but options of this form should be available in all drivers.

cdl_option CYGDAT_IO_ADC_EXAMPLE_CHANNELN_NAME

This option specifies the name of the device for an ADC channel. Channel names should be of the form `"/dev/adcXY"` where X is the device number and Y the channel within that device.

cdl_option CYGNUM_IO_ADC_EXAMPLE_CHANNELN_BUFSIZE

This option specifies the buffer size for an ADC channel. The value is expressed in multiples of `cyg_adc_sample_t` rather than bytes. The default value is 128.

cdl_option CYGNUM_IO_ADC_EXAMPLE_DEFAULT_RATE

This option defines the initial default sample rate for all channels. The hardware driver may place constraints on the range of values this option may take.

ADC Device Drivers

Name

Overview — ADC Device Drivers

Introduction

This section describes how to write an ADC hardware device. While users of ADC devices do not need to read it, it may provide added insight into how the devices work.

Data Structures

An ADC hardware driver is represented by a number of data structures. These are generic device and channel data structures, a driver private device data structure, a generic character device table entry and a driver function table. Most of these structures are instantiated using macros, which will be described here.

The data structure instantiation for a typical single device, four channel ADC would look like this:

```
//=====
// Instantiate data structures

// -----
// Driver functions:

CYG_ADC_FUNCTIONS( example_adc_funs,
                   example_adc_enable,
                   example_adc_disable,
                   example_adc_set_rate );

// -----
// Device instance:

static example_adc_info example_adc_info0 =
{
    .base          = CYGARC_HAL_EXAMPLE_ADC_BASE,
    .vector        = CYGNUM_HAL_INTERRUPT_ADC
};

CYG_ADC_DEVICE( example_adc_device,
               &example_adc_funs,
               &example_adc_info0,
               CYGNUM_IO_ADC_EXAMPLE_DEFAULT_RATE );

// -----
// Channel instances:

#define EXAMPLE_ADC_CHANNEL( __chan ) \
CYG_ADC_CHANNEL( example_adc_channel##_chan, \
                __chan, \
                CYGNUM_IO_ADC_EXAMPLE_CHANNEL##_chan##_BUFSIZE, \
                &example_adc_device ); \
\
DEVTAB_ENTRY( example_adc_channel##_chan##_device, \
              CYGDAT_IO_ADC_EXAMPLE_CHANNEL##_chan##_NAME, \
```

```

        0,                                     \
        &cyg_io_adc_devio,                     \
        example_adc_init,                     \
        example_adc_lookup,                   \
        &example_adc_channel##_chan );

EXAMPLE_ADC_CHANNEL( 0 );
EXAMPLE_ADC_CHANNEL( 1 );
EXAMPLE_ADC_CHANNEL( 2 );
EXAMPLE_ADC_CHANNEL( 3 );

```

The macro `CYG_ADC_FUNCTIONS()` instantiates a function table called `example_adc_funs` and populates it with the ADC driver functions (see later for details).

Then an instance of the driver private device data structure is instantiated. In addition to the device base address and interrupt vector shown here, this structure should contain the interrupt object and handle for attaching to the vector. It may also contain any other variables needed to manage the device.

The macro `CYG_ADC_DEVICE()` instantiates a `cyg_adc_device` structure, named `example_adc_device` which will contain pointers to the function table and private data structure. The initial sample rate is also supplied here.

For each channel, an ADC channel structure and a device table entry must be created. The macro `EXAMPLE_ADC_CHANNEL()` is defined to simplify this process. The macro `CYG_ADC_CHANNEL` defines a `cyg_adc_channel` structure, which contains the channel number, the buffer size, and a pointer to the device object defined earlier. The call to `DEVTAB_ENTRY()` generates a device table entry containing the configured channel name, a pointer to a device function table defined in the generic ADC driver, pointers to init and lookup functions implemented here, and a pointer to the channel data structure just defined.

Finally, four channels, numbered 0 to 3 are created.

Functions

There are several classes of function that need to be defined in an ADC driver. These are those function that go into the channel's device table, those that go into the ADC device's function table, calls that the driver makes into the generic ADC package, and interrupt handling functions.

Device Table Functions

These functions are placed in the standard device table entry for each channel and handle initialization and location of the device within the generic driver infrastructure.

`static bool example_adc_init(struct cyg_devtab_entry *tab)` This function is called from the device IO infrastructure to initialize the device. It should perform any work needed to start up the device, short of actually starting the generation of samples. This function will be called for each channel, so if there is initialization that only needs to be done once, such as creating an interrupt object, then care should be taken to do this. This function should also call `cyg_adc_device_init()` to initialize the generic parts of the driver.

`static Cyg_ErrNo example_adc_lookup(struct cyg_devtab_entry **tab, struct cyg_devtab_entry *sub_tab, const char *name)` This function is called when a client looks up or opens a channel. It should call `cyg_adc_channel_init()` to initialize the generic part of the channel. It should also perform any operations needed to start the channel generating samples.

Driver Functions

These are the functions installed into the driver function table by the `CYG_ADC_FUNCTIONS()` macro.

`static void example_adc_enable(cyg_adc_channel *chan)` This function is called from the generic ADC package to enable the channel in response to a `CYG_IO_SET_CONFIG_ADC_ENABLE` config operation. It should take any steps needed to start the channel generating samples.

`static void example_adc_disable(cyg_adc_channel *chan)` This function is called from the generic ADC package to enable the channel in response to a `CYG_IO_SET_CONFIG_ADC_DISABLE` config operation. It should take any steps needed to stop the channel generating samples.

`static void example_adc_set_rate(cyg_adc_channel *chan, cyg_uint32 rate)` This function is called from the generic ADC package to enable the channel in response to a `CYG_IO_SET_CONFIG_ADC_RATE` config operation. It should take any steps needed to change the sample rate of the channel, or of the entire device.

Generic Package Functions

These functions are called by a hardware ADC device driver to perform operations in the generic ADC package.

`__externC void cyg_adc_device_init(cyg_adc_device *device)` This function is called from the driver's init function and is used to initialize the `cyg_adc_device` object.

`__externC void cyg_adc_channel_init(cyg_adc_channel *chan)` This function is called from the driver's lookup function and is used to initialize the `cyg_adc_channel` object.

`__externC cyg_uint32 cyg_adc_receive_sample(cyg_adc_channel *chan, cyg_adc_sample_t sample)` This function is called from the driver's ISR to add a new sample to the buffer. The return value will be either zero, or `CYG_ISR_CALL_DSR` and should be ORed with the return value of the ISR.

`__externC void cyg_adc_wakeup(cyg_adc_channel *chan)` This function is called from the driver's DSR to cause any threads waiting for data to wake up when a new sample is available. It should only be called if the *wakeup* field of the channel object is *true*.

Interrupt Functions

These functions are internal to the driver, but make calls on generic package functions. Typically an ADC device will have a single interrupt vector with which it signals available samples on the channels and any error conditions such as overruns.

`static cyg_uint32 example_adc_isr(cyg_vector_t vector, cyg_addrword_t data)` This function is the ISR attached to the ADC device's interrupt vector. It is responsible for reading samples from the channels and passing them on to the generic layer. It needs to check each channel for data, and call `cyg_adc_receive_sample()` for each new sample available, and then ready the device for the next interrupt. Its activities are best explained by example:

```
static cyg_uint32 example_adc_isr(cyg_vector_t vector, cyg_addrword_t data)
{
    cyg_adc_device *example_device = (cyg_adc_device *) data;
    example_adc_info *example_info = example_device->dev_priv;
    cyg_uint32 res = 0;
    int i;

    // Deal with errors if necessary
    DEVICE_CHECK_ERRORS( example_info );

    // Look for all channels with data available
```

```

    for( i = 0; i < CHANNEL_COUNT; i++ )
    {
        if( CHANNEL_SAMPLE_AVAILABLE(i) )
        {
            // Fetch data from this channel and pass up to higher
            // level.

            cyg_adc_sample_t data = CHANNEL_GET_SAMPLE(i);

            res |= CYG_ISR_HANDLED | cyg_adc_receive_sample( example_info->channel[i], data );
        }
    }

    // Clear any interrupt conditions
    DEVICE_CLEAR_INTERRUPTS( example_info );

    cyg_drv_interrupt_acknowledge(example_info->vector);

    return res;
}

static void example_adc_dsr(cyg_vector_t vector, cyg_ucount32 count, cyg_addrword_t
data) This function is the DSR attached to the ADC device's interrupt vector. It is called by the kernel if the
ISR return value contains the CYG_ISR_HANDLED bit. It needs to call cyg_adc_wakeup( ) for each channel that
has its wakeup field set. Again, and example should make it all clear:

static void example_adc_dsr(cyg_vector_t vector, cyg_ucount32 count, cyg_addrword_t data)
{
    cyg_adc_device *example_device = (cyg_adc_device *) data;
    example_adc_info *example_info = example_device->dev_priv;
    int i;

    // Look for all channels with pending wakeups
    for( i = 0; i < CHANNEL_COUNT; i++ )
    {
        if( example_info->channel[i]->wakeup )
            cyg_adc_wakeup( example_info->channel[i] );
    }
}

```

XI. Framebuffer Support

Overview

Name

Overview — eCos Support for Framebuffer Devices

Description

Framebuffer devices are the most common way for a computer system to display graphical output to users. There are immense variations in the implementations of such devices. `CYGPKG_IO_FRAMEBUFFER` provides an abstraction layer for use by application code and other packages. It defines an API for manipulating framebuffers, mapping this API on to functionality provided by the appropriate device driver. It also defines the interface which such device drivers should implement. For simple hardware it provides default implementations of much of this interface, greatly reducing the effort needed to write a device driver.

This package does not constitute a graphics library. It does not implement functionality like drawing text or arbitrary lines, let alone any kind of windowing system. Instead it operates at the lower level of individual pixels and blocks of pixels, in addition to control operations such as hardware initialization. Some applications may use the framebuffer API directly. Others will instead use a higher-level graphics library, and it is that library which uses the framebuffer API.

It is assumed that users are already familiar with the fundamentals of computer graphics, and no attempt is made here to explain terms like display depth, palette or pixel.

Note: This package is work-in-progress. The support for 1bpp, 2bpp and 4bpp display depths is incomplete. For double-buffered displays the code does not yet maintain a bounding box of the updated parts of the display. The package has also been designed to allow for [expansion](#) with new functionality.

Configuration

`CYGPKG_IO_FRAMEBUFFER` only contains hardware-independent code. It should be complemented by one or more framebuffer device drivers appropriate for the target platform. These drivers may be specific to the platform, or they may be more generic with platform-specific details such as the framebuffer memory base address provided by the platform HAL. When creating a configuration for a given target the device driver(s) will always be included automatically (assuming one has been written or ported). However by default this driver will be inactive and will not get built, so does not add any unnecessary size overhead for applications which do not require graphics. To activate the device driver `CYGPKG_IO_FRAMEBUFFER` must be added explicitly to the configuration, for example using `ecosconfig add framebuffer`. After this the full framebuffer API will be available to other packages and to application code.

This package contains very few configuration options. Instead it is left to device drivers or higher-level code to provide appropriate configurability. One option, `CYGFUN_IO_FRAMEBUFFER_INSTALL_DEFAULT_PALETTE`, relates to the initialization of [paletted displays](#).

There are a number of calculated and inferred configuration options and a number of interfaces. These provide information such as whether or not there is a backlight. The most important one is `CYGDAT_IO_FRAMEBUFFER_DEVICES`, which holds a list of framebuffer identifiers for use with the [macro-based API](#). If there is a single framebuffer device driver which supports one display in either landscape or portrait mode, the configuration option may hold a value like `240x320x8 320x240x8r90`.

Application Programmer Interfaces

Framebuffer devices require a difficult choice between flexibility and performance. On the one hand the API should be able to support multiple devices driving separate displays, or a single device operating in different modes at different times. On the other hand graphics tends to involve very large amounts of I/O: even something as simple as drawing a background image can involve setting many thousands of pixels. Efficiency requires avoiding all possible overheads including function calls. Instead the API should make extensive use of macros or inline functions. Ideally details of the framebuffer device such as the stride would be known constants at compile-time, giving the compiler as much opportunity as possible to optimize the code. Clearly this is difficult if multiple framebuffer devices are in use or if the device mode may get changed at run-time.

To meet the conflicting requirements the generic framebuffer package provides two APIs: a fast macro API which requires selecting a single framebuffer device at compile or configure time; and a slower function API without this limitation. The two are very similar, for example:

```
#include <cyg/io/framebuf.h>

void
clear_screen(cyg_fb* fb, cyg_fb_colour colour)
{
    cyg_fb_fill_block(fb, 0, 0,
                      fb->fb_width, fb->fb_height,
                      colour);
}
```

or the equivalent macro version:

```
#include <cyg/io/framebuf.h>

#define FRAMEBUF 240x320x8

void
clear_screen(cyg_fb_colour colour)
{
    CYG_FB_FILL_BLOCK(FRAMEBUF, 0, 0,
                      CYG_FB_WIDTH(FRAMEBUF), CYG_FB_HEIGHT(FRAMEBUF),
                      colour);
}
```

The function-based API works in terms of `cyg_fb` structures, containing all the information needed to manipulate the device. Each framebuffer device driver will export one or more of these structures, for example `cyg_alaia_fb_240x320x8`, and the driver documentation should list the variable names. The macro API works in terms of identifiers such as `240x320x8`, and by a series of substitutions the main macro gets expanded to the appropriate device-specific code, usually inline. Again the device driver documentation should list the supported identifiers. In addition the configuration option `CYGDAT_IO_FRAMEBUFFER_DEVICES` will contain the full list. By convention the identifier will be specified by a `#define`'d symbol such as `FRAMEBUF`, or in the case of graphics libraries by a configuration option.

If a platform has multiple framebuffer devices connected to different displays then there will be separate `cyg_fb` structures and macro identifiers for each one. In addition some devices can operate in multiple modes. For example a PC VGA card can operate in a monochrome 640x480 mode, an 8bpp 320x200 mode, and many other modes, but only one of these can be active at a time. The different modes are also represented by different `cyg_fb` structures and identifiers, effectively treating the modes as separate devices. It is the responsibility of higher-level code to ensure that only one mode is in use at a time.

It is possible to use the macro API with more than one device, basically by compiling the code twice with different values of `FRAMEBUF`, taking appropriate care to avoid identifier name clashes. This gives the higher performance of the macros at the cost of increased code size.

All of the framebuffer API, including exports of the device-specific `cyg_fb` structures, is available through a single header file `<cyg/io/framebuf.h>`. The API follows a number of conventions. Coordinates (0,0) correspond to the top-left corner of the display. All functions and macros which take a pair of coordinates have `x` first, `y` second. For block operations these coordinates are followed by width, then height. Coordinates and dimensions use `cyg_ccount16` variables, which for any processor should be the most efficient unsigned data type with at least 16 bits - usually plain unsigned integers. Colours are identified by `cyg_fb_colour` variables, again usually unsigned integers.

To allow for the different variants of the English language, the API allows for a number of alternate spellings. Colour and color can be used interchangeably, so there are data types `cyg_fb_colour` and `cyg_fb_color`, and functions `cyg_fb_make_colour` and `cyg_fb_make_color`. Similarly gray is accepted as a variant of grey so the predefined colours `CYG_FB_DEFAULT_PALETTE_LIGHTGREY` and `CYG_FB_DEFAULT_PALETTE_LIGHTGRAY` are equivalent.

The API is split into the following categories:

parameters

getting information about a given framebuffer device such as width, height and depth. Colours management is complicated so has its own [category](#).

control

operations such as switching the display on and off, and more device-specific ones such as manipulating the backlight.

colours

determining the colour format (monochrome, paletted, ...), manipulating the palette, or constructing true colours.

drawing

primitives for manipulating pixels and blocks of pixels.

iteration

efficiently iterating over blocks of pixels.

Thread Safety

The framebuffer API never performs any locking so is not thread-safe. Instead it assumes that higher-level code such as a graphics library performs any locking that may be needed. Adding a mutex lock and unlock around every drawing primitive, including pixel writes, would be prohibitively expensive.

It is also assumed that the framebuffer will only be updated from thread context. With most hardware it will also be possible to access a framebuffer from DSR or ISR context, but this should be avoided in portable code.

Framebuffer Parameters

Name

Parameters — determining framebuffer capabilities

Synopsis

```
#include <cyg/io/framebuf.h>

typedef struct cyg_fb {
    cyg_uint16    fb_depth;
    cyg_uint16    fb_format;
    cyg_uint16    fb_width;
    cyg_uint16    fb_height;
#ifdef CYGHWI_IO_FRAMEBUFFER_FUNCTIONALITY_VIEWPORT
    cyg_uint16    fb_viewport_width;
    cyg_uint16    fb_viewport_height;
#endif
    void*         fb_base;
    cyg_uint16    fb_stride;
    cyg_uint32    fb_flags0;
    ...
} cyg_fb;

cyg_fb* CYG_FB_STRUCT(Framebuffer);
cyg_uint16 CYG_FB_DEPTH(Framebuffer);
cyg_uint16 CYG_FB_FORMAT(Framebuffer);
cyg_uint16 CYG_FB_WIDTH(Framebuffer);
cyg_uint16 CYG_FB_HEIGHT(Framebuffer);
cyg_uint16 CYG_FB_VIEWPORT_WIDTH(Framebuffer);
cyg_uint16 CYG_FB_VIEWPORT_HEIGHT(Framebuffer);
void* CYG_FB_BASE(Framebuffer);
cyg_uint16 CYG_FB_STRIDE(Framebuffer);
cyg_uint32 CYG_FB_FLAGS0(Framebuffer);
```

Description

When developing an application for a specific platform the various framebuffer parameters such as width and height are known, and the code can be written accordingly. However when writing code that should work on many platforms with different framebuffer devices, for example a graphics library, the code must be able to get these parameters and adapt.

Code using the function API can extract the parameters from the `cyg_fb` structures at run-time. The macro API provides dedicated macros for each parameter. These do not follow the usual eCos convention where the result is provided via an extra argument. Instead the result is returned as normal, and is guaranteed to be a compile-time constant. This allows code like the following:

```
#if CYG_FB_DEPTH(Framebuffer) < 8
    ...
#else
    ...
```

```
#endif
```

or alternatively:

```
if (CYG_FB_DEPTH(FRAMEBUF) < 8) {  
    ...  
} else {  
    ...  
}
```

or:

```
switch (CYG_FB_DEPTH(FRAMEBUF)) {  
    case 1 : ... break;  
    case 2 : ... break;  
    case 4 : ... break;  
    case 8 : ... break;  
    case 16 : ... break;  
    case 32 : ... break;  
}
```

In terms of the code actually generated by the compiler these approaches have much the same effect. The macros expand to a compile-time constant so unnecessary code can be easily eliminated.

The available parameters are as follows:

depth

The number of bits per pixel or bpp. The common depths are 1, 2, 4, 8, 16 and 32.

format

How the pixel values are mapped on to visible [colours](#), for example true colour or paletted or greyscale.

width

height

The number of framebuffer pixels horizontally and vertically.

viewport width

viewport height

With some devices the framebuffer height and/or width are greater than what the display can actually show. The display is said to offer a viewport into the larger framebuffer. The number of visible pixels is determined from the viewport width and height. The position of the viewport is controlled via an [ioctl](#). Within a `cyg_fb` structure these fields are only present if `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_VIEWPORT` is defined, to avoid wasting data space on fields that are unnecessary for the current platform. For the macro API the viewport macros should only be used if `CYG_FB_FLAGS0_VIEWPORT` is set for the framebuffer:

```
#if (CYG_FB_FLAGS0(FRAMEBUF) & CYG_FB_FLAGS0_VIEWPORT)  
    ...  
#endif
```

base
stride

For [linear](#) framebuffers these parameters provide the information needed to access framebuffer memory. The stride is in bytes.

flags0

This gives further information about the hardware capabilities. Some of this overlaps with other parameters, especially when it comes to colour, because it is often easier to test for a single flag than for a range of colour modes. The current flags are:

CYG_FB_FLAGS0_LINEAR_FRAMEBUFFER

Framebuffer memory is organized in a conventional fashion and can be [accessed](#) directly by higher-level code using the base and stride parameters.

CYG_FB_FLAGS0_LE

This flag is only relevant for 1bpp, 2bpp and 4bpp devices and controls how the pixels are organized within each byte. If the flag is set then the layout is little-endian: for a 1bpp device pixel (0,0) occupies bit 0 of the first byte of framebuffer memory. The more common layout is big-endian where pixel (0,0) occupies bit 7 of the first byte.

CYG_FB_FLAGS0_TRUE_COLOUR

The framebuffer uses a true colour format where the value of each pixel directly encodes the red, green and blue intensities. This is common for 16bpp and 32bpp devices, and is occasionally used for 8bpp devices.

CYG_FB_FLAGS0_PALETTE

The framebuffer uses a palette. A pixel value does not directly encode the colours, but instead acts as an index into a separate table of colour values. That table may be read-only or read-write. Paletted displays are common for 8bpp and some 4bpp displays.

CYG_FB_FLAGS0_WRITEABLE_PALETTE

The palette is read-write.

CYG_FB_FLAGS0_DELAYED_PALETTE_UPDATE

Palette updates can be synchronized to a vertical blank, in other words a brief time period when the display is not being updated, by using `CYG_FB_UPDATE_VERTICAL_RETRACE` as the last argument to `cyg_fb_write_palette` or `CYG_FB_WRITE_PALETTE`. With some hardware updating the palette in the middle of a screen update may result in visual noise.

CYG_FB_FLAGS0_VIEWPORT

The framebuffer contains more pixels than can be shown on the display. Instead the display provides a viewport into the framebuffer. An [ioctl](#) can be used to move the viewport.

CYG_FB_FLAGS0_DOUBLE_BUFFER

The display does not show the current contents of the framebuffer, so the results of drawing into the framebuffer are not immediately visible. Instead higher-level code needs to perform an explicit [synch](#) operation to update the display.

CYG_FB_FLAGS0_PAGE_FLIPPING

The hardware supports two or more pages, each of width*height pixels, only one of which is visible on the display. This allows higher-level code to update one page without disturbing what is currently visible. An `ioctl` is used to switch the visible page.

CYG_FB_FLAGS0_BLANK

The display can be **blanked** without affecting the framebuffer contents or settings.

CYG_FB_FLAGS0_BACKLIGHT

There is a backlight which can be **switched** on or off. Some hardware provides finer-grained control over the backlight intensity.

CYG_FB_FLAGS0_MUST_BE_ON

Often it is desirable to perform some initialization such as clearing the screen or setting the palette before the display is **switched on**, to avoid visual noise. However not all hardware allows this. If this flag is set then it is possible to access framebuffer memory and the palette before the `cyg_fb_on` or `CYG_FB_ON` operation. It may also be possible to perform some other operations such as activating the backlight, but that is implementation-defined.

To allow for future expansion there are also `flags1`, `flags2`, and `flags3` fields. These may get used for encoding additional `ioctl` functionality, support for hardware acceleration, and similar features.

Linear Framebuffers

There are drawing primitives for writing and reading individual pixels. However these involve a certain amount of arithmetic each time to get from a position to an address within the frame buffer, plus function call overhead if the function API is used, and this will slow down graphics operations.

When the framebuffer device is known at compile-time and the macro API is used then there are additional macros specifically for **iterating** over parts of the frame buffer. These should prove very efficient for many graphics operations. However if the device is selected at run-time then the macros are not appropriate and code may want to manipulate framebuffer memory directly. This is possible if two conditions are satisfied:

1. The `CYG_FB_FLAGS0_LINEAR_FRAMEBUFFER` flag must be set. Otherwise framebuffer memory is either not directly accessible or has a non-linear layout.
2. The `CYG_FB_FLAGS0_DOUBLE_BUFFER` flag must be clear. An efficient double buffer synch operation requires knowing what part of the framebuffer have been updated, and the various drawing primitives will keep track of this. If higher-level code then starts manipulating the framebuffer directly the synch operation may perform only a partial update.

The base, stride, depth, width and height parameters, plus the `CYG_FB_FLAGS0_LE` flag for 1bpp, 2bpp and 4bpp devices, provide all the information needed to access framebuffer memory. A linear framebuffer has pixel (0,0) at the base address. Incrementing y means adding stride bytes to the pointer.

The base and stride parameters may be set even if `CYG_FB_FLAGS0_LINEAR_FRAMEBUFFER` is clear. This can be useful if for example the display is rotated in software from landscape to portrait mode. However the meaning of these parameters for non-linear framebuffers is implementation-defined.

Framebuffer Control Operations

Name

Control Operations — managing a framebuffer

Synopsis

```
#include <cyg/io/framebuf.h>

int cyg_fb_on(cyg_fb* fbdev);
int cyg_fb_off(cyg_fb* fbdev);
int cyg_fb_ioctl(cyg_fb* fbdev, cyg_uint16 key, void* data, size_t* len);
int CYG_FB_ON(FRAMEBUF);
int CYG_FB_OFF(FRAMEBUF);
int CYG_FB_IOCTL(FRAMEBUF, cyg_uint16 key, void* data, size_t* len);
```

Description

The main operations on a framebuffer are drawing and colour management. However on most hardware it is also necessary to switch the display [on](#) before the user can see anything, and application code should be able to control when this happens. There are also miscellaneous operations such as manipulating the backlight or moving the viewpoint. These do not warrant dedicated functions, especially since the functionality will only be available on some hardware, so an [ioctl](#) interface is used.

Switching the Display On or Off

With most hardware nothing will be visible until there is a call to `cyg_fb_on` or an invocation of the `CYG_FB_ON` macro. This will initialize the framebuffer control circuitry, start sending the data signals to the display unit, and switch on the display if necessary. The exact initialization semantics are left to the framebuffer device driver. In some cases the hardware may already be partially or fully initialized by a static constructor or by boot code that ran before eCos.

There are some circumstances in which initialization can fail, and this is indicated by a POSIX error code such as `ENODEV`. An example would be plug and play hardware where the framebuffer device is not detected at run-time. Another example is hardware which can operate in several modes, with separate `cyg_fb` structures for each mode, if the hardware is already in use for a different mode. A return value of 0 indicates success.

Some but not all hardware allows the framebuffer memory and, if present, the palette to be manipulated before the device is switched on. That way the user does not see random noise on the screen during system startup. The flag `CYG_FB_FLAGS0_MUST_BE_ON` should be checked:

```
static void
init_screen(cyg_fb_colour background)
{
    int result;

    #if (! (CYG_FB_FLAGS0(FRAMEBUF) & CYG_FB_FLAGS0_MUST_BE_ON))
        CYG_FB_FILL_BLOCK(FRAMEBUF, 0, 0,
```

```

                                CYG_FB_WIDTH(FRAMEBUF), CYG_FB_HEIGHT(FRAMEBUF),
                                background);
#endif

    result = CYG_FB_ON(FRAMEBUF);
    if (0 != result) {
        <handle unusual error condition>
    }

#if (CYG_FB_FLAGS0(FRAMEBUF) & CYG_FB_FLAGS0_MUST_BE_ON)
    CYG_FB_FILL_BLOCK(FRAMEBUF, 0, 0,
                      CYG_FB_WIDTH(FRAMEBUF), CYG_FB_HEIGHT(FRAMEBUF),
                      background);
#endif
}

```

Obviously if the application has already manipulated framebuffer memory or the palette but then the `cyg_fb_on` operation fails, the system is left in an undefined state.

It is also possible to switch a framebuffer device off, using the function `cyg_fb_off` or the macro `CYG_FB_OFF`, although this functionality is rarely used in embedded systems. The exact semantics of switching a device off are implementation-defined, but typically it involves shutting down the display, stopping the data signals to the display, and halting the control circuitry. The framebuffer memory and the palette are left in an undefined state, and application code should assume that both need full reinitializing when the device is switched back on. Some hardware may also provide a [blank](#) operation which typically just manipulates the display, not the whole framebuffer device. Normally `cyg_fb_on` returns 0. The API allows for a POSIX error code as with `cyg_fb_on`, but switching a device off is not an operation that is likely to fail.

If a framebuffer device can operate in several modes, represented by several `cyg_fb` structures and macro identifiers, then switching modes requires turning the current device off before turning the next one on.

Miscellaneous Control Operations

Some hardware functionality such as an LCD panel backlight is common but not universal. Supporting these does not warrant dedicated functions. Instead a catch-all `ioctl` interface is provided, with the arguments just passed straight to the device driver. This approach also allows for future expansion and for device-specific operations. `cyg_fb_ioctl` and `CYG_FB_IOCTL` take four arguments: a `cyg_fb` structure or framebuffer identifier; a key that specifies the operation to be performed; an arbitrary pointer, which should usually be a pointer to a data structure specific to the key; and a length field. Key values from 0 to 0x7fff are generic. Key values from 0x8000 onwards are reserved for the individual framebuffer device drivers, for device-specific functionality. The length field should be set to the size of the data structure, and may get updated by the device driver.

With most `ioctl` operations the device can indicate whether or not it supports the functionality by one of the flags, for example:

```

void
backlight_off(cyg_fb* fb)
{
    if (fb->fb_flags0 & CYG_FB_FLAGS0_BACKLIGHT) {
        cyg_fb_ioctl_backlight  new_setting;
        size_t                    len = sizeof(cyg_fb_ioctl_backlight);
        int                       result;

        new_setting.fbbl_current = 0;
        result = cyg_fb_ioctl(fb, CYG_FB_IOCTL_BACKLIGHT_SET,

```

```

                                &new_setting, &len);
    if (0 != result) {
        ...
    }
}
}

```

The operation returns zero for success or a POSIX error code on failure, for example `ENOSYS` if the device driver does not implement the requested functionality.

Viewport

```

# define CYG_FB_IOCTL_VIEWPORT_GET_POSITION    0x0100
# define CYG_FB_IOCTL_VIEWPORT_SET_POSITION    0x0101

typedef struct cyg_fb_ioctl_viewport {
    cyg_uint16    fbvp_x;        // position of top-left corner of the viewport within
    cyg_uint16    fbvp_y;        // the framebuffer
    cyg_uint16    fbvp_when;     // set-only, now or vert retrace
} cyg_fb_ioctl_viewport;

```

On some targets the framebuffer device has a higher resolution than the display. Only a subset of the pixels, the viewport, is currently visible. Application code can exploit this functionality to achieve certain effects, for example smooth scrolling. Framebuffers which support this functionality will have the `CYG_FB_FLAGS0_VIEWPORT` flag set. The viewport dimensions are available as additional [parameters](#) to the normal framebuffer width and height.

The current position of the viewport can be obtained using an `CYG_FB_IOCTL_VIEWPORT_GET_POSITION` ioctl operation. The data argument should be a pointer to a `cyg_fb_ioctl_viewport` structure. On return the `fbvp_x` and `fbvp_y` fields will be filled in. To move the viewport use `CYG_FB_IOCTL_VIEWPORT_SET_POSITION` with `fbvp_x` and `fbvp_y` set to the top left corner of the new viewport within the framebuffer, and `fbvp_when` set to either `CYG_FB_UPDATE_NOW` or `CYG_FB_UPDATE_VERTICAL_RETRACE`. If the device driver cannot easily synchronize to a vertical retrace period then this last field is ignored.

```

void
move_viewport(cyg_fb* fb, int dx, int dy)
{
#ifdef CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_VIEWPORT
    cyg_fb_ioctl_viewport viewport;
    int len = sizeof(cyg_fb_ioctl_viewport);
    int result;

    result = cyg_fb_ioctl(fb, CYG_FB_IOCTL_VIEWPORT_GET_POSITION,
                          &viewport, &len);
    if (result != 0) {
        ...
    }
    if (((int)viewport.fbvp_x + dx) < 0) {
        viewport.fbvp_x = 0;
    } else if ((viewport.fbvp_x + dx + fb->fb_viewport_width) > fb->fb_width) {
        viewport.fbvp_x = fb->fb_width - fb->fb_viewport_width;
    } else {
        viewport.fbvp_x += dx;
    }
    if (((int)viewport.fbvp_y + dy) < 0) {

```

```

        viewport.fbvp_y = 0;
    } else if ((viewport.fbvp_y + dy + fb->fb_viewport_height) > fb->fb_height) {
        viewport.fbvp_y = fb->fb_height - fb->fb_viewport_height;
    } else {
        viewport.fbvp_y += dy;
    }
    result = cyg_fb_ioctl(fb, CYG_FB_IOCTL_VIEWPORT_SET_POSITION,
                        &viewport, &len);

    if (result != 0) {
        ...
    }
#else
    CYG_UNUSED_PARAM(cyg_fb*, fb);
    CYG_UNUSED_PARAM(int, dx);
    CYG_UNUSED_PARAM(int, dy);
#endif
}

```

If an attempt is made to move the viewport beyond the boundaries of the framebuffer then the resulting behaviour is undefined. Some hardware may behave reasonably, wrapping around as appropriate, but portable code cannot assume this. The above code fragment is careful to clip the viewport to the framebuffer dimensions.

Page Flipping

```

# define CYG_FB_IOCTL_PAGE_FLIPPING_GET_PAGES    0x0200
# define CYG_FB_IOCTL_PAGE_FLIPPING_SET_PAGES    0x0201

typedef struct cyg_fb_ioctl_page_flip {
    cyg_uint32    fbpf_number_pages;
    cyg_uint32    fbpf_visible_page;
    cyg_uint32    fbpf_drawable_page;
    cyg_ushort16  fbpf_when; // set-only, now or vert retrace
} cyg_fb_ioctl_page_flip;

```

On some targets the framebuffer has enough memory for several pages, only one of which is visible at a time. This allows the application to draw into one page while displaying another. Once drawing is complete the display is flipped to the newly drawn page, and the previously displayed page is now available for updating. This technique is used for smooth animation, especially in games. The flag `CYG_FB_FLAGS0_PAGE_FLIPPING` indicates support for this functionality.

`CYG_FB_IOCTL_PAGE_FLIPPING_GET_PAGES` can be used to get the current settings of the page flipping support. The data argument should be a pointer to a `cyg_fb_ioctl_page_flip` structure. The resulting `fbpf_number_pages` field indicates the total number of pages available: 2 is common, but more pages are possible. `fbpf_visible_page` gives the page that is currently visible to the user, and will be between 0 and (`fbpf_number_pages` - 1). Similarly `fbpf_drawable_page` gives the page that is currently visible. It is implementation-defined whether or not the visible and drawable page can be the same one.

`CYG_FB_IOCTL_PAGE_FLIPPING_SET_PAGES` can be used to change the visible and drawable page. The `fbpf_number_pages` field is ignored. `fbpf_visible_page` and `fbpf_drawable_page` give the new settings. `fbpf_when` should be one of `CYG_FB_UPDATE_NOW` or `CYG_FB_UPDATE_VERTICAL_RETRACE`, but may be ignored by some device drivers.

```

#if ! (CYG_FB_FLAGS0(FRAMEBUF) & CYG_FB_FLAGS0_PAGE_FLIPPING)

```



```
# error Current framebuffer device does not support page flipping
#endif

static cyg_uint32 current_visible = 0;

static void
page_flip_init(cyg_fb_colour background)
{
    cyg_fb_ioctl_page_flip flip;
    size_t len = sizeof(cyg_fb_ioctl_page_flip);

    flip.fbpf_visible_page = current_visible;
    flip.fbpf_drawable_page = 1 - current_visible;
    flip.fbpf_when = CYG_FB_UPDATE_NOW;
    CYG_FB_IOCTL(FRAMEBUF, CYG_FB_IOCTL_PAGE_FLIPPING_SET_PAGES,
                 &flip, &len);
    CYG_FB_FILL_BLOCK(FRAMEBUF, 0, 0,
                      CYG_FB_WIDTH(FRAMEBUF), CYG_FB_HEIGHT(FRAMEBUF),
                      background);
    flip.fbpf_visible_page = 1 - current_visible;
    flip.fbpf_drawable_page = current_visible;
    CYG_FB_IOCTL(FRAMEBUF, CYG_FB_IOCTL_PAGE_FLIPPING_SET_PAGES,
                 &flip, &len);
    CYG_FB_FILL_BLOCK(FRAMEBUF, 0, 0,
                      CYG_FB_WIDTH(FRAMEBUF), CYG_FB_HEIGHT(FRAMEBUF),
                      background);
    current_visible = 1 - current_visible;
}

static void
page_flip_toggle(void)
{
    cyg_fb_ioctl_page_flip flip;
    size_t len = sizeof(cyg_fb_ioctl_page_flip);

    flip.fbpf_visible_page = 1 - current_visible;
    flip.fbpf_drawable_page = current_visible;
    CYG_FB_IOCTL(FRAMEBUF, CYG_FB_IOCTL_PAGE_FLIPPING_SET_PAGES,
                 &flip, &len);
    current_visible = 1 - current_visible;
}
```

A page flip typically just changes a couple of pointers within the hardware and device driver. No attempt is made to synchronize the contents of the pages, that is left to higher-level code.

Blanking the Screen

```
# define CYG_FB_IOCTL_BLANK_GET          0x0300
# define CYG_FB_IOCTL_BLANK_SET          0x0301

typedef struct cyg_fb_ioctl_blank {
    cyg_bool    fbbl_on;
} cyg_fb_ioctl_blank;
```

Some hardware allows the display to be switched off or blanked without shutting down the entire framebuffer device, greatly reducing power consumption. The current blanking state can be obtained using `CYG_FB_IOCTL_BLANK_GET` and the state can be updated using `CYG_FB_IOCTL_BLANK_SET`. The data argument should be a pointer to a `cyg_fb_ioctl_blank` structure. Support for this functionality is indicated by the `CYG_FB_FLAGS0_BLANK` flag.

```
static cyg_bool
display_blanked(cyg_fb_* fb)
{
    cyg_fb_ioctl_blank blank;
    size_t len = sizeof(cyg_fb_ioctl_blank);

    if (!(fb->fb_flags0 & CYG_FB_FLAGS0_BLANK)) {
        return false;
    }
    (void) cyg_fb_ioctl(fb, CYG_FB_IOCTL_BLANK_GET, &blank, &len);
    return !blank.fbbl_on;
}
```

Controlling the Backlight

```
# define CYG_FB_IOCTL_BACKLIGHT_GET          0x0400
# define CYG_FB_IOCTL_BACKLIGHT_SET          0x0401

typedef struct cyg_fb_ioctl_backlight {
    cyg_uint32    fbbl_current;
    cyg_uint32    fbbl_max;
} cyg_fb_ioctl_backlight;
```

Many LCD panels provide some sort of backlight, making the display easier to read at the cost of increased power consumption. Support for this is indicated by the `CYG_FB_FLAGS0_BACKLIGHT` flag. `CYG_FB_IOCTL_BACKLIGHT_GET` can be used to get both the current setting and the maximum value. If the maximum is 1 then the backlight can only be switched on or off. Otherwise it is possible to control the intensity.

```
static void
set_backlight_50_percent(void)
{
    #if (CYG_FB_FLAGS0(FRAMEBUF) & CYG_FB_FLAGS0_BACKLIGHT)
        cyg_fb_ioctl_backlight backlight;
        size_t len = sizeof(cyg_fb_ioctl_backlight);

        CYG_FB_IOCTL(FRAMEBUF, CYG_FB_IOCTL_BACKLIGHT_GET, &backlight, &len);
        backlight.fbbl_current = (backlight.fbbl_max + 1) >> 1;
        CYG_FB_IOCTL(FRAMEBUF, CYG_FB_IOCTL_BACKLIGHT_SET, &backlight, &len);
    #endif
}
```

Framebuffer Colours

Name

Colours — formats and palette management

Synopsis

```
#include <cyg/io/framebuf.h>

typedef struct cyg_fb {
    cyg_ucount16    fb_depth;
    cyg_ucount16    fb_format;
    cyg_uint32      fb_flags0;
    ...
} cyg_fb;

extern const cyg_uint8  cyg_fb_palette_ega[16 * 3];
extern const cyg_uint8  cyg_fb_palette_vga[256 * 3];

#define CYG_FB_DEFAULT_PALETTE_BLACK      0x00
#define CYG_FB_DEFAULT_PALETTE_BLUE      0x01
#define CYG_FB_DEFAULT_PALETTE_GREEN     0x02
#define CYG_FB_DEFAULT_PALETTE_CYAN      0x03
#define CYG_FB_DEFAULT_PALETTE_RED        0x04
#define CYG_FB_DEFAULT_PALETTE_MAGENTA   0x05
#define CYG_FB_DEFAULT_PALETTE_BROWN     0x06
#define CYG_FB_DEFAULT_PALETTE_LIGHTGREY  0x07
#define CYG_FB_DEFAULT_PALETTE_LIGHTGRAY  0x07
#define CYG_FB_DEFAULT_PALETTE_DARKGREY   0x08
#define CYG_FB_DEFAULT_PALETTE_DARKGRAY   0x08
#define CYG_FB_DEFAULT_PALETTE_LIGHTBLUE  0x09
#define CYG_FB_DEFAULT_PALETTE_LIGHTGREEN 0x0A
#define CYG_FB_DEFAULT_PALETTE_LIGHTCYAN  0x0B
#define CYG_FB_DEFAULT_PALETTE_LIGHTRED   0x0C
#define CYG_FB_DEFAULT_PALETTE_LIGHTMAGENTA 0x0D
#define CYG_FB_DEFAULT_PALETTE_YELLOW     0x0E
#define CYG_FB_DEFAULT_PALETTE_WHITE      0x0F

cyg_ucount16 CYG_FB_FORMAT(framebuf);
void cyg_fb_read_palette(cyg_fb* fb, cyg_ucount32 first, cyg_ucount32 count, void* data);
void cyg_fb_write_palette(cyg_fb* fb, cyg_ucount32 first, cyg_ucount32 count, const void* data, cyg_ucount16 when);
cyg_fb_colour cyg_fb_make_colour(cyg_fb* fb, cyg_ucount8 r, cyg_ucount8 g, cyg_ucount8 b);
void cyg_fb_break_colour(cyg_fb* fb, cyg_fb_colour colour, cyg_ucount8* r, cyg_ucount8* g, cyg_ucount8* b);
void CYG_FB_READ_PALETTE(FRAMEBUF, cyg_ucount32 first, cyg_ucount32 count, void* data);
void CYG_FB_WRITE_PALETTE(FRAMEBUF, cyg_ucount32 first, cyg_ucount32 count, const void* data, cyg_ucount16 when);
cyg_fb_colour CYG_FB_MAKE_COLOUR(FRAMEBUF, cyg_ucount8 r, cyg_ucount8 g, cyg_ucount8 b);
void CYG_FB_BREAK_COLOUR(FRAMEBUF, cyg_fb_colour colour, cyg_ucount8* r, cyg_ucount8* g, cyg_ucount8* b);
```

Description

Managing colours can be one of the most difficult aspects of writing graphics code, especially if that code is intended to be portable to many different platforms. Displays can vary from 1bpp monochrome, via 2bpp and 4bpp greyscale, through 4bpp and 8bpp paletted, and up to 16bpp and 32bpp true colour - and those are just the more common scenarios. The various [drawing primitives](#) like `cyg_fb_write_pixel` work in terms of `cyg_fb_colour` values, usually an unsigned integer. Exactly how the hardware interprets a `cyg_fb_colour` depends on the format.

Colour Formats

There are a number of ways of finding out how these values will be interpreted by the hardware:

1. The `CYG_FB_FLAGS0_TRUE_COLOUR` flag is set for all true colour displays. The format parameter can be examined for more details but this is not usually necessary. Instead code can use `cyg_fb_make_colour` or `CYG_FB_MAKE_COLOUR` to construct a `cyg_fb_colour` value from red, green and blue components.
2. If the `CYG_FB_FLAGS0_WRITEABLE_PALETTE` flag is set then a `cyg_fb_colour` value is an index into a lookup table known as the palette, and this table contains red, green and blue components. The size of the palette is determined by the display depth, so 16 entries for a 4bpp display and 256 entries for an 8bpp display. Application code or a graphics library can [install](#) its own palette so can control exactly what colour each `cyg_fb_colour` value corresponds to. Alternatively there is support for installing a default palette.
3. If `CYG_FB_FLAGS0_PALETTE` is set but `CYG_FB_FLAGS0_WRITEABLE_PALETTE` is clear then the hardware uses a fixed palette. There is no easy way for portable software to handle this case. The palette can be read at run-time, allowing the application's desired colours to be mapped to whichever palette entry provides the best match. However normally it will be necessary to write code specifically for the fixed palette.
4. Otherwise the display is monochrome or greyscale, depending on the depth. There are still variations, for example on a monochrome display colour 0 can be either white or black.

As an alternative or to provide additional information, the exact colour format is provided by the `fb_format` field of the `cyg_fb` structure or by the `CYG_FB_FORMAT` macro. It can be one of the following (more entries may be added in future):

`CYG_FB_FORMAT_1BPP_MONO_0_BLACK`

simple 1bpp monochrome display, with 0 as black or the darker of the two colours, and 1 as white or the higher colour.

`CYG_FB_FORMAT_1BPP_MONO_0_WHITE`

simple 1bpp monochrome display, with 0 as white or the lighter of the two colours, and 1 as black or the darker colour.

`CYG_FB_FORMAT_1BPP_PAL888`

a 1bpp display which cannot easily be described as monochrome. This is unusual and not readily supported by portable code. It can happen if the framebuffer normally runs at a higher depth, for example 4bpp or 8bpp paletted, but is run at only 1bpp to save memory. Hence only two of the palette entries are used, but can be set to arbitrary colours. The palette may be read-only or read-write.

`CYG_FB_FORMAT_2BPP_GREYSCALE_0_BLACK`

a 2bpp display offering four shades of grey, with 0 as black or the darkest of the four shades, and 3 as white or the lightest.

`CYG_FB_FORMAT_2BPP_GREYSCALE_0_WHITE`

a 2bpp display offering four shades of grey, with 0 as white or the lightest of the four shades, and 3 as black or the darkest.

`CYG_FB_FORMAT_2BPP_PAL888`

a 2bpp display which cannot easily be described as greyscale, for example providing black, red, blue and white as the four colours. This is unusual and not readily supported by portable code. It can happen if the framebuffer normally runs at a higher depth, for example 4bpp or 8bpp paletted, but is run at only 2bpp to save memory. Hence only four of the palette entries are used, but can be set to arbitrary colours. The palette may be read-only or read-write.

`CYG_FB_FORMAT_4BPP_GREYSCALE_0_BLACK`

a 4bpp display offering sixteen shades of grey, with 0 as black or the darkest of the 16 shades, and 15 as white or the lightest.

`CYG_FB_FORMAT_4BPP_GREYSCALE_0_WHITE`

a 4bpp display offering sixteen shades of grey, with 0 as white or the lightest of the 16 shades, and 15 as black or the darkest.

`CYG_FB_FORMAT_4BPP_PAL888`

a 4bpp paletted display, allowing for 16 different colours on screen at the same time. The palette may be read-only or read-write.

`CYG_FB_FORMAT_8BPP_PAL888`

an 8bpp paletted display, allowing for 256 different colours on screen at the same time. The palette may be read-only or read-write.

`CYG_FB_FORMAT_8BPP_TRUE_332`

an 8bpp true colour display, with three bits (eight levels) of red and green intensity and two bits (four levels) of blue intensity.

`CYG_FB_FORMAT_16BPP_TRUE_565`

a 16bpp true colour display with 5 bits each for red and blue and 6 bits for green.

`CYG_FB_FORMAT_16BPP_TRUE_555`

a 16bpp true colour display with five bits each for red, green and blue, and one unused bit.

`CYG_FB_FORMAT_32BPP_TRUE_0888`

a 32bpp true colour display with eight bits each for red, green and blue and eight bits unused.

For the true colour formats the format does not define exactly which bits in the pixel are used for which colour. Instead the `cyg_fb_make_colour` and `cyg_fb_break_colour` functions or the equivalent macros should be used to construct or decompose pixel values.

Paletted Displays

Palettes are the common way of implementing low-end colour displays. There are two variants. A read-only palette provides a fixed set of colours and it is up to application code to use these colours appropriately. A read-

write palette allows the application to select its own set of colours. Displays providing a read-write palette will have the `CYG_FB_FLAGS0_WRITEABLE_PALETTE` flag set in addition to `CYG_FB_FLAGS0_PALETTE`.

Even if application code can install its own palette, many applications do not exploit this functionality and instead stick with a default. There are two standard palettes: the 16-entry PC EGA for 4bpp displays; and the 256-entry PC VGA, a superset of the EGA one, for 8bpp displays. This package provides the data for both, in the form of arrays `cyg_fb_palette_ega` and `cyg_fb_palette_vga`, and 16 `#define`'s such as `CYG_FB_DEFAULT_PALETTE_BLACK` for the EGA colours and the first 16 VGA colours. By default device drivers for read-write paletted displays will install the appropriate default palette, but this can be suppressed using configuration option `CYGFUN_IO_FRAMEBUFFER_INSTALL_DEFAULT_PALETTE`. If a custom palette will be used then installing the default palette involves wasting 48 or 768 bytes of memory.

It should be emphasized that displays vary widely. A colour such as `CYG_FB_DEFAULT_PALETTE_YELLOW` may appear rather differently on two different displays, although it should always be recognizable as yellow. Developers may wish to fine-tune the palette for specific hardware.

The current palette can be retrieved using `cyg_fb_read_palette` or `CYG_FB_READ_PALETTE`. The *first* and *count* arguments control which palette entries should be retrieved. For example, to retrieve just palette entry 12 *first* should be set to 12 and *count* should be set to 1. To retrieve all 256 entries for an 8bpp display, *first* should be set to 0 and *count* should be set to 256. The *data* argument should point at an array of bytes, allowing three bytes for every entry. Byte 0 will contain the red intensity for the first entry, byte 1 green and byte 2 blue.

For read-write palettes the palette can be updated using `cyg_fb_write_palette` or `CYG_FB_WRITE_PALETTE`. The *first* and *count* arguments are the same as for `cyg_fb_read_palette`, and the *data* argument should point at a suitable byte array packed in the same way. The *when* argument should be one of `CYG_FB_UPDATE_NOW` or `CYG_FB_UPDATE_VERTICAL_RETRACE`. With some displays updating the palette in the middle of an update may result in visual noise, so synchronizing to the vertical retrace avoids this. However not all device drivers will support this.

There is an assumption that palette entries use 8 bits for each of the red, green and blue colour intensities. This is not always the case, but the device drivers will perform appropriate adjustments. Some hardware may use only 6 bits per colour, and the device driver will ignore the bottom two bits of the supplied intensity values. Occasionally hardware may use more than 8 bits, in which case the supplied 8 bits are shifted left appropriately and zero-padded. Device drivers for such hardware may also provide device-specific routines to manipulate the palette in a non-portable fashion.

True Colour displays

True colour displays are often easier to manage than paletted displays. However this comes at the cost of extra memory. A 16bpp true colour display requires twice as much memory as an 8bpp paletted display, yet can offer only 32 or 64 levels of intensity for each colour as opposed to the 256 levels provided by a palette. It also requires twice as much video memory bandwidth to send all the pixel data to the display for every refresh, which may impact the performance of the rest of the system. A 32bpp true colour display offers the same colour intensities but requires four times the memory and four times the bandwidth.

Exactly how the colour bits are organized in a `cyg_fb_colour` pixel value is not defined by the colour format. Instead code should use the `cyg_fb_make_colour` or `CYG_FB_MAKE_COLOUR` primitives. These take 8-bit intensity levels for red, green and blue, and return the corresponding `cyg_fb_colour`. When using the macro interface the arithmetic happens at compile-time, for example:

```
#define BLACK      CYG_FB_MAKE_COLOUR(FRAMEBUF,  0,  0,  0)
#define WHITE      CYG_FB_MAKE_COLOUR(FRAMEBUF, 255, 255, 255)
#define RED        CYG_FB_MAKE_COLOUR(FRAMEBUF, 255,  0,  0)
#define GREEN      CYG_FB_MAKE_COLOUR(FRAMEBUF,  0, 255,  0)
```

```
#define BLUE          CYG_FB_MAKE_COLOUR(FRAMEBUF,  0,  0, 255)
#define YELLOW        CYG_FB_MAKE_COLOUR(FRAMEBUF, 255, 255, 80)
```

Displays vary widely so the numbers may need to be adjusted to give the exact desired colours.

For symmetry there are also `cyg_fb_break_colour` and `CYG_FB_BREAK_COLOUR` primitives. These take a `cyg_fb_colour` value and decompose it into its red, green and blue components.

Framebuffer Drawing Primitives

Name

Drawing Primitives — updating the display

Synopsis

```
#include <cyg/io/framebuf.h>

void cyg_fb_write_pixel(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_fb_colour
colour);
cyg_fb_colour cyg_fb_read_pixel(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y);
void cyg_fb_write_hline(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16
len, cyg_fb_colour colour);
void cyg_fb_write_vline(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16
len, cyg_fb_colour colour);
void cyg_fb_fill_block(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16
width, cyg_ucount16 height, cyg_fb_colour colour);
void cyg_fb_write_block(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16
width, cyg_ucount16 height, const void* data, cyg_ucount16 offset, cyg_ucount16
stride);
void cyg_fb_read_block(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16
width, cyg_ucount16 height, void* data, cyg_ucount16 offset, cyg_ucount16 stride);
void cyg_fb_move_block(cyg_fb* fbdev, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16
width, cyg_ucount16 height, cyg_ucount16 new_x, cyg_ucount16 new_y);
void cyg_fb_synch(cyg_fb* fbdev, cyg_ucount16 when);
void CYG_FB_WRITE_PIXEL(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_fb_colour
colour);
cyg_fb_colour CYG_FB_READ_PIXEL(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y);
void CYG_FB_WRITE_HLINE(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 len,
cyg_fb_colour colour);
void CYG_FB_WRITE_VLINE(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 len,
cyg_fb_colour colour);
void CYG_FB_FILL_BLOCK(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 width,
cyg_ucount16 height, cyg_fb_colour colour);
void CYG_FB_WRITE_BLOCK(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 width,
cyg_ucount16 height, const void* data, cyg_ucount16 offset, cyg_ucount16 stride);
void CYG_FB_READ_BLOCK(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 width,
cyg_ucount16 height, void* data, cyg_ucount16 offset, cyg_ucount16 stride);
void CYG_FB_MOVE_BLOCK(FRAMEBUF, cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 width,
cyg_ucount16 height, cyg_ucount16 new_x, cyg_ucount16 new_y);
void CYG_FB_SYNCH(FRAMEBUF, cyg_ucount16 when);
```

Description

The eCos framebuffer infrastructure defines a small number of drawing primitives. These are not intended to provide full graphical functionality like multiple windows, drawing text in arbitrary fonts, or anything like that. Instead they provide building blocks for higher-level graphical toolkits. The available primitives are:

1. Manipulating individual pixels.
2. Drawing horizontal and vertical lines.

3. Block fills.
4. Moving blocks between the framebuffer and main memory.
5. Moving blocks within the framebuffer.
6. For double-buffered devices, synchronizing the framebuffer contents with the actual display.

There are two versions for each primitive: a macro and a function. The macro can be used if the desired framebuffer device is known at compile-time. Its first argument should be a framebuffer identifier, for example 320x240x16, and must be one of the entries in the configuration option `CYGDAT_IO_FRAMEBUFFER_DEVICES`. In the examples below it is assumed that `FRAMEBUF` has been `#define`'d to a suitable identifier. The function can be used if the desired framebuffer device is selected at run-time. Its first argument should be a pointer to the appropriate `cyg_fb` structure.

The pixel, line, and block fill primitives take a `cyg_fb_colour` argument. For details of colour handling see [Framebuffer Colours](#). This argument should have no more bits set than are appropriate for the display depth. For example on a 4bpp only the bottom four bits of the colour may be set, otherwise the behaviour is undefined.

None of the primitives will perform any run-time error checking, except possibly for some assertions in a debug build. If higher-level code provides invalid arguments, for example trying to write a block which extends past the right hand side of the screen, then the system's behaviour is undefined. It is the responsibility of higher-level code to perform clipping to the screen boundaries.

Manipulating Individual Pixels

The primitives for manipulating individual pixels are very simple: a pixel can be written or read back. The following example shows one way of drawing a diagonal line:

```
void
draw_diagonal(cyg_fb* fb,
              cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 len,
              cyg_fb_colour colour)
{
    while ( len-- ) {
        cyg_fb_write_pixel(fb, x++, y++, colour);
    }
}
```

The next example shows how to draw a horizontal XOR line on a 1bpp display.

```
void
draw_horz_xor(cyg_ucount16 x, cyg_ucount16 y, cyg_ucount16 len)
{
    cyg_fb_colour colour;
    while ( len-- ) {
        colour = CYG_FB_READ_PIXEL(FRAMEBUF, x, y);
        CYG_FB_WRITE_PIXEL(FRAMEBUF, x++, y, colour ^ 0x01);
    }
}
```

The pixel macros should normally be avoided. Determining the correct location within framebuffer memory corresponding to a set of coordinates for each pixel is a comparatively expensive operation. Instead there is direct support for [iterating](#) over parts of the display, avoiding unnecessary overheads.

Drawing Simple Lines

Higher-level graphics code often needs to draw single-pixel horizontal and vertical lines. If the application involves multiple windows then these will usually have thin borders around them. Widgets such as buttons and scrollbars also often have thin borders.

`cyg_fb_draw_hline` and `CYG_FB_DRAW_HLINE` draw a horizontal line of the specified *colour*, starting at the *x* and *y* coordinates and extending to the right (increasing *x*) for a total of *len* pixels. A 50 pixel line starting at (100,100) will end at (149,100).

`cyg_fb_draw_vline` and `CYG_FB_DRAW_VLINE` take the same arguments, but the line extends down (increasing *y*).

These primitives do not directly support drawing lines more than one pixel thick, but [block fills](#) can be used to achieve those. There is no generic support for drawing arbitrary lines, instead that is left to higher-level graphics toolkits.

Block Fills

Filling a rectangular part of the screen with a solid colour is another common requirement for higher-level code. The simplest example is during initialization, to set the display's whole background to a known value. Block fills are also often used when creating new windows or drawing the bulk of a simple button or scrollbar widget. `cyg_fb_fill_block` and `CYG_FB_FILL_BLOCK` provide this functionality.

The *x* and *y* arguments specify the top-left corner of the block to be filled. The *width* and *height* arguments specify the number of pixels affected, a total of *width* * *height*. The following example illustrates part of the process for initializing a framebuffer, assumed here to have a writeable palette with default settings.

```
int
display_init(void)
{
    int result = CYG_FB_ON(FRAMEBUF);
    if ( result ) {
        return result;
    }
    CYG_FB_FILL_BLOCK(FRAMEBUF, 0, 0,
                      CYG_FB_WIDTH(FRAMEBUF), CYG_FB_HEIGHT(FRAMEBUF),
                      CYG_FB_DEFAULT_PALETTE_WHITE);
    ...
}
```

Copying Blocks between the Framebuffer and Main Memory

The block transfer primitives serve two main purposes: drawing images. and saving parts of the current display to be restored later. For simple linear framebuffers the primitives just implement copy operations, with no data conversion of any sort. For non-linear ones the primitives act as if the framebuffer memory was linear. For example, consider a 2bpp display where the two bits for a single pixel are split over two separate bytes in framebuffer memory, or two planes. For a block write operation the source data should still be organized with four full pixels per byte, as for a linear framebuffer of the same depth. and the block write primitive will distribute the bits over the framebuffer memory as required. Similarly a block read will combine the appropriate bits from different locations in framebuffer memory and the resulting memory block will have four full pixels per byte.

Because the block transfer primitives perform no data conversion, if they are to be used for rendering images then those images should be pre-formatted appropriately for the framebuffer device. For small images this would normally happen on the host-side as part of the application build process. For larger images it will usually be better to store them in a compressed format and decompress them at run-time, trading off memory for cpu cycles.

The *x* and *y* arguments specify the top-left corner of the block to be transferred, and the *width* and *height* arguments determine the size. The *data*, *offset* and *stride* arguments determine the location and layout of the block in main memory:

data

The source or destination for the transfer. For 1bpp, 2bpp and 4bpp devices the data will be packed in accordance with the framebuffer device's endianness as per the `CYG_FB_FLAGS0_LE` flag. Each row starts in a new byte so there may be some padding on the right. For 16bpp and 32bpp the data should be aligned to the appropriate boundary.

offset

Sometimes only part of an image should be written to the screen. A vertical offset can be achieved simply by adjusting *data* to point at the appropriate row within the image instead of the top row. For 8bpp, 16bpp and 32bpp displays an additional horizontal offset can also be achieved by adjusting *data*. However for 1bpp, 2bpp and 4bpp displays the starting position within the image may be in the middle of a byte. Hence the horizontal pixel offset can instead be specified with the *offset* argument.

stride

This indicates the number of bytes between rows. Usually it will be related to the *width*, but there are exceptions such as when drawing only part of an image.

The following example fills a 4bpp display with an image held in memory and already in the right format. If the image is smaller than the display it will be centered. If the image is larger then the center portion will fill the entire display.

```
void
draw_image(const void* data, int width, int height)
{
    cyg_uint16 stride;
    cyg_uint16 x, y, offset;

    #if (4 != CYG_FB_DEPTH(FRAMEBUF))
    # error This code assumes a 4bpp display
    #endif

    stride = (width + 1) >> 1; // 4bpp to byte stride

    if (width < CYG_FB_WIDTH(FRAMEBUF)) {
        x = (CYG_FB_WIDTH(FRAMEBUF) - width) >> 1;
        offset = 0;
    } else {
        x = 0;
        offset = (width - CYG_FB_WIDTH(FRAMEBUF)) >> 1;
        width = CYG_FB_WIDTH(FRAMEBUF);
    }
    if (height < CYG_FB_HEIGHT(FRAMEBUF)) {
        y = (CYG_FB_HEIGHT(FRAMEBUF) - height) >> 1;
    } else {
        y = 0;
    }
}
```

```

    data    = (const void*)((const cyg_uint8*)data +
                  (stride * ((height - CYG_FB_HEIGHT(FRAMEBUF)) >> 1)));
    height = CYG_FB_HEIGHT(FRAMEBUF);
}
CYG_FB_WRITE_BLOCK(FRAMEBUF, x, y, width, height, data, offset, stride);
}

```

Moving Blocks with the Framebuffer

Sometimes it is necessary to move a block of data around the screen, especially when using a higher-level graphics toolkit that supports multiple windows. Block moves can be implemented by a read into main memory followed by a write block, but this is expensive and imposes an additional memory requirement. Instead the framebuffer infrastructure provides a generic block move primitive. It will handle all cases where the source and destination positions overlap. The *x* and *y* arguments specify the top-left corner of the block to be moved, and *width* and *height* determine the block size. *new_x* and *new_y* specify the destination. The source data will remain unchanged except in areas where it overlaps the destination.

Synchronizing Double-Buffered Displays

Some framebuffer devices are double-buffered: the framebuffer memory that gets manipulated by the drawing primitives is separate from what is actually displayed, and a synch operation is needed to update the display. In some cases this may be because the actual display memory is not directly accessible by the processor, for example it may instead be attached via an SPI bus. Instead drawing happens in a buffer in main memory, and then this gets transferred over the SPI bus to the actual display hardware during a synch. In other cases it may be a software artefact. Some drawing operations, especially ones involving complex curves, can take a very long time and it may be considered undesirable to have the user see this happening a few pixels at a time. Instead the drawing happens in a separate buffer in main memory and then a double buffer synch just involves a block move to framebuffer memory. Typically that block move is much faster than the drawing operation. Obviously there is a cost: an extra area of memory, and the synch operation itself can consume many cycles and much of the available memory bandwidth.

It is the responsibility of the framebuffer device driver to provide the extra main memory. As far as higher-level code is concerned the only difference between an ordinary and a double-buffered display is that with the latter changes do not become visible until a synch operation has been performed. The framebuffer infrastructure provides support for a bounding box, keeping track of what has been updated since the last synch. This means only the updated part of the screen has to be transferred to the display hardware.

The synch primitives take two arguments. The first identifies the framebuffer device. The second should be one of `CYG_FB_UPDATE_NOW` for an immediate update, or `CYG_FB_UPDATE_VERTICAL_RETRACE`. Some display hardware involves a lengthy vertical retrace period every 10-20 milliseconds during which nothing gets drawn to the screen, and performing the synch during this time means that the end user is unaware of the operation (assuming the synch can be completed in the time available). When the hardware supports it, specifying `CYG_FB_UPDATE_VERTICAL_RETRACE` means that the synch operation will block until the next vertical retrace takes place and then perform the update. This may be an expensive operation, for example it may involve polling a bit in a register. In a multi-threaded environment it may also be unreliable because the thread performing the synch may get interrupted or rescheduled in the middle of the operation. When the hardware does not involve vertical retraces, or when there is no easy way to detect them, the second argument to the synch operation will just be ignored and the update will always happen immediately.

It is up to higher level code to determine when a synch operation is appropriate. One approach for typical event-driven code is to perform the synch at the start of the event loop, just before waiting for an input or timer

event. This may not be optimal. For example if there two small updates to opposite corners of the screen then it would be better to make two synch calls with small bounding boxes, rather than a single synch call with a large bounding box that requires most of the framebuffer memory to be updated.

Leaving out the synch operations leads to portability problems. On hardware which does not involve double-buffering the synch operation is a no-op, usually eliminated at compile-time, so invoking synch does not add any code size or cpu cycle overhead. On double-buffered hardware, leaving out the synch means the user cannot see what has been drawn into the framebuffer.

Framebuffer Pixel Manipulation

Name

Pixel Manipulation — iterating over the display

Synopsis

```
#include <cyg/io/framebuf.h>

CYG_FB_PIXEL0_VAR(FRAMEBUF);
void CYG_FB_PIXEL0_SET(FRAMEBUF, cyg_uint16 x, cyg_uint16 y);
void CYG_FB_PIXEL0_GET(FRAMEBUF, cyg_uint16 x, cyg_uint16 y);
void CYG_FB_PIXEL0_ADDX(FRAMEBUF, cyg_uint16 incr);
void CYG_FB_PIXEL0_ADDY(FRAMEBUF, cyg_uint16 incr);
void CYG_FB_PIXEL0_WRITE(FRAMEBUF, cyg_fb_colour colour);
cyg_fb_colour CYG_FB_PIXEL0_READ(FRAMEBUF);
void CYG_FB_PIXEL0_FLUSHABS(FRAMEBUF, cyg_uint16 x0, cyg_uint16 y0, cyg_uint16
width, cyg_uint16 height);
void CYG_FB_PIXEL0_FLUSHREL(FRAMEBUF, cyg_uint16 x0, cyg_uint16 y0, cyg_uint16
dx, cyg_uint16 dy);
```

Description

A common requirement for graphics code is to iterate over parts of the framebuffer. Drawing text typically involves iterating over a block of pixels for each character, say 8 by 8, setting each pixel to either a foreground or background colour. Drawing arbitrary lines typically involves moving to the start position and then adjusting the x and y coordinates until the end position is reached, setting a single pixel each time around the loop. Drawing images which are not in the frame buffer's native format typically involves iterating over a block of pixels, from top to bottom and left to right, setting pixels as the image is decoded.

Functionality like this can be implemented in several ways. One approach is to use the pixel write primitive. Typically this involves some arithmetic to get from the x and y coordinates to a location within framebuffer memory so it is fairly expensive compared with a loop which just increments a pointer. Another approach is to write the data first to a separate buffer in memory and then use a block write primitive to move it to the framebuffer, but again this involves overhead. The eCos framebuffer support provides a third approach: a set of macros specifically for iterating over the frame buffer. Depending on the operation being performed and the details of the framebuffer implementation, these macros may be optimal or near-optimal. Obviously there are limitations. Most importantly the framebuffer device must be known at compile-time: the compiler can do a better job optimizing the code if information such as the frame buffer width are constant. Also each iteration must be performed within a single variable scope: it is not possible to do some of the iteration in one function, some in another.

The Pixel Macros

All the pixel macros take a framebuffer identifier as their first argument. This is the same identifier that can be used with the other macros like `CYG_FB_WRITE_HLINE` and `CYG_FB_ON`, one of the entries in the configuration option `CYGDAT_IO_FRAMEBUFFER_DEVICES`. Using an invalid identifier will result in numerous compile-time error

messages which may bear little resemblance to the original code. In the examples below it is assumed that `FRAMEBUF` has been `#define`'d to a suitable identifier.

Typical use of the pixel macros will look like this:

```
CYG_FB_PIXEL0_VAR(FRAMEBUF);
...
CYG_FB_PIXEL0_FLUSHABS(FRAMEBUF, x, y, width, height);
```

The `VAR` macro will define one or more local variables to keep track of the current pixel position, as appropriate to the framebuffer device. The other pixel macros will then use these variables. For a simple 8bpp linear framebuffer there will be just a byte pointer. For a 1bpp display there may be several variables: a byte pointer, a bit index within that byte, and possibly a cached byte; using a cached value means that the framebuffer may only get read and written once for every 8 pixels, and the compiler may well allocate a register for the cached value; on some platforms framebuffer access will bypass the processor's main cache, so reading from or writing to framebuffer memory will be slow; reducing the number of framebuffer accesses may greatly improve performance.

Because the `VAR` macro defines one or more local variables it is normally placed at the start of a function or block, alongside other local variable definitions.

Once the iteration has been completed there should be a `FLUSHABS` or `FLUSHREL` macro. This serves two purposes. First, if the local variables involve a dirty cached value or similar state then this will be written back. Second, for double-buffered displays the macro sets a bounding box for the part of the screen that has been updated. This allows the double buffer synch operation to update only the part of the display that has been modified, without having to keep track of the current bounding box for every updated pixel. For `FLUSHABS` the `x0` and `y0` arguments specify the top-left corner of the bounding box, which extends for *width* by *height* pixels. For `FLUSHREL` `x0` and `y0` still specify the top-left corner, but the bottom-right corner is now determined from the current pixel position offset by *dx* and *dy*. More specifically, *dx* should move the current horizontal position one pixel to the right of the right-most pixel modified, such that $(x + dx) - x0$ gives the width of the bounding box. Similarly *dy* should move the current vertical position one pixel below the bottom-most pixel modified. In typical code the current pixel position will already correspond in part or in whole to the bounding box corner, as a consequence of iterating over the block of memory.

If a pixel variable has been used only for reading framebuffer memory, not for modifying it, then it should still be flushed. A `FLUSHABS` with a width and height of 0 can be used to indicate that the bounding box is empty. If it is known that the framebuffer device being used does not support double-buffering then again it is possible to specify an empty bounding box. Otherwise portable code should specify a correct bounding box. If the framebuffer device that ends up being used does not support double buffering then the relevant macro arguments are eliminated at compile-time and do not result in any unnecessary code. In addition if there is no cached value or other state then the whole flush operation will be a no-op and no code will be generated.

Failure to perform the flush may result in strange drawing artefacts on some displays which can be very hard to debug. A `FLUSHABS` or `FLUSHREL` macro only needs to be invoked once, at the end of the iteration.

The `SET` macro sets the current position within the framebuffer. It can be used many times within an iteration. However it tends to be somewhat more expensive than `ADDX` or `ADDY`, so usually `SET` is only executed once at the start of an iteration.

```
CYG_FB_PIXEL0_VAR(FRAMEBUF);
CYG_FB_PIXEL0_SET(FRAMEBUF, x, y);
...
CYG_FB_PIXEL0_FLUSHREL(FRAMEBUF, x, y, 0, 0);
```

The `GET` macro retrieves the *x* and *y* coordinates corresponding to the current position. It is provided mainly for symmetry, but can prove useful for debugging.


```

CYG_FB_PIXEL0_VAR(FRAMEBUF);
CYG_FB_PIXEL0_SET(FRAMEBUF, x, y);
...
#ifdef DEBUG
    CYG_FB_PIXEL0_GET(FRAMEBUF, new_x, new_y);
    diag_printf("Halfway through: x now %d, y now %d\n", new_x, new_y);
#endif
...
CYG_FB_PIXEL0_FLUSHREL(FRAMEBUF, x, y, 0, 0);

```

The `ADDX` and `ADDY` macros adjust the current position. The most common increments are 1 and -1, moving to the next or previous pixel horizontally or vertically, but any increment can be used.

```

CYG_FB_PIXEL0_VAR(FRAMEBUF);
CYG_FB_PIXEL0_SET(FRAMEBUF, x, y);
for (rows = height; rows; rows--) {
    for (columns = width; columns; columns--) {
        <perform operation>
        CYG_FB_PIXEL0_ADDX(FRAMEBUF, 1);
    }
    CYG_FB_PIXEL0_ADDX(FRAMEBUF, -1 * width);
    CYG_FB_PIXEL0_ADDY(FRAMEBUF, 1);
}
CYG_FB_PIXEL0_FLUSHREL(FRAMEBUF, x, y, width, 0);

```

Here the current position is moved one pixel to the right each time around the inner loop. In the outer loop the position is first moved back to the start of the current row, then moved one pixel down. For the final flush the current x position is off by width, but the current y position is already correct.

The final two macros `READ` and `WRITE` can be used to examine or update the current pixel value.

```

CYG_FB_PIXEL0_VAR(FRAMEBUF);
CYG_FB_PIXEL0_SET(FRAMEBUF, x, y);
for (rows = height; rows; rows--) {
    for (columns = width; columns; columns--) {
        cyg_fb_colour colour = CYG_FB_PIXEL0_READ(FRAMEBUF);
        if (colour == colour_to_replace) {
            CYG_FB_PIXEL0_WRITE(FRAMEBUF, replacement);
        }
        CYG_FB_PIXEL0_ADDX(FRAMEBUF, 1);
    }
    CYG_FB_PIXEL0_ADDX(FRAMEBUF, -1 * width);
    CYG_FB_PIXEL0_ADDY(FRAMEBUF, 1);
}
CYG_FB_PIXEL0_FLUSHREL(FRAMEBUF, x, y, width, 0);

```

Concurrent Iterations

Although uncommon, in some cases application code may need to iterate over two or more blocks. An example might be an advanced block move where each copied pixel requires some processing. To support this there are `PIXEL1`, `PIXEL2` and `PIXEL3` variants of all the `PIXEL0` macros. For example:

```

CYG_FB_PIXEL0_VAR(FRAMEBUF);
CYG_FB_PIXEL1_VAR(FRAMEBUF);

CYG_FB_PIXEL0_SET(FRAMEBUF, dest_x, dest_y);
CYG_FB_PIXEL1_SET(FRAMEBUF, source_x, source_y);

```

```

for (rows = height; rows; rows--) {
    for (columns = width; columns; columns--) {
        colour = CYG_FB_PIXEL1_READ(FRAMEBUF);
        <do some processing on colour>
        CYG_FB_PIXEL0_WRITE(FRAMEBUF, colour);
        CYG_FB_PIXEL0_ADDX(FRAMEBUF, 1);
        CYG_FB_PIXEL1_ADDX(FRAMEBUF, 1);
    }
    CYG_FB_PIXEL0_ADDX(FRAMEBUF, -100);
    CYG_FB_PIXEL0_ADDY(FRAMEBUF, 1);
    CYG_FB_PIXEL1_ADDX(FRAMEBUF, -100);
    CYG_FB_PIXEL1_ADDY(FRAMEBUF, 1);
}

CYG_FB_PIXEL0_FLUSHABS(FRAMEBUF, source_x, source_y, width, height);
CYG_FB_PIXEL1_FLUSHABS(FRAMEBUF, 0, 0, 0, 0); // Only used for reading

```

The `PIXEL0`, `PIXEL1`, `PIXEL2` and `PIXEL3` macros all use different local variables so there are no conflicts. The variable names also depend on the framebuffer device. If the target has two displays and two active framebuffer devices then the pixel macros can be used with the two devices without conflict:

```

CYG_FB_PIXEL0_VAR(FRAMEBUF0);
CYG_FB_PIXEL0_VAR(FRAMEBUF1);
...

```

Writing a Framebuffer Device Driver

Name

Porting — writing a new framebuffer device driver

Description

As with most device drivers, the easiest way to write a new framebuffer package is to start with an existing one. Suitable ones include the PC VGA mode13 driver, an 8bpp paletted display, and the ARM iPAQ driver, a 16bpp true colour display. This document only outlines the process.

Before writing any code it is necessary to decide how many framebuffer devices should be provided by the device driver. Each such device requires a `cyg_fb` structure and appropriate functions, and an identifier for use with the macro API plus associated macros. There are no hard rules here. Some device drivers may support just a single device, others may support many devices which drive the hardware in different modes or orientations. Optional functionality such as viewports and page flipping may be supported by having different `cyg_fb` devices, or by a number of configuration options which affect a single `cyg_fb` device. Usually providing multiple `cyg_fb` structures is harmless because the unused ones will get eliminated at link-time.

Configuration

The CDL for a framebuffer package is usually straightforward. A framebuffer package should be a hardware package and reside in the `devs/framebuf` hierarchy, further organized by architecture. Generic framebuffer packages, if any, can go into a `generic` subdirectory, and will normally rely on the platform HAL to provide some platform-specific information such as base addresses. The package should be part of the target definition and hence loaded automatically, but should be `active_if CYGPKG_IO_FRAMEBUFFER` so that the driver only gets built if the generic framebuffer support is explicitly added to the configuration.

The configuration option `CYGDAT_IO_FRAMEBUFFER_DEVICES` should hold all the valid identifiers which can be used as the first argument for the macro API. This helps application developers to select the appropriate identifier, and allows higher-level graphics library packages to check that they have been configured correctly. This is achieved using something like the following, where `mode13_320x200x8` is a valid identifier for the PC VGA driver:

```
requires { is_substr(CYGDAT_IO_FRAMEBUFFER_DEVICES, " mode13_320x200x8 ") }
```

The spaces ensure that the CDL inference engine keeps the identifiers separate.

`CYGPKG_IO_FRAMEBUFFER` contains a number of interfaces which should be implemented by individual device drivers when appropriate. This is used to eliminate some code or data structure fields at compile-time, keeping down memory requirements. The interfaces are `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_32BPP`, `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_TRUE_COLOUR`, `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_PALETTE`, `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_WRITEABLE_PALETTE`, `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_DOUBLE_BUFFER`, and `CYGHWR_IO_FRAMEBUFFER_FUNCTIONALITY_VIEWPORT`. For example if a device driver provides a true colour display but fails to implement the relevant interface then functions like `cyg_fb_make_colour` will be no-ops.

Device drivers for paletted displays should observe the generic configuration option `CYGFUN_IO_FRAMEBUFFER_INSTALL_DEFAULT_PALETTE` and install either `cyg_fb_palette_ega` or `cyg_fb_palette_vga` as part of their `cyg_fb_on` implementation.

Exported Header File(s)

Each framebuffer device driver should export one or more header files to `cyg/io/framebufs`. A custom build step in `CYGPKG_IO_FRAMEBUFFER` ensures that application code can just `#include cyg/io/framebuf.h` and this will automatically include the device-specific headers. Drivers may export one header per `cyg_fb` device or a single header for all devices, without affecting any code outside the device driver.

Each exported header serves two purposes. First it defines the [parameters](#), [drawing primitive](#) macros, and [iteration](#) macros for each device. Second it declares the `cyg_fb` structure.

Parameters

The parameter section should resemble the following:

```
#define CYG_FB_320x240x16_STRUCT          cyg_ipaq_fb_320x240x16
#define CYG_FB_320x240x16_DEPTH          16
#define CYG_FB_320x240x16_FORMAT          CYG_FB_FORMAT_16BPP_TRUE_565
#define CYG_FB_320x240x16_WIDTH           320
#define CYG_FB_320x240x16_HEIGHT          240
#define CYG_FB_320x240x16_VIEWPORT_WIDTH 320
#define CYG_FB_320x240x16_VIEWPORT_HEIGHT 240
#define CYG_FB_320x240x16_FLAGS0          (CYG_FB_FLAGS0_LINEAR_FRAMEBUFFER | \
                                             CYG_FB_FLAGS0_TRUE_COLOUR    | \
                                             CYG_FB_FLAGS0_BLANK           | \
                                             CYG_FB_FLAGS0_BACKLIGHT)

#define CYG_FB_320x240x16_FLAGS1          0
#define CYG_FB_320x240x16_FLAGS2          0
#define CYG_FB_320x240x16_FLAGS3          0
#define CYG_FB_320x240x16_BASE             ((void*)0x01FC0020)
#define CYG_FB_320x240x16_STRIDE           640
```

Here `320x240x16` is the framebuffer identifier for use with the macro API. Application code like:

```
#define FRAMEBUF 320x240x16
cyg_ucount16 width = CYG_FB_WIDTH(FRAMEBUF);
```

will end up using the `CYG_FB_320x240x16_WIDTH` definition. To allow for efficient portable code all parameters must be compile-time constants. If the hardware may allow some of the parameters to be varied, for example different resolutions, then this should be handled either by defining separate devices for each resolution or by configuration options.

The viewport width and height should always be defined. If the device driver does not support a viewport then these will be the same as the standard width and height.

To allow for future expansion there are `FLAGS1`, `FLAGS2` and `FLAGS3` parameters. No flags are defined for these at present, but device drivers should still define the parameters.

Drawing Primitives

For each device the exported header file should define macros for the drawing primitives, using the same naming convention as for parameters. In the case of true colour displays there should also be macros for the make-colour and break-colour primitives:

```
#define CYG_FB_320x240x16_WRITE_PIXEL(_x_, _y_, _colour_) ...
#define CYG_FB_320x240x16_READ_PIXEL(_x_, _y_) ...
```

```

#define CYG_FB_320x240x16_WRITE_HLINE(_x_, _y_, _len_, _colour_) ...
#define CYG_FB_320x240x16_WRITE_VLINE(_x_, _y_, _len_, _colour_) ...
#define CYG_FB_320x240x16_FILL_BLOCK(_x_, _y_, _w_, _h_, _colour_) ...
#define CYG_FB_320x240x16_WRITE_BLOCK(_x_, _y_, _w_, _h_, _data_, _off_, _s_) ...
#define CYG_FB_320x240x16_READ_BLOCK(_x_, _y_, _w_, _h_, _data_, _off_, _s_) ...
#define CYG_FB_320x240x16_MOVE_BLOCK(_x_, _y_, _w_, _h_, _new_x_, _new_y_) ...
#define CYG_FB_320x240x16_MAKE_COLOUR(_r_, _g_, _b_) ...
#define CYG_FB_320x240x16_BREAK_COLOUR(_colour_, _r_, _g_, _b_) ...

```

For typical linear framebuffers there are default implementations of all of these primitives in the generic framebuffer package, held in the exported header `cyg/io/framebuf.inl`. Hence the definitions will typically look something like:

```

#include <cyg/io/framebuf.inl>
...
#define CYG_FB_320x240x16_WRITE_PIXEL(_x_, _y_, _colour_)      \
    CYG_MACRO_START                                           \
    cyg_fb_linear_write_pixel_16_inl(CYG_FB_320x240x16_BASE, \
                                     CYG_FB_320x240x16_STRIDE, \
                                     _x_, _y_, _colour_);      \
    CYG_MACRO_END
#define CYG_FB_320x240x16_READ_PIXEL(_x_, _y_)                \
    ({ cyg_fb_linear_read_pixel_16_inl(CYG_FB_320x240x16_BASE, \
                                       CYG_FB_320x240x16_STRIDE, \
                                       _x_, _y_); })
...

```

All of the drawing primitives have variants for the common display depths and layouts: 1le, 1be, 2le, 2be, 4le, 4be, 8, 16 and 32. The inlines take the framebuffer memory base address as the first argument, and the stride in bytes as the second. Similarly there are default definitions of the true colour primitives for 8BPP_TRUE_332, 16BPP_TRUE_565, 16BPP_TRUE_555, and 32BPP_TRUE_0888:

```

#define CYG_FB_320x240x16_MAKE_COLOUR(_r_, _g_, _b_)          \
    ({ CYG_FB_MAKE_COLOUR_16BPP_TRUE_565(_r_, _g_, _b_); })
#define CYG_FB_320x240x16_BREAK_COLOUR(_colour_, _r_, _g_, _b_) \
    CYG_MACRO_START                                           \
    CYG_FB_BREAK_COLOUR_16BPP_TRUE_565(_colour_, _r_, _g_, _b_); \
    CYG_MACRO_END

```

These default definitions assume the most common layout of colours within a pixel value, so for example `CYG_FB_MAKE_COLOUR_16BPP_TRUE_565` assumes bits 0 to 4 hold the blue intensity, bits 5 to 10 the green, and bits 11 to 15 the red.

If the hardware does not implement a linear framebuffer then obviously writing the device driver will be significantly more work. The macros will have to perform the operations themselves instead of relying on generic implementations. The required functionality should be obvious, and the generic implementations can still be consulted as a reference. For complicated hardware it may be appropriate to map the macros onto function calls, rather than try to implement everything inline.

Note: At the time of writing the support for linear framebuffers is incomplete. Only 8bpp, 16bpp and 32bpp depths have full support. There may also be future extensions, for example `r90`, `r180` and `r270` variants to support rotation in software, and `db` variants to support double-buffered displays.

Iteration Macros

In addition to the drawing primitives the exported header file should define iteration macros:

```
#define CYG_FB_320x240x16_PIXELx_VAR( _fb_, _id_) ...
#define CYG_FB_320x240x16_PIXELx_SET( _fb_, _id_, _x_, _y_) ...
#define CYG_FB_320x240x16_PIXELx_GET( _fb_, _id_, _x_, _y_) ...
#define CYG_FB_320x240x16_PIXELx_ADDX( _fb_, _id_, _incr_) ...
#define CYG_FB_320x240x16_PIXELx_ADDY( _fb_, _id_, _incr_) ...
#define CYG_FB_320x240x16_PIXELx_WRITE( _fb_, _id_, _colour_) ...
#define CYG_FB_320x240x16_PIXELx_READ( _fb_, _id_)...
#define CYG_FB_320x240x16_PIXELx_FLUSHABS( _fb_, _id_, _x0_, _y0_, _w_, _h_) ...
#define CYG_FB_320x240x16_PIXELx_FLUSHREL( _fb_, _id_, _x0_, _y0_, _dx_, _dy_) ...
```

The `_fb_` argument will be the identifier, in this case 320x240x16, and the `_id_` will be a small number, 0 for a `PIXEL0` iteration, 1 for `PIXEL1`, and so on. Together these two should allow unique local variable names to be constructed. Again there are default definitions of the macros in `cyg/io/framebuf.inl` for linear framebuffers:

```
#define CYG_FB_320x240x16_PIXELx_VAR( _fb_, _id_) \
    CYG_FB_PIXELx_VAR_16( _fb_, _id_)
#define CYG_FB_320x240x16_PIXELx_SET( _fb_, _id_, _x_, _y_) \
    CYG_MACRO_START \
    CYG_FB_PIXELx_SET_16( _fb_, _id_, \
        CYG_FB_320x240x16_BASE, \
        320, _x_, _y_); \
    CYG_MACRO_END
```

The linear `SET` and `GET` macros take base and stride information. The `ADDX` and `ADDY` macros only need the stride. By convention most of the macros are wrapped in `CYG_MACRO_START/CYG_MACRO_END` or `{/}` pairs, allowing debug code to be inserted if necessary. However the `_VAR` macro must not be wrapped in this way: its purpose is to define one or more local variables; wrapping the macro would declare the variables in a new scope, inaccessible to the other macros.

Again for non-linear framebuffers it will be necessary to implement these macros fully rather than rely on generic implementations, but the generic versions can be consulted as a reference.

The `cyg_fb` declaration

Finally there should be an export of the `cyg_fb` structure or structures. Typically this uses the `_STRUCT` parameter, reducing the possibility of an accidental mismatch between the macro and function APIs:

```
extern cyg_fb    CYG_FB_320x240x16_STRUCT;
```

Driver-Specific Source Code

Exporting parameters and macros in a header file is not enough. It is also necessary to actually define the `cyg_fb` structure or structures, and to provide hardware-specific versions of the control operations. For non-linear framebuffers it will also be necessary to provide the drawing functions. There is a utility macro `CYG_FB_FRAMEBUFFER` for instantiating a `cyg_fb` structure. Drivers may ignore this macro and do the work themselves, but at an increased risk of compatibility problems with future versions of the generic code.

```

CYG_FB_FRAMEBUFFER(CYG_FB_320x240x16_STRUCT,
    CYG_FB_320x240x16_DEPTH,
    CYG_FB_320x240x16_FORMAT,
    CYG_FB_320x240x16_WIDTH,
    CYG_FB_320x240x16_HEIGHT,
    CYG_FB_320x240x16_VIEWPORT_WIDTH,
    CYG_FB_320x240x16_VIEWPORT_HEIGHT,
    CYG_FB_320x240x16_BASE,
    CYG_FB_320x240x16_STRIDE,
    CYG_FB_320x240x16_FLAGS0,
    CYG_FB_320x240x16_FLAGS1,
    CYG_FB_320x240x16_FLAGS2,
    CYG_FB_320x240x16_FLAGS3,
    0, 0, 0, 0, // fb_driver0 -> fb_driver3
    &cyg_ipaq_fb_on,
    &cyg_ipaq_fb_off,
    &cyg_ipaq_fb_ioctl,
    &cyg_fb_nop_synch,
    &cyg_fb_nop_read_palette,
    &cyg_fb_nop_write_palette,
    &cyg_fb_dev_make_colour_16bpp_true_565,
    &cyg_fb_dev_break_colour_16bpp_true_565,
    &cyg_fb_linear_write_pixel_16,
    &cyg_fb_linear_read_pixel_16,
    &cyg_fb_linear_write_hline_16,
    &cyg_fb_linear_write_vline_16,
    &cyg_fb_linear_fill_block_16,
    &cyg_fb_linear_write_block_16,
    &cyg_fb_linear_read_block_16,
    &cyg_fb_linear_move_block_16,
    0, 0, 0, 0 // fb_spare0 -> fb_spare3
);

```

The first 13 arguments to the macro correspond to the device parameters. The next four are arbitrary `CYG_ADDRWORD` values for use by the device driver. Typically these are used to share on/off/ioctl functions between multiple `cyg_fb` structure. They are followed by function pointers: on/off/ioctl control; double buffer synch; palette management; true colour support; and the drawing primitives. `nop` versions of the on, off, ioctl, synch, palette management and true colour functions are provided by the generic framebuffer package, and often these arguments to the `CYG_FB_FRAMEBUFFER` macro will be discarded at compile-time because the relevant CDL interface is not implemented. The final four arguments are currently unused and should be 0. They are intended for future expansion, with a value of 0 indicating that a device driver does not implement non-core functionality.

As with the macros there are default implementations of the true colour primitives for `8bpp_true_332`, `16bpp_true_565`, `16bpp_true_555` and `32bpp_true_0888`, assuming the most common layout for these colour modes. There are also default implementations of the drawing primitives for linear framebuffers, with variants for the common display depths and layouts. Obviously non-linear framebuffers will need rather more work.

Typically a true colour or grey scale framebuffer device driver will have to implement just three hardware-specific functions:

```

int
cyg_ipaq_fb_on(cyg_fb* fb)
{
    ...
}

```

```
int
cyg_ipaq_fb_off(cyg_fb* fb)
{
    ...
}

int
cyg_ipaq_fb_ioctl(cyg_fb* fb, cyg_ucount16 key, void* data, size_t* len)
{
    int result;

    switch(key) {
        case CYG_FB_IOCTL_BLANK_GET: ...
        ...
        default: result = ENOSYS; break;
    }
    return result;
}
```

These control operations are entirely hardware-specific and cannot be implemented by generic code. Paletted displays will need two more functions, again hardware-specific:

```
void
cyg_pcvga_fb_read_palette(cyg_fb* fb, cyg_ucount32 first, cyg_ucount32 len,
                          void* data)
{
    ...
}

void
cyg_pcvga_fb_write_palette(cyg_fb* fb, cyg_ucount32 first, cyg_ucount32 len,
                           const void* data, cyg_ucount16 when)
{
    ...
}
```

Future Expansion

As has been mentioned before framebuffer hardware varies widely. The design of a generic framebuffer API requires complicated trade-offs between efficiency, ease of use, ease of porting, and still supporting a very wide range of hardware. To some extent this requires a lowest common denominator approach, but the design allows for some future expansion and optional support for more advanced features like hardware acceleration.

The most obvious route for expansion is the `ioctl` interface. Device drivers can define their own keys, values `0x8000` and higher, for any operation. Alternatively a device driver does not have to implement just the interface provided by the generic framebuffer package: additional functions and macros can be exported as required.

Currently there are only a small number of `ioctl` operations. Additional ones may get added in future, for example to support a hardware mouse cursor, but only in cases where the functionality is likely to be provided by a significant number of framebuffer devices. Adding new generic functionality adds to the maintenance overhead of both code and documentation. When a new generic `ioctl` operation is added there will usually also be one or more new flags, so that device drivers can indicate they support the functionality. At the time of writing only 12 of the 32 `FLAGS0` flags are used, and a further 96 are available in `FLAGS1`, `FLAGS2` and `FLAGS3`.

Another route for future expansion is the four spare arguments to the `CYG_FB_FRAMEBUFFER` macro. As an example of how these may get used in future, consider support for 3d hardware acceleration. One of the spare fields would become another table of function pointers to the various accelerators, or possibly a structure. A `FLAGS0` flag would indicate that the device driver implements such functionality.

Other forms of expansion such as defining a new standard drawing primitive would be more difficult, since this would normally involve changing the `CYG_FB_FRAMEBUFFER` macro. Such expansion should not be necessary because the existing primitives provide all reasonable core functionality. Instead other packages such as graphics libraries can work on top of the existing primitives.

XII. eCos POSIX compatibility layer

Chapter 31. POSIX Standard Support

eCos contains support for the POSIX Specification (ISO/IEC 9945-1)[POSIX].

POSIX support is divided between the POSIX and the FILEIO packages. The POSIX package provides support for threads, signals, synchronization, timers and message queues. The FILEIO package provides support for file and device I/O. The two packages may be used together or separately, depending on configuration.

This document takes a functional approach to the POSIX library. Support for a function implies that the data types and definitions necessary to support that function, and the objects it manipulates, are also defined. Any exceptions to this are noted, and unless otherwise noted, implemented functions behave as specified in the POSIX standard.

This document only covers the differences between the eCos implementation and the standard; it does not provide complete documentation. For full information, see the POSIX standard [POSIX]. Online, the Open Group Single Unix Specification [SUS2] provides complete documentation of a superset of POSIX. If you have access to a Unix system with POSIX compatibility, then the manual pages for this will be of use. There are also a number of books available. [Lewine] covers the process, signal, file and I/O functions, while [Lewis1], [Lewis2], [Nichols] and [Norton] cover Pthreads and related topics (see Bibliography, xref). However, many of these books are oriented toward using POSIX in non-embedded systems, so care should be taken in applying them to programming under eCos.

The remainder of this chapter broadly follows the structure of the POSIX Specification. References to the appropriate section of the Standard are included.

Omitted functions marked with “// TBA” are potential candidates for later implementation.

Process Primitives [POSIX Section 3]

Functions Implemented

```
int kill(pid_t pid, int sig);
int pthread_kill(pthread_t thread, int sig);
int sigaction(int sig, const struct sigaction *act,
              struct sigaction *oact);
int sigqueue(pid_t pid, int sig, const union sigval value);
int sigprocmask(int how, const sigset_t *set,
               sigset_t *oset);
int pthread_sigmask(int how, const sigset_t *set,
                   sigset_t *oset);
int sigpending(sigset_t *set);
int sigsuspend(const sigset_t *set);
int sigwait(const sigset_t *set, int *sig);
int sigwaitinfo(const sigset_t *set, siginfo_t *info);
int sigtimedwait(const sigset_t *set, siginfo_t *info,
                const struct timespec *timeout);
int sigemptyset(sigset_t *set);
int sigfillset(sigset_t *set);
int sigaddset(sigset_t *set, int signo);
int sigdelset(sigset_t *set, int signo);
int sigismember(const sigset_t *set, int signo);
unsigned int alarm( unsigned int seconds );
int pause( void );
unsigned int sleep( unsigned int seconds );
```

Functions Omitted

```
pid_t fork(void);
int execl( const char *path, const char *arg, ... );
int execv( const char *path, char *const argv[] );
int execl( const char *path, const char *arg, ... );
int execve( const char *path, char *const argv[],
            char *const envp[] );
int execlp( const char *path, const char *arg, ... );
int execvp( const char *path, char *const argv[] );
int pthread_atfork( void(*prepare)(void),
                   void (*parent)(void),
                   void (*child)() );
pid_t wait( int *stat_loc );
pid_t waitpid( pid_t pid, int *stat_loc,
               int options );
void _exit( int status );
```

Notes

- Signal handling may be enabled or disabled with the `CYGPKG_POSIX_SIGNALS` option. Since signals are used by other POSIX components, such as timers, disabling signals will disable those components too.
- `kill()` and `sigqueue()` may only take a **pid** argument of zero, which maps to the current process.
- The `SIGEV_THREAD` notification type is not currently implemented.
- Job Control and Memory Protection signals are not supported.
- An extra implementation defined `si_code` value, `SI_EXCEPT`, is defined to distinguish hardware generated exceptions from others.
- Extra signals are defined: `_SIGTRAP_`, `_SIGIOT_`, `_SIGEMT_`, and `_SIGSYS_`. These are largely to maintain compatibility with the signal numbers used by GDB.
- Signal delivery may currently occur at unexpected places in some API functions. Using `longjmp()` to transfer control out of a signal handler may result in the interrupted function not being able to complete properly. This may result in later function calls failing or deadlocking.

Process Environment [POSIX Section 4]

Functions Implemented

```
int uname( struct utsname *name );
time_t time( time_t *tloc );
char *getenv( const char *name );
int isatty( int fd );
long sysconf( int name );
```

Functions Omitted

```

pid_t getpid( void );
pid_t getppid( void );
uid_t getuid( void );
uid_t geteuid( void );
gid_t getgid( void );
gid_t getegid( void );
int setuid( uid_t uid );
int setgid( gid_t gid );
int getgroups( int gidsetsize, gid_t grouplist[] );
char *getlogin( void );
int getlogin_r( char *name, size_t namesize );
pid_t getpgrp( void );
pid_t setsid( void );
int setpgid( pid_t pid, pid_t pgid );
char *ctermid( char *s);
char *ttyname( int fd ); // TBA
int ttyname_r( int fd, char *name, size_t namesize); // TBA
clock_t times( struct tms *buffer ); // TBA

```

Notes

- The fields of the *utsname* structure are initialized as follows:

```

sysname "eCos"
nodename "" (gethostname() is currently not available)

release Major version number of the kernel
version Minor version number of the kernel
machine "" (Requires some config tool changes)

```

The sizes of these strings are defined by `CYG_POSIX_UTSNAME_LENGTH` and `CYG_POSIX_UTSNAME_NODENAME_LENGTH`. The latter defaults to the value of the former, but may also be set independently to accommodate a longer node name.

- The *time()* function is currently implemented in the C library.
- A set of environment strings may be defined at configuration time with the `CYGDAT_LIBC_DEFAULT_ENVIRONMENT` option. The application may also define an environment by direct assignment to the **environ** variable.
- At present *isatty()* assumes that any character device is a tty and that all other devices are not ttys. Since the only kind of device that eCos currently supports is serial character devices, this is an adequate distinction.
- All system variables supported by `sysconf` will yield a value. However, those that are irrelevant to eCos will either return the default minimum defined in `<limits.h>`, or zero.

Files and Directories [POSIX Section 5]

Functions Implemented

```
DIR *opendir( const char *dirname );
struct dirent *readdir( DIR *dirp );
int readdir_r( DIR *dirp, struct dirent *entry,
               struct dirent **result );
void rewinddir( DIR *dirp );
int closedir( DIR *dirp );
int chdir( const char *path );
char *getcwd( char *buf, size_t size );
int open( const char * path , int oflag , ... );
int creat( const char * path, mode_t mode );
int link( const char *existing, const char *new );
int mkdir( const char *path, mode_t mode );
int unlink( const char *path );
int rmdir( const char *path );
int rename( const char *old, const char *new );
int stat( const char *path, struct stat *buf );
int fstat( int fd, struct stat *buf );
int access( const char *path, int amode );
long pathconf(const char *path, int name);
long fpathconf(int fd, int name);
```

Functions Omitted

```
mode_t umask( mode_t cmask );
int mkfifo( const char *path, mode_t mode );
int chmod( const char *path, mode_t mode );    // TBA
int fchmod( int fd, mode_t mode );             // TBA
int chown( const char *path, uid_t owner, gid_t group );
int utime( const char *path, const struct utimbuf *times ); // TBA
int ftruncate( int fd, off_t length );          // TBA
```

Notes

- If a call to `open()` or `creat()` supplies the third `_mode_` parameter, it will currently be ignored.
- Most of the functionality of these functions depends on the underlying filesystem.
- Currently `access()` only checks the `F_OK` mode explicitly, the others are all assumed to be true by default.
- The maximum number of open files allowed is supplied by the `CYGNUM_FILEIO_NFILE` option. The maximum number of file descriptors is supplied by the `CYGNUM_FILEIO_NFD` option.

Input and Output [POSIX Section 6]

Functions Implemented

```
int dup( int fd );
int dup2( int fd, int fd2 );
int close( int fd );
ssize_t read( int fd, void *buf, size_t nbyte );
ssize_t write( int fd, const void *buf, size_t nbyte );
int fcntl( int fd, int cmd, ... );
off_t lseek( int fd, off_t offset, int whence );
int fsync( int fd );
int fdatasync( int fd );
```

Functions Omitted

```
int pipe( int fildes[2] );
int aio_read( struct aiocb *aiocbp ); // TBA
int aio_write( struct aiocb *aiocbp ); // TBA
int lio_listio( int mode, struct aiocb *const list[],
               int nent, struct sigevent *sig ); // TBA
int aio_error( struct aiocb *aiocbp ); // TBA
int aio_return( struct aiocb *aiocbp ); // TBA
int aio_cancel( int fd, struct aiocb *aiocbp ); // TBA
int aio_suspend( const struct aiocb *const list[],
               int nent, const struct timespec *timeout ); // TBA
int aio_fsync( int op, struct aiocb *aiocbp );
// TBA
```

Notes

- Only the *F_DUPFD* command of *fcntl()* is currently implemented.
- Most of the functionality of these functions depends on the underlying filesystem.

Device and Class Specific Functions [POSIX Section 7]

Functions Implemented

```
speed_t cfgetospeed( const struct termios *termios_p );
int cfsetospeed( struct termios *termios_p, speed_t speed );
speed_t cfgetispeed( const struct termios *termios_p );
int cfsetispeed( struct termios *termios_p, speed_t speed );
int tcgetattr( int fd, struct termios *termios_p );
int tcsetattr( int fd, int optional_actions,
              const struct termios *termios_p );
int tcsendbreak( int fd, int duration );
int tcdrain( int fd );
int tcflush( int fd, int queue_selector );
```

```
int tcsendbreak( int fd, int action );
```

Functions Omitted

```
pid_t tcgetpgrp( int fd );
int tcsetpgrp( int fd, pid_t pgrp );
```

Notes

- Only the functionality relevant to basic serial device control is implemented. Only very limited support for canonical input is provided, and then only via the “tty” devices, not the “serial” devices. None of the functionality relevant to job control, controlling terminals and sessions is implemented.
- Only *MIN* = 0 and *TIME* = 0 functionality is provided.
- Hardware flow control is supported if the underlying device driver and serial port support it.
- Support for break, framing and parity errors depends on the functionality of the hardware and device driver.

C Language Services [POSIX Section 8]

Functions Implemented

```
char *setlocale( int category, const char *locale );
int fileno( FILE *stream );
FILE *fdopen( int fd, const char *type );
int getc_unlocked( FILE *stream );
int getchar_unlocked( void );
int putc_unlocked( FILE *stream );
int putchar_unlocked( void );
char *strtok_r( char *s, const char *sep,
               char **lasts );
char *asctime_r( const struct tm *tm, char *buf );
char *ctime_r( const time_t *clock, char *buf );
struct tm *gmtime_r( const time_t *clock,
                    struct tm *result );
struct tm *localtime_r( const time_t *clock,
                      struct tm *result );
int rand_r( unsigned int *seed );
```

Functions Omitted

```
void flockfile( FILE *file );
int ftrylockfile( FILE *file );
void funlockfile( FILE *file );
int sigsetjmp( sigjmp_buf env, int savemask ); // TBA
void siglongjmp( sigjmp_buf env, int val ); // TBA
void tzset(void); // TBA
```

Notes

- *setlocale()* is implemented in the C library Internationalization package.
- Functions *fileno()* and *fdopen()* are implemented in the C library STDIO package.
- Functions *getc_unlocked()*, *getchar_unlocked()*, *putc_unlocked()* and *putchar_unlocked()* are defined but are currently identical to their non-unlocked equivalents.
- *strtok_r()*, *asctime_r()*, *ctime_r()*, *gmtime_r()*, *localtime_r()* and *rand_r()* are all currently in the C library, alongside their non-reentrant versions.

System Databases [POSIX Section 9]

Functions Implemented

<none>

Functions Omitted

```
struct group *getgrgid( gid_t gid );
int getgrgid( gid_t gid, struct group *grp, char *buffer,
              size_t bufsize, struct group **result );
struct group *getgrname( const char *name );
int getgrname_r( const char *name, struct group *grp,
                 char *buffer, size_t bufsize, struct group **result );
struct passwd *getpwuid( uid_t uid );
int getpwuid_r( uid_t uid, struct passwd *pwd,
                char *buffer, size_t bufsize, struct passwd **result );
struct passwd *getpwnam( const char *name );
int getpwnam_r( const char *name, struct passwd *pwd,
                char *buffer, size_t bufsize, struct passwd **result );
```

Notes

- None of the functions in this section are implemented.

Data Interchange Format [POSIX Section 10]

This section details *tar* and *cpio* formats. Neither of these is supported by eCos.

Synchronization [POSIX Section 11]

Functions Implemented

```

int sem_init(sem_t *sem, int pshared, unsigned int value);
int sem_destroy(sem_t *sem);
int sem_wait(sem_t *sem);
int sem_trywait(sem_t *sem);
int sem_post(sem_t *sem);
int sem_getvalue(sem_t *sem, int *sval);
int pthread_mutexattr_init( pthread_mutexattr_t *attr);
int pthread_mutexattr_destroy( pthread_mutexattr_t *attr);
int pthread_mutex_init(pthread_mutex_t *mutex,
    const pthread_mutexattr_t *mutex_attr);
int pthread_mutex_destroy(pthread_mutex_t *mutex);
int pthread_mutex_lock(pthread_mutex_t *mutex);
int pthread_mutex_trylock(pthread_mutex_t *mutex);
int pthread_mutex_timedlock(pthread_mutex_t *mutex,
    const struct timespec *abstime);

int pthread_mutex_unlock(pthread_mutex_t *mutex);
int pthread_condattr_init(pthread_condattr_t *attr);
int pthread_condattr_destroy(pthread_condattr_t *attr);
int pthread_cond_init(pthread_cond_t *cond,
    const pthread_condattr_t *attr);
int pthread_cond_destroy(pthread_cond_t *cond);
int pthread_cond_signal(pthread_cond_t *cond);
int pthread_cond_broadcast(pthread_cond_t *cond);
int pthread_cond_wait(pthread_cond_t *cond,
    pthread_mutex_t *mutex);
int pthread_cond_timedwait(pthread_cond_t *cond,
    pthread_mutex_t *mutex,
    const struct timespec *abstime);

```

Functions Omitted

```

sem_t *sem_open(const char *name, int oflag, ...); // TBA
int sem_close(sem_t *sem); // TBA
int sem_unlink(const char *name); // TBA
int pthread_mutexattr_getpshared( const pthread_mutexattr_t *attr,
    int *pshared );
int pthread_mutexattr_setpshared( const pthread_mutexattr_t *attr,
    int pshared );
int pthread_condattr_getpshared( const pthread_condattr_t *attr,
    int *pshared);
int pthread_condattr_setpshared( const pthread_condattr_t *attr,
    int pshared);

```

Notes

- The presence of semaphores is controlled by the `CYGPKG_POSIX_SEMAPHORES` option. This in turn causes the `_POSIX_SEMAPHORES` feature test macro to be defined and the semaphore API to be made available.

- The **pshared** argument to *sem_init()* is not implemented, its value is ignored.
- Functions *sem_open()*, *sem_close()* and *sem_unlink()* are present but always return an error (ENOSYS).
- The exact priority inversion protocols supported may be controlled with the `_POSIX_THREAD_PRIO_INHERIT` and `_POSIX_THREAD_PRIO_PROTECT` configuration options.
- `{_POSIX_THREAD_PROCESS_SHARED}` is not defined, so the **process-shared** mutex and condition variable attributes are not supported, and neither are the functions *pthread_mutexattr_getpshared()*, *pthread_mutexattr_setpshared()*, *pthread_condattr_getpshared()* and *pthread_condattr_setpshared()*.
- Condition variables do not become bound to a particular mutex when *pthread_cond_wait()* is called. Hence different threads may wait on a condition variable with different mutexes. This is at variance with the standard, which requires a condition variable to become (dynamically) bound by the first waiter, and unbound when the last finishes. However, this difference is largely benign, and the cost of policing this feature is non-trivial.

Memory Management [POSIX Section 12]

Functions Implemented

<none>

Functions Omitted

```
int mlockall( int flags );
int munlockall( void );
int mlock( const void *addr, size_t len );
int munlock( const void *addr, size_t len );
void mmap( void *addr, size_t len, int prot, int flags,
           int fd, off_t off );
int munmap( void *addr, size_t len );
int mprotect( const void *addr, size_t len, int prot );
int msync( void *addr, size_t len, int flags );
int shm_open( const char *name, int oflag, mode_t mode );
int shm_unlink( const char *name );
```

Notes

None of these functions are currently provided. Some may be implemented in a restricted form in the future.

Execution Scheduling [POSIX Section 13]

Functions Implemented

```
int sched_yield(void);
int sched_get_priority_max(int policy);
```

```

int sched_get_priority_min(int policy);
int sched_rr_get_interval(pid_t pid, struct timespec *t);
int pthread_attr_setscope(pthread_attr_t *attr, int scope);
int pthread_attr_getscope(const pthread_attr_t *attr, int *scope);
int pthread_attr_setinheritsched(pthread_attr_t *attr, int inherit);
int pthread_attr_getinheritsched(const pthread_attr_t *attr, int *inherit);
int pthread_attr_setschedpolicy(pthread_attr_t *attr, int policy);
int pthread_attr_getschedpolicy(const pthread_attr_t *attr, int *policy);
int pthread_attr_setschedparam( pthread_attr_t *attr, const struct sched_param *param);
int pthread_attr_getschedparam( const pthread_attr_t *attr,
                                struct sched_param *param);
int pthread_setschedparam(pthread_t thread, int policy,
                           const struct sched_param *param);
int pthread_getschedparam(pthread_t thread, int *policy,
                           struct sched_param *param);
int pthread_mutexattr_setprotocol( pthread_mutexattr_t *attr,
                                   int protocol);
int pthread_mutexattr_getprotocol( pthread_mutexattr_t *attr,
                                   int *protocol);
int pthread_mutexattr_setprioceiling( pthread_mutexattr_t *attr,
                                       int prioceiling);
int pthread_mutexattr_getprioceiling( pthread_mutexattr_t *attr,
                                       int *prioceiling);
int pthread_mutex_setprioceiling( pthread_mutex_t *mutex,
                                   int prioceiling,
                                   int *old_ceiling);
int pthread_mutex_getprioceiling( pthread_mutex_t *mutex,
                                   int *prioceiling);

```

Functions Omitted

```

int sched_setparam(pid_t pid, const struct sched_param *param);
int sched_getparam(pid_t pid, struct sched_param *param);
int sched_setscheduler(pid_t pid, int policy,
                       const struct sched_param *param);
int sched_getscheduler(pid_t pid);

```

Notes

- The functions *sched_setparam()*, *sched_getparam()*, *sched_setscheduler()* and *sched_getscheduler()* are present but always return an error.
- The scheduler policy *SCHED_OTHER* is equivalent to *SCHED_RR*.
- Only *PTHREAD_SCOPE_SYSTEM* is supported as a **contentionscope** attribute.
- The default thread scheduling attributes are:

contentionscope	PTHREAD_SCOPE_SYSTEM
inheritsched	PTHREAD_INHERIT_SCHED
schedpolicy	SCHED_OTHER
schedparam.sched	0

- Mutex priority inversion protection is controlled by a number of kernel configuration options. If `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_INHERIT`

is defined then `{_POSIX_THREAD_PRIO_INHERIT}` will be defined and `PTHREAD_PRIO_INHERIT` may be set as the protocol in a *pthread_mutexattr_t* object. If `CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_CEILING` is defined then `{_POSIX_THREAD_PRIO_PROTECT}` will be defined and `PTHREAD_PRIO_PROTECT` may be set as the protocol in a *pthread_mutexattr_t* object.

- The default attribute values set by *pthread_mutexattr_init()* is to set the protocol attribute to `PTHREAD_PRIO_NONE` and the prioceiling attribute to zero.

Clocks and Timers [POSIX Section 14]

Functions Implemented

```
int clock_settime( clockid_t clock_id,
const struct timespec *tp);
int clock_gettime( clockid_t clock_id, struct timespec *tp);
int clock_getres( clockid_t clock_id, struct timespec *tp);
int timer_create( clockid_t clock_id, struct sigevent *evp,
timer_t *timer_id);
int timer_delete( timer_t timer_id );
int timer_settime( timer_t timerid, int flags,
const struct itimerspec *value,
struct itimerspec *ovalue );
int timer_gettime( timer_t timerid, struct itimerspec *value );
int timer_getoverrun( timer_t timerid );
int nanosleep( const struct timespec *rqtp, struct timespec *rmtp);
int gettimeofday(struct timeval *tv, struct timezone* tz);
```

Functions Omitted

<none>

Notes

- Currently *timer_getoverrun()* only reports timer notifications that are delayed in the timer subsystem. If they are delayed in the signal subsystem, due to signal masks for example, this is not counted as an overrun.
- The option `CYGPKG_POSIX_TIMERS` allows the timer support to be enabled or disabled, and causes `_POSIX_TIMERS` to be defined appropriately. This will cause other parts of the POSIX system to have limited functionality.

Message Passing [POSIX Section 15]

Functions Implemented

```
mqd_t mq_open( const char *name, int oflag, ... );
int mq_close( mqd_t mqdes );
int mq_unlink( const char *name );
int mq_send( mqd_t mqdes, const char *msg_ptr,
             size_t msg_len, unsigned int msg_prio );
ssize_t mq_receive( mqd_t mqdes, char *msg_ptr,
                   size_t msg_len, unsigned int *msg_prio );
int mq_setattr( mqd_t mqdes, const struct mq_attr *mqstat,
               struct mq_attr *omqstat );
int mq_getattr( mqd_t mqdes, struct mq_attr *mqstat );
int mq_notify( mqd_t mqdes, const struct sigevent *notification );
```

From POSIX 1003.1d draft:

```
int mq_send( mqd_t mqdes, const char *msg_ptr,
            size_t msg_len, unsigned int msg_prio,
            const struct timespec *abs_timeout );
ssize_t mq_receive( mqd_t mqdes, char *msg_ptr,
                   size_t msg_len, unsigned int *msg_prio,
                   const struct timespec *abs_timeout );
```

Functions Omitted

<none>

Notes

- The presence of message queues is controlled by the CYGPKG_POSIX_MQUEUES option. Setting this will cause [_POSIX_MESSAGE_PASSING] to be defined and the message queue API to be made available.
- Message queues are not currently filesystem objects. They live in their own name and descriptor spaces.

Thread Management [POSIX Section 16]

Functions Implemented

```
int pthread_attr_init(pthread_attr_t *attr);
int pthread_attr_destroy(pthread_attr_t *attr);
int pthread_attr_setdetachstate(pthread_attr_t *attr,
                               int detachstate);
int pthread_attr_getdetachstate(const pthread_attr_t *attr,
                               int *detachstate);
int pthread_attr_setstackaddr(pthread_attr_t *attr,
                              void *stackaddr);
int pthread_attr_getstackaddr(const pthread_attr_t *attr,
```



```

        void **stackaddr);
int pthread_attr_setstacksize(pthread_attr_t *attr,
                             size_t stacksize);
int pthread_attr_getstacksize(const pthread_attr_t *attr,
                             size_t *stacksize);
int pthread_create( pthread_t *thread,
                   const pthread_attr_t *attr,
                   void *(*start_routine)(void *),
                   void *arg);
pthread_t pthread_self( void );
int pthread_equal(pthread_t thread1, pthread_t thread2);
void pthread_exit(void *retval);
int pthread_join(pthread_t thread, void **thread_return);
int pthread_detach(pthread_t thread);
int pthread_once(pthread_once_t *once_control,
                 void (*init_routine)(void));

```

Functions Omitted

<none>

Notes

- The presence of thread support as a whole is controlled by the the CYGPKG_POSIX_PTHREAD configuration option. Note that disabling this will also disable many other features of the POSIX package, since these are intimately bound up with the thread mechanism.
- The default (non-scheduling) thread attributes are:

detachstate	PTHREAD_CREATE_JOINABLE
stackaddr	unset
stacksize	unset

- Dynamic thread stack allocation is only provided if there is an implementation of *malloc()* configured (i.e. a package implements the CYGINT_MEMALLOC_MALLOC_ALLOCATORS interface). If there is no *malloc()* available, then the thread creator must supply a stack. If only a stack address is supplied then the stack is assumed to be PTHREAD_STACK_MIN bytes long. This size is seldom useful for any but the most trivial of threads. If a different sized stack is used, both the stack address and stack size must be supplied.
- The value of PTHREAD_THREADS_MAX is supplied by the CYGNUM_POSIX_PTHREAD_THREADS_MAX option. This defines the maximum number of threads allowed. The POSIX standard requires this value to be at least 64, and this is the default value set.
- When the POSIX package is installed, the thread that calls *main()* is initialized as a POSIX thread. The priority of that thread is controlled by the CYGNUM_POSIX_MAIN_DEFAULT_PRIORITY option.

Thread-Specific Data [POSIX Section 17]

Functions Implemented

```
int pthread_key_create(pthread_key_t *key,  
                      void (*destructor)(void *));  
int pthread_setspecific(pthread_key_t key, const void *pointer);  
void *pthread_getspecific(pthread_key_t key);  
int pthread_key_delete(pthread_key_t key);
```

Functions Omitted

<none>

Notes

- The value of PTHREAD_DESTRUCTOR_ITERATIONS is provided by the CYGNUM_POSIX_PTHREAD_DESTRUCTOR_ITERATIONS option. This controls the number of times that a key destructor will be called while the data item remains non-NULL.
- The value of PTHREAD_KEYS_MAX is provided by the CYGNUM_POSIX_PTHREAD_KEYS_MAX option. This defines the maximum number of per-thread data items supported. The POSIX standard calls for this to be a minimum of 128, which is rather large for an embedded system. The default value for this option is set to 128 for compatibility but it should be reduced to a more usable value.

Thread Cancellation [POSIX Section 18]

Functions Implemented

```
int pthread_cancel(pthread_t thread);  
int pthread_setcancelstate(int state, int *oldstate);  
int pthread_setcanceltype(int type, int *oldtype);  
void pthread_testcancel(void);  
void pthread_cleanup_push( void (*routine)(void *),  
                          void *arg);  
void pthread_cleanup_pop( int execute);
```

Functions Omitted

<none>

Notes

Asynchronous cancellation is only partially implemented. In particular, cancellation may occur in unexpected places in some functions. It is strongly recommended that only synchronous cancellation be used.

Non-POSIX Functions

In addition to the standard POSIX functions defined above, the following non-POSIX functions are defined in the FILEIO package.

General I/O Functions

```
int ioctl( int fd, CYG_ADDRWORD com, CYG_ADDRWORD data );
int select( int nfd, fd_set *in, fd_set *out, fd_set *ex, struct timeval *tv);
```

Socket Functions

```
int socket( int domain, int type, int protocol);
int bind( int s, const struct sockaddr *sa, unsigned int len);
int listen( int s, int len);
int accept( int s, struct sockaddr *sa, socklen_t *addrlen);
int connect( int s, const struct sockaddr *sa, socklen_t len);
int getpeername( int s, struct sockaddr *sa, socklen_t *len);
int getsockname( int s, struct sockaddr *sa, socklen_t *len);
int setsockopt( int s, int level, int optname, const void *optval,
               socklen_t optlen);
int getsockopt( int s, int level, int optname, void *optval,
               socklen_t *optlen);
ssize_t recvmsg( int s, struct msghdr *msg, int flags);
ssize_t recvfrom( int s, void *buf, size_t len, int flags,
                 struct sockaddr *from, socklen_t *fromlen);
ssize_t recv( int s, void *buf, size_t len, int flags);
ssize_t sendmsg( int s, const struct msghdr *msg, int flags);
ssize_t sendto( int s, const void *buf, size_t len, int flags,
               const struct sockaddr *to, socklen_t tolen);
ssize_t send( int s, const void *buf, size_t len, int flags);
int shutdown( int s, int how);
```

Notes

- The precise behaviour of these functions depends mainly on the functionality of the underlying filesystem or network stack to which they are applied.

References and Bibliography

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XIII. μ ITRON

Chapter 32. μ ITRON API

Introduction to μ ITRON

The μ ITRON specification defines a highly flexible operating system architecture designed specifically for application in embedded systems. The specification addresses features which are common to the majority of processor architectures and deliberately avoids virtualization which would adversely impact real-time performance. The μ ITRON specification may be implemented on many hardware platforms and provides significant advantages by reducing the effort involved in understanding and porting application software to new processor architectures.

Several revisions of the μ ITRON specification exist. In this release, *eCos* supports the μ ITRON version 3.02 specification, with complete “Standard functionality” (level S), plus many “Extended” (level E) functions. An exception is `get_tid()` which has μ ITRON 4 semantics. The definitive reference on μ ITRON is Dr. Sakamura’s book: *μ ITRON 3.0, An Open and Portable Real-Time Operating System for Embedded Systems*. The book can be purchased from the IEEE Press, and an ASCII version of the standard can be found online at <http://www.assoc.tron.org/eng/document.html>. The old address <http://www.sakamura-lab.org/TRON/ITRON/> still exists as a mirror site.

μ ITRON and eCos

The *eCos* kernel implements the functionality used by the μ ITRON compatibility subsystem. The configuration of the kernel influences the behavior of μ ITRON programs.

In particular, the default configuration has time slicing (also known as round-robin scheduling) switched on; this means that a task can be moved from `RUN` state to `READY` state at any time, in order that one of its peers may run. This is not strictly conformant to the μ ITRON specification, which states that timeslicing may be implemented by periodically issuing a `rot_rdq(0)` call from within a periodic task or cyclic handler; otherwise it is expected that a task runs until it is pre-empted in consequence of synchronization or communication calls it makes, or the effects of an interrupt or other external event on a higher priority task cause that task to become `READY`. To disable timeslicing functionality in the kernel and μ ITRON compatibility environment, please disable the `CYGSEM_KERNEL_SCHED_TIMESLICE` configuration option in the kernel package. A description of kernel scheduling is in [Kernel Overview](#).

For another example, the semantics of task queueing when waiting on a synchronization object depend solely on the way the underlying kernel is configured. As discussed above, the multi-level queue scheduler is the only one which is μ ITRON compliant, and it queues waiting tasks in FIFO order. Future releases of that scheduler might be configurable to support priority ordering of task queues. Other schedulers might be different again: for example the bitmap scheduler can be used with the μ ITRON compatibility layer, even though it only allows one task at each priority and as such is not μ ITRON compliant, but it supports only priority ordering of task queues. So which queueing scheme is supported is not really a property of the μ ITRON compatibility layer; it depends on the kernel.

In this version of the μ ITRON compatibility layer, the calls to disable and enable scheduling and interrupts (`dis_dsp()`, `ena_dsp()`, `loc_cpu()` and `unl_cpu()`) call underlying kernel functions; in particular, the `xxx_dsp()` functions lock the scheduler entirely, which prevents dispatching of DSRs; functions implemented by DSRs include clock counters and alarm timers. Thus time “stops” while dispatching is disabled with `dis_dsp()`.

Like all parts of the *eCos* system, the detailed semantics of the μ ITRON layer are dependent on its configuration and the configuration of other components that it uses. The μ ITRON configuration options are all defined in

the file `pkgconf/uitron.h`, and can be set using the configuration tool or editing the `.ecc` file in your build directory by hand.

An important configuration option for the μ ITRON compatibility layer is “Option: Return Error Codes for Bad Params” (`CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS`), which allows a lot of the error checking code in the μ ITRON compatibility layer to be removed. Of course this leaves a program open to undetected errors, so it should only be used once an application is fully debugged and tested. Its benefits include reduced code size and faster execution. However, it affects the API significantly, in that with this option enabled, bad calls do not return errors, but cause an assert failure (if that is itself enabled) or malfunction internally. There is discussion in more detail about this in each section below.

We now give a brief description of the μ ITRON functions which are implemented in this release. Note that all C and C++ source files should have the following `#include` statement:

```
#include <cyg/compat/uitron/uit_func.h>
```

Task Management Functions

The following functions are fully supported in this release:

```
ER sta_tsk(
    ID tskid,
    INT stacd )

void ext_tsk( void )

void exd_tsk( void )

ER dis_dsp( void )

ER ena_dsp( void )

ER chg_pri(
    ID tskid,
    PRI tskpri )

ER rot_rdq(
    PRI tskpri )

ER get_tid(
    ID *p_tskid )

ER ref_tsk(
    T_RTsk *pk_rtsk,
    ID tskid )

ER ter_tsk(
    ID tskid )

ER rel_wai(
    ID tskid )
```

The following two functions are supported in this release, when enabled with the configuration option `CYGPkg_UITRON_TASKS_CREATE_DELETE` with some restrictions:

```
ER cre_tsk(
    ID tskid,
    T_CTsk *pk_ctsk )
```



```
ER del_tsk(
    ID tskid )
```

These functions are restricted as follows:

Because of the static initialization facilities provided for system objects, a task is allocated stack space statically in the configuration. So while tasks can be created and deleted, the same stack space is used for that task (task ID number) each time. Thus the stack size (`pk_ctsk->stksz`) requested in `cre_tsk()` is checked for being less than that which was statically allocated, and otherwise ignored. This ensures that the new task will have enough stack to run. For this reason `del_tsk()` does not in any sense free the memory that was in use for the task's stack.

The task attributes (`pk_ctsk->tskatr`) are ignored; current versions of *eCos* do not need to know whether a task is written in assembler or C/C++ so long as the procedure call standard appropriate to the CPU is followed.

Extended information (`pk_ctsk->exinf`) is ignored.

Error checking

For all these calls, an invalid task id (`tskid`) (less than 1 or greater than the number of configured tasks) only returns `E_ID` when bad params return errors (`CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS` is enabled, see above).

Similarly, the following conditions are only checked for, and only return errors if `CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS` is enabled:

- `pk_crtk` in `cre_tsk()` is a valid pointer, otherwise return `E_PAR`
- `ter_tsk()` or `rel_wai()` on the calling task returns `E_OBJ`
- the CPU is not locked already in `dis_dsp()` and `ena_dsp()`; returns `E_CTX`
- priority level in `chg_pri()` and `rot_rdq()` is checked for validity, `E_PAR`
- return value pointer in `get_tid()` and `ref_tsk()` is a valid pointer, or `E_PAR`

The following conditions are checked for, and return error codes if appropriate, regardless of the setting of `CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS`:

- When create and delete functions `cre_tsk()` and `del_tsk()` are supported, all calls which use a valid task ID number check that the task exists; if not, `E_NOEXS` is returned
- When supported, `cre_tsk()`: the task must not already exist; otherwise `E_OBJ`
- When supported, `cre_tsk()`: the requested stack size must not be larger than that statically configured for the task; see the configuration options “Static initializers”, and “Default stack size”. Else `E_NOMEM`
- When supported, `del_tsk()`: the underlying *eCos* thread must not be running - this would imply either a bug or some program bypassing the μ ITRON compatibility layer and manipulating the thread directly. `E_OBJ`
- `sta_tsk()`: the task must be dormant, else `E_OBJ`
- `ter_tsk()`: the task must not be dormant, else `E_OBJ`
- `chg_pri()`: the task must not be dormant, else `E_OBJ`
- `rel_wai()`: the task must be in `WAIT` or `WAIT-SUSPEND` state, else `E_OBJ`

Task-Dependent Synchronization Functions

These functions are fully supported in this release:

```
ER sus_tsk(
    ID tskid )

ER rsm_tsk(
    ID tskid )

ER frsm_tsk(
    ID tskid )

ER slp_tsk( void )

ER tslp_tsk(
    TMO tmout )

ER wup_tsk(
    ID tskid )

ER can_wup(
    INT *p_wupcnt,    ID tskid )
```

Error checking

The following conditions are only checked for, and only return errors if CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS is enabled (see the configuration option “Return Error Codes for Bad Params”):

- invalid tskid; less than 1 or greater than CYGNUM_UITRON_TASKS returns E_ID
- wup_tsk(), sus_tsk(), rsm_tsk(), frsm_tsk() on the calling task returns E_OBJ
- dispatching is enabled in tslp_tsk() and slp_tsk(), or E_CTX
- tmout must be positive, otherwise E_PAR
- return value pointer in can_wup() is a valid pointer, or E_PAR

The following conditions are checked for, and can return error codes, regardless of the setting of CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS:

- When create and delete functions cre_tsk() and del_tsk() are supported, all calls which use a valid task ID number check that the task exists; if not, E_NOEXS is returned
- sus_tsk(): the task must not be dormant, else E_OBJ
- frsm/rsm_tsk(): the task must be suspended, else E_OBJ
- tslp/slp_tsk(): return codes E_TMOUT, E_RLWAI and E_DLT are returned depending on the reason for terminating the sleep
- wup_tsk() and can_wup(): the task must not be dormant, or E_OBJ is returned

Synchronization and Communication Functions

These functions are fully supported in this release:

```

ER sig_sem(
    ID semid )

ER wai_sem(
    ID semid )

ER preq_sem(
    ID semid )

ER twai_sem(
    ID semid,      TMO tmout )

ER ref_sem(
    T_RSEM *pk_rsem ,      ID semid )

ER set_flg(
    ID flgid,      UINT setptn )

ER clr_flg(
    ID flgid,      UINT clrptn )

ER wai_flg(
    UINT *p_flgptn,      ID flgid ,
    UINT waiptn ,      UINT wfmode )

ER pol_flg(
    UINT *p_flgptn,      ID flgid ,
    UINT waiptn ,      UINT wfmode )

ER twai_flg(
    UINT *p_flgptn      ID flgid ,
    UINT waiptn ,      UINT wfmode,      TMO tmout )

ER ref_flg(
    T_RFLG *pk_rflg,      ID flgid )

ER snd_msg(
    ID mbxid,      T_MSG *pk_msg )

ER rcv_msg(
    T_MSG **ppk_msg,      ID mbxid )

ER prcv_msg(
    T_MSG **ppk_msg,      ID mbxid )

ER trcv_msg(
    T_MSG **ppk_msg,      ID mbxid ,      TMO tmout )

ER ref_mbx(
    T_RMBX *pk_rmbx,      ID mbxid )

```

The following functions are supported in this release (with some restrictions) if enabled with the appropriate configuration option for the object type (for example CYGPKG_UITRON_SEMAS_CREATE_DELETE):

```

ER cre_sem(
    ID semid,      T_CSEM *pk_csem )

ER del_sem(

```

```

        ID semid )

ER cre_flg(
    ID flgid,      T_CFLG *pk_cflg )

ER del_flg(
    ID flgid )

ER cre_mbx(
    ID mbxid,      T_CMBX *pk_cmbx )

ER del_mbx(
    ID mbxid )

```

In general the queueing order when waiting on a synchronization object depends on the underlying kernel configuration. The multi-level queue scheduler is required for strict μ ITRON conformance and it queues tasks in FIFO order, so requests to create an object with priority queueing of tasks (`pk_cxxx->xxxatr = TA_TPRI`) are rejected with `E_RSATR`. Additional undefined bits in the attributes fields must be zero.

In general, extended information (`pk_cxxx->exinf`) is ignored.

For semaphores, the initial semaphore count (`pk_csem->isemcnt`) is supported; the new semaphore's count is set. The maximum count is not supported, and is not in fact defined in type `pk_csem`.

For flags, multiple tasks are allowed to wait. Because single task waiting is a subset of this, the W bit (`TA_WMUL`) of the flag attributes is ignored; all other bits must be zero. The initial flag value is supported.

For mailboxes, the buffer count is defined statically by kernel configuration option `CYGNUM_KERNEL_SYNCH_MBOX_QUEUE_SIZE`; therefore the buffer count field is not supported and is not in fact defined in type `pk_cmbx`. Queueing of messages is FIFO ordered only, so `TA_MPRI` (in `pk_cmbx->mbxatr`) is not supported.

Error checking

The following conditions are only checked for, and only return errors if `CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS` is enabled:

- invalid object id; less than 1 or greater than `CYGNUM_UITRON_TASKS/SEMAS/MBOXES` as appropriate returns `E_ID`
- dispatching is enabled in any call which can sleep, or `E_CTX`
- `tmout` must be positive, otherwise `E_PAR`
- `pk_cxxx` pointers in `cre_xxx()` must be valid pointers, or `E_PAR`
- return value pointer in `ref_xxx()` is valid pointer, or `E_PAR`
- flag wait pattern must be non-zero, and mode must be valid, or `E_PAR`
- return value pointer in flag wait calls is a valid pointer, or `E_PAR`

The following conditions are checked for, and can return error codes, regardless of the setting of `CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS`:

- When create and delete functions `cre_xxx()` and `del_xxx()` are supported, all calls which use a valid object ID number check that the object exists. If not, `E_NOEXS` is returned.
- In create functions `cre_xxx()`, when supported, if the object already exists, then `E_OBJ`

- In any call which can sleep, such as `twai_sem()` : return codes `E_TMOUT`, `E_RLWAI`, `E_DLT` or of course `E_OK` are returned depending on the reason for terminating the sleep
- In polling functions such as `preq_sem()` return codes `E_TMOUT` or `E_OK` are returned depending on the state of the synchronization object
- In creation functions, the attributes must be compatible with the selected underlying kernel configuration: in `cre_sem()` `pk_csem->sematr` must be equal to `TA_TFIFO` else `E_RSATR`.
- In `cre_flg()` `pk_cflg->flgatr` must be either `TA_WMUL` or `TA_WSGL` else `E_RSATR`.
- In `cre_mbx()` `pk_cmbx->mbxatr` must be `TA_TFIFO + TA_MFIFO` else `E_RSATR`.

Extended Synchronization and Communication Functions

None of these functions are supported in this release.

Interrupt management functions

These functions are fully supported in this release:

```
void ret_int( void )

ER loc_cpu( void )

ER unl_cpu( void )

ER dis_int(
    UINT eintno )

ER ena_int(
    UINT eintno )

void ret_wup(
    ID tskid )

ER iwup_tsk(
    ID tskid )

ER isig_sem(
    ID semid )

ER iset_flg(
    ID flgid ,
    UID setptn )

ER isend_msg(
    ID mbxid ,
    T_MSG *pk_msg )
```

Note that `ret_int()` and the `ret_wup()` are implemented as macros, containing a “return” statement.

Also note that `ret_wup()` and the `ixxx_yyy()` style functions will only work when called from an ISR whose associated DSR is `cyg_uitron_dsr()`, as specified in include file `<cyg/compat/uitron/uit_ifnc.h>`, which defines the `ixxx_yyy()` style functions also.

If you are writing interrupt handlers more in the *eCos* style, with separate ISR and DSR routines both of your own devising, do not use these special functions from a DSR: use plain `xxx_yyy()` style functions (with no ‘i’ prefix) instead, and do not call any μ ITRON functions from the ISR at all.

The following functions are not supported in this release:

```
ER def_int(
    UINT dintno,
    T_DINT *pk_dint )

ER chg_iXX(
    UINT iXXXX )

ER ref_iXX(
    UINT * p_iXXXX )
```

These unsupported functions are all Level C (CPU dependent). Equivalent functionality is available via other *eCos*-specific APIs.

Error checking

The following conditions are only checked for, and only return errors if `CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS` is enabled:

- `loc/unl_cpu()` : these must only be called in a μ ITRON task context, else `E_CTX`.
- `dis/ena_int()` : the interrupt number must be in range as specified by the platform HAL in question, else `E_PAR`.

Memory pool Management Functions

These functions are fully supported in this release:

```
ER get_blf(
    VP *p_blf,    ID mpfid )

ER pget_blf(
    VP *p_blf,    ID mpfid )

ER tget_blf(
    VP *p_blf,    ID mpfid,    TMO tmout )

ER rel_blf(
    ID mpfid,    VP blf )

ER ref_mpf(
    T_RMPF *pk_rmpf,    ID mpfid )

ER get_blk(
    VP *p_blk,    ID mplid,    INT blksz )

ER pget_blk(
    VP *p_blk,    ID mplid,    INT blksz )

ER tget_blk(
```

```

        VP *p_blk,      ID mplid,      INT blkksz,      TMO tmout )

ER rel_blk(
    ID mplid,      VP blk )

ER ref_mpl(
    T_RMPL *pk_rmpl,      ID mplid )

```

Note that of the memory provided for a particular pool to manage in the static initialization of the memory pool objects, some memory will be used to manage the pool itself. Therefore the number of blocks * the blocksize will be less than the total memory size.

The following functions are supported in this release, when enabled with `CYGPKG_UITRON_MEMPOOLVAR_CREATE_DELETE` or `CYGPKG_UITRON_MEMPOOLFIXED_CREATE_DELETE` as appropriate, with some restrictions:

```

ER cre_mpl(
    ID mplid,      T_CMPL *pk_cmpl )

ER del_mpl(
    ID mplid )

ER cre_mpf(
    ID mpfid,      T_CMPF *pk_cmpf )

ER del_mpf(
    ID mpfid )

```

Because of the static initialization facilities provided for system objects, a memory pool is allocated a region of memory to manage statically in the configuration. So while memory pools can be created and deleted, the same area of memory is used for that memory pool (memory pool ID number) each time. The requested variable pool size (`pk_cmpl->mplsz`) or the number of fixed-size blocks (`pk_cmpf->mpfcnt`) times the block size (`pk_cmpf->blfsz`) are checked for fitting within the statically allocated memory area, so if a create call succeeds, the resulting pool will be at least as large as that requested. For this reason `del_mpl()` and `del_mpf()` do not in any sense free the memory that was managed by the deleted pool for use by other pools; it may only be managed by a pool of the same object id.

For both fixed and variable memory pools, the queueing order when waiting on a synchronization object depends on the underlying kernel configuration. The multi-level queue scheduler is required for strict μ ITRON conformance and it queues tasks in FIFO order, so requests to create an object with priority queueing of tasks (`pk_cxxx->xxxatr = TA_TPRI`) are rejected with `E_RSATR`. Additional undefined bits in the attributes fields must be zero.

In general, extended information (`pk_cxxx->exinf`) is ignored.

Error checking

The following conditions are only checked for, and only return errors if `CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS` is enabled:

- invalid object id; less than 1 or greater than `CYGNUM_UITRON_MEMPOOLVAR/MEMPOOLFIXED` as appropriate returns `E_ID`
- dispatching is enabled in any call which can sleep, or `E_CTX`
- `tmout` must be positive, otherwise `E_PAR`
- `pk_cxxx` pointers in `cre_xxx()` must be valid pointers, or `E_PAR`

- return value pointer in `ref_xxx()` is a valid pointer, or E_PAR
- return value pointers in get block routines is a valid pointer, or E_PAR
- blocksize request in get variable block routines is greater than zero, or E_PAR

The following conditions are checked for, and can return error codes, regardless of the setting of CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS:

- When create and delete functions `cre_xxx()` and `del_xxx()` are supported, all calls which use a valid object ID number check that the object exists. If not, E_NOEXS is returned.
- When create functions `cre_xxx()` are supported, if the object already exists, then E_OBJ
- In any call which can sleep, such as `get_blk()` : return codes E_TMOUT, E_RLWAI, E_DLT or of course E_OK are returned depending on the reason for terminating the sleep
- In polling functions such as `pget_blk()` return codes E_TMOUT or E_OK are returned depending on the state of the synchronization object
- In creation functions, the attributes must be compatible with the selected underlying kernel configuration: in `cre_mpl()` `pk_cmpl->mplatr` must be equal to TA_TFIFO else E_RSATR.
- In `cre_mpf()` `pk_cmpf->mpfatr` must be equal to TA_TFIFO else E_RSATR.
- In creation functions, the requested size of the memory pool must not be larger than that statically configured for the pool else E_RSATR; see the configuration option “Option: Static initializers”. In `cre_mpl()` `pk_cmpl->mplsz` is the field of interest
- In `cre_mpf()` the product of `pk_cmpf->blfsz` and `pk_cmpf->mpfcnt` must be smaller than the memory statically configured for the pool else E_RSATR
- In functions which return memory to the pool `rel_blk()` and `rel_blf()` , if the free fails, for example because the memory did not come from that pool originally, then E_PAR is returned

Time Management Functions

These functions are fully supported in this release:

```
ER set_tim(
    SYSTIME *pk_tim )
```

Caution

Setting the time may cause erroneous operation of the kernel, for example a task performing a wait with a time-out may never awaken.

```
ER get_tim(
    SYSTIME *pk_tim )
```

```
ER dly_tsk(
    DLYTIME dlytim )
```

```
ER def_cyc(
    HNO cycno,      T_DCYC *pk_dcyc )
```

```
ER act_cyc(
    HNO cycno,      UINT cycact )
```



```

ER ref_cyc(
    T_RCYC *pk_rcyc,    HNO cycno )

ER def_alm(
    HNO almno,    T_DALM *pk_dalm )

ER ref_alm(
    T_RALM *pk_ralm,    HNO almno )

void ret_tmr( void )

```

Error checking

The following conditions are only checked for, and only return errors if CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS is enabled:

- invalid handler number; less than 1 or greater than CYGNUM_UITRON_CYCLICS/ALARMS as appropriate, or E_PAR
- dispatching is enabled in dly_tsk() , or E_CTX
- dlytim must be positive or zero, otherwise E_PAR
- return value pointer in ref_xxx() is a valid pointer, or E_PAR
- params within pk_dalm and pk_dcyc must be valid, or E_PAR
- cycact in act_cyc() must be valid, or E_PAR
- handler must be defined in ref_xxx() and act_cyc() , or E_NOEXS
- parameter pointer must be a good pointer in get_tim() and set_tim() , otherwise E_PAR is returned

The following conditions are checked for, and can return error codes, regardless of the setting of CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS :

- dly_tsk() : return code E_RLWAI is returned depending on the reason for terminating the sleep

System Management Functions

These functions are fully supported in this release:

```

ER get_ver(
    T_VER *pk_ver )

ER ref_sys(
    T_RSYS *pk_rsys )

ER ref_cfg(
    T_RCFG *pk_rcfg )

```

Note that the information returned by each of these calls may be configured to match the user's own versioning system, and the values supplied by the default configuration may be inappropriate.

These functions are not supported in this release:

```

ER def_svc(
    FN s_fncd,

```

```
T_DSVC *pk_dsvc )

ER def_exc(
    UINT exckind,
    T_DEXC *pk_dexc )
```

Error checking

The following conditions are only checked for, and only return errors if CYGSEM_UITRON_BAD_PARAMS_RETURN_ERRORS is enabled:

- return value pointer in all calls is a valid pointer, or E_PAR

Network Support Functions

None of these functions are supported in this release.

μ ITRON Configuration FAQ

Q: How are μ ITRON objects created?

For each type of μ ITRON object (tasks, semaphores, flags, mboxs, mpf, mpl) these two quantities are controlled by configuration:

- The *maximum* number of this type of object.
- The number of these objects which exist *initially*.

This is assuming that for the relevant object type, *create* and *delete* operations are enabled; enabled is the default. For example, the option CYGPKG_UITRON_MBOXES_CREATE_DELETE controls whether the functions `cre_mbx()` and `del_mbx()` exist in the API. If not, then the maximum number of mboxs is the same as the initial number of mboxs, and so on for all μ ITRON object types.

Mboxes have no initialization, so there are only a few, simple configuration options:

- CYGNUM_UITRON_MBOXES is the total number of mboxs that you can have in the system. By default this is 4, so you can use mboxs 1,2,3 and 4. You cannot create mboxs outside this range; trying to `cre_mbx(5, ...)` will return an error.
- CYGNUM_UITRON_MBOXES_INITIALLY is the number of mboxs created automatically for you, during startup. By default this is 4, so all 4 mboxs exist already, and an attempt to create one of these eg. `cre_mbx(3, ...)` will return an error because the mbox in question already exists. You can delete a pre-existing mbox, and then re-create it.

If you change CYGNUM_UITRON_MBOXES_INITIALLY, for example to 0, no mboxs are created automatically for you during startup. Any attempt to use an mbox without creating it will return E_NOEXS because the mbox does not exist. You can create an mbox, say `cre_mbx(3, ...)` and then use it, say `snd_msg(3, &foo)`, and all will be well.

Q: How are μ ITRON objects initialized?

Some object types have optional initialization. Semaphores are an example. You could have `CYGNUM_UITRON_SEMAS=10` and `CYGNUM_UITRON_SEMAS_INITIALLY=5` which means you can use semaphores 1-5 straight off, but you must create semaphores 6-10 before you can use them. If you decide not to initialize semaphores, semaphores 1-5 will have an initial count of zero. If you decide to initialize them, you must supply a dummy initializer for semaphores 6-10 also. For example, in terms of the configuration output in `pkgconf/uitron.h`:

```
#define CYGDAT_UITRON_SEMA_INITIALIZERS \
    CYG_UIT_SEMA( 1 ),      \
    CYG_UIT_SEMA( 0 ),      \
    CYG_UIT_SEMA( 0 ),      \
    CYG_UIT_SEMA( 99 ),     \
    CYG_UIT_SEMA( 1 ),      \
    CYG_UIT_SEMA_NOEXS,     \
    CYG_UIT_SEMA_NOEXS,     \
    CYG_UIT_SEMA_NOEXS,     \
    CYG_UIT_SEMA_NOEXS,     \
    CYG_UIT_SEMA_NOEXS
```

Semaphore 1 will have initial count 1, semaphores 2 and 3 will be zero, number 4 will be 99 initially, 5 will be one and numbers 6 through 10 do not exist initially.

Aside: this is how the definition of the symbol would appear in the configuration header file `pkgconf/uitron.h` — unfortunately editing such a long, multi-line definition is somewhat cumbersome in the GUI config tool in current releases. The macros `CYG_UIT_SEMA()` — to create a semaphore initializer — and `CYG_UIT_SEMA_NOEXS` — to invoke a dummy initializer — are provided in the environment to help with this. Similar macros are provided for other object types. The resulting `#define` symbol is used in the context of a C++ array initializer, such as:

```
Cyg_Counting_Semaphore2 cyg_uitron_SEMAS[ CYGNUM_UITRON_SEMAS ] = {
    CYGDAT_UITRON_SEMA_INITIALIZERS
};
```

which is eventually macro-processed to give

```
Cyg_Counting_Semaphore2 cyg_uitron_SEMAS[ 10 ] = {
    Cyg_Counting_Semaphore2( ( 1 ) ),
    Cyg_Counting_Semaphore2( ( 0 ) ),
    Cyg_Counting_Semaphore2( ( 0 ) ),
    Cyg_Counting_Semaphore2( ( 99 ) ),
    Cyg_Counting_Semaphore2( ( 1 ) ),
    Cyg_Counting_Semaphore2(0),
    Cyg_Counting_Semaphore2(0),
    Cyg_Counting_Semaphore2(0),
    Cyg_Counting_Semaphore2(0),
    Cyg_Counting_Semaphore2(0),
};
```

so you can see how it is necessary to include the dummy entries in that definition, otherwise the resulting code will not compile correctly.

If you choose `CYGNUM_UITRON_SEMAS_INITIALLY=0` it is meaningless to initialize them, for they must be created and so initialized then, before use.

Q: What about μ ITRON tasks?

Some object types require initialization. Tasks are an example of this. You must provide a task with a priority, a function to enter when the task starts, a name (for debugging purposes), and some memory to use for the stack. For example (again in terms of the resulting definitions in `pkgconf/uitron.h`):

```

#define CYGNUM_UITRON_TASKS 4           // valid task ids are 1,2,3,4
#define CYGNUM_UITRON_TASKS_INITIALLY 4 // they all exist at start

#define CYGDAT_UITRON_TASK_EXTERNS \
extern "C" void startup( unsigned int ); \
extern "C" void worktask( unsigned int ); \
extern "C" void lowtask( unsigned int ); \
static char stack1[ CYGNUM_UITRON_STACK_SIZE ], \
            stack2[ CYGNUM_UITRON_STACK_SIZE ], \
            stack3[ CYGNUM_UITRON_STACK_SIZE ], \
            stack4[ CYGNUM_UITRON_STACK_SIZE ];

#define CYGDAT_UITRON_TASK_INITIALIZERS \
CYG_UIT_TASK( "main task", 8, startup, &stack1, sizeof( stack1 ) ), \
CYG_UIT_TASK( "worker 2" , 9, worktask, &stack2, sizeof( stack2 ) ), \
CYG_UIT_TASK( "worker 3" , 9, worktask, &stack3, sizeof( stack3 ) ), \
CYG_UIT_TASK( "low task" ,20, lowtask, &stack4, sizeof( stack4 ) ), \

```

So this example has all four tasks statically configured to exist, ready to run, from the start of time. The “main task” runs a routine called `startup()` at priority 8. Two “worker” tasks run both a priority 9, and a “low priority” task runs at priority 20 to do useful non-urgent background work.

Task ID number	Exists at startup	Function entry	Priority	Stack address	Stack size
1	Yes	startup	8	&stack1	CYGNUM...
2	Yes	worktask	9	&stack2	CYGNUM...
3	Yes	worktask	9	&stack3	CYGNUM...
4	Yes	lowtask	20	&stack4	CYGNUM...

Q: How can I create μ ITRON tasks in the program?

You must provide free slots in the task table in which to create new tasks, by configuring the number of tasks existing initially to be smaller than the total. For a task ID which does not initially exist, it will be told what routine to call, and what priority it is, when the task is created. But you must still set aside memory for the task to use for its stack, and give it a name during initialization. For example:

```

#define CYGNUM_UITRON_TASKS 4           // valid task ids are 1-4
#define CYGNUM_UITRON_TASKS_INITIALLY 1 // only task #1 exists

#define CYGDAT_UITRON_TASK_EXTERNS \
extern "C" void startup( unsigned int ); \
static char stack1[ CYGNUM_UITRON_STACK_SIZE ], \
            stack2[ CYGNUM_UITRON_STACK_SIZE ], \
            stack3[ CYGNUM_UITRON_STACK_SIZE ], \
            stack4[ CYGNUM_UITRON_STACK_SIZE ];

#define CYGDAT_UITRON_TASK_INITIALIZERS \
CYG_UIT_TASK( "main", 8, startup, &stack1, sizeof( stack1 ) ), \
CYG_UIT_TASK_NOEXS( "slave", &stack2, sizeof( stack2 ) ), \
CYG_UIT_TASK_NOEXS( "slave2", &stack3, sizeof( stack3 ) ), \
CYG_UIT_TASK_NOEXS( "slave3", &stack4, sizeof( stack4 ) ), \

```

So tasks numbered 2,3 and 4 have been given their stacks during startup, though they do not yet exist in terms of `cre_tsk()` and `del_tsk()` so you can create tasks 2–4 at runtime.

Task ID number	Exists at startup	Function entry	Priority	Stack address	Stack size
1	Yes	startup	8	&stack1	CYGNUM...
2	No	slave	9	&stack2	CYGNUM...
3	No	slave2	9	&stack3	CYGNUM...
4	No	slave3	9	&stack4	CYGNUM...

1		Yes		startup		8		&stack1		CYGNUM...
2		No		N/A		N/A		&stack2		CYGNUM...
3		No		N/A		N/A		&stack3		CYGNUM...
4		No		N/A		N/A		&stack4		CYGNUM...
-----+-----+-----+-----+-----+-----										

(you must have at least one task at startup in order that the system can actually run; this is not so for other μ ITRON object types)

Q: Can I have different stack sizes for μ ITRON tasks?

Simply set aside different amounts of memory for each task to use for its stack. Going back to a typical default setting for the μ ITRON tasks, the definitions in `pkgconf/uitron.h` might look like this:

```
#define CYGDAT_UITRON_TASK_EXTERNS \
extern "C" void task1( unsigned int ); \
extern "C" void task2( unsigned int ); \
extern "C" void task3( unsigned int ); \
extern "C" void task4( unsigned int ); \
static char stack1[ CYGNUM_UITRON_STACK_SIZE ], \
             stack2[ CYGNUM_UITRON_STACK_SIZE ], \
             stack3[ CYGNUM_UITRON_STACK_SIZE ], \
             stack4[ CYGNUM_UITRON_STACK_SIZE ];

#define CYGDAT_UITRON_TASK_INITIALIZERS \
    CYG_UIT_TASK( "t1", 1, task1, &stack1, CYGNUM_UITRON_STACK_SIZE ), \
    CYG_UIT_TASK( "t2", 2, task2, &stack2, CYGNUM_UITRON_STACK_SIZE ), \
    CYG_UIT_TASK( "t3", 3, task3, &stack3, CYGNUM_UITRON_STACK_SIZE ), \
    CYG_UIT_TASK( "t4", 4, task4, &stack4, CYGNUM_UITRON_STACK_SIZE )
```

Note that `CYGNUM_UITRON_STACK_SIZE` is used to control the size of the stack objects themselves, and to tell the system what size stack is being provided.

Suppose instead stack sizes of 2000, 1000, 800 and 800 were required: this could be achieved by using the GUI config tool to edit these options, or editing the `.ecc` file to get these results in `pkgconf/uitron.h`:

```
#define CYGDAT_UITRON_TASK_EXTERNS \
extern "C" void task1( unsigned int ); \
extern "C" void task2( unsigned int ); \
extern "C" void task3( unsigned int ); \
extern "C" void task4( unsigned int ); \
static char stack1[ 2000 ], \
             stack2[ 1000 ], \
             stack3[ 800 ], \
             stack4[ 800 ];

#define CYGDAT_UITRON_TASK_INITIALIZERS \
    CYG_UIT_TASK( "t1", 1, task1, &stack1, sizeof( stack1 ) ), \
    CYG_UIT_TASK( "t2", 2, task2, &stack2, sizeof( stack2 ) ), \
    CYG_UIT_TASK( "t3", 3, task3, &stack3, sizeof( stack3 ) ), \
    CYG_UIT_TASK( "t4", 4, task4, &stack4, sizeof( stack4 ) )
```

Note that the `sizeof()` operator has been used to tell the system what size stacks are provided, rather than quoting a number (which is difficult for maintenance) or the symbol `CYGNUM_UITRON_STACK_SIZE` (which is wrong).

We recommend using (if available in your release) the stacksize symbols provided in the architectural HAL for your target, called `CYGNUM_HAL_STACK_SIZE_TYPICAL` and `CYGNUM_HAL_STACK_SIZE_MINIMUM`. So a better (more portable) version of the above might be:

```
#define CYGDAT_UITRON_TASK_EXTERNS \
```

```
extern "C" void task1( unsigned int ); \
extern "C" void task2( unsigned int ); \
extern "C" void task3( unsigned int ); \
extern "C" void task4( unsigned int ); \
static char stack1[ CYGNUM_HAL_STACK_SIZE_TYPICAL + 1200 ], \
             stack2[ CYGNUM_HAL_STACK_SIZE_TYPICAL + 200 ], \
             stack3[ CYGNUM_HAL_STACK_SIZE_TYPICAL      ], \
             stack4[ CYGNUM_HAL_STACK_SIZE_TYPICAL      ];

#define CYGDAT_UITRON_TASK_INITIALIZERS \
    CYG_UIT_TASK( "t1", 1, task1, &stack1, sizeof( stack1 ) ), \
    CYG_UIT_TASK( "t2", 2, task2, &stack2, sizeof( stack2 ) ), \
    CYG_UIT_TASK( "t3", 3, task3, &stack3, sizeof( stack3 ) ), \
    CYG_UIT_TASK( "t4", 4, task4, &stack4, sizeof( stack4 ) )
```

XIV. TCP/IP Stack Support for eCos

The Common Networking for eCos package provides support for a complete TCP/IP networking stack. The design allows for the actual stack to be modular and at the current time two different implementations, one based on OpenBSD from 2000 and a new version based on FreeBSD, are available. The particulars of each stack implementation are presented in separate sections following this top-level discussion.

Chapter 33. Ethernet Driver Design

Currently, the networking stack only supports ethernet based networking.

The network drivers use a two-layer design. One layer is hardware independent and contains all the stack specific code. The other layer is platform dependent and communicates with the hardware independent layer via a very simple API. In this way, hardware device drivers can actually be used with other stacks, if the same API can be provided by that stack. We designed the drivers this way to encourage the development of other stacks in eCos while allowing re-use of the actual hardware specific code.

More comprehensive documentation of the ethernet device driver and the associated API can be found in the eCos generic ethernet device driver documentation. The driver and API is the same as the minimal debug stack used by the RedBoot application. See the RedBoot documentation for further information.

Chapter 34. Sample Code

Many examples using the networking support are provided. These are arranged as eCos test programs, primarily for use in verifying the package, but they can also serve as useful frameworks for program design. We have taken a KISS approach to building programs which use the network. A single include file `<network.h>` is all that is required to access the stack. A complete, annotated test program can be found at `net/common/VERSION/tests/ftp_test.c`, with its associated files.

Chapter 35. Configuring IP Addresses

Each interface (“eth0” and “eth1”) has independent configuration of its setup. Each can be set up manually (in which case you must write code to do this), or by using BOOTP/DHCP, or explicitly, with configured values. If additional interfaces are added, these must be configured manually.

The configurable values are:

- IP address
- netmask
- broadcast address
- gateway/router
- server address.

Server address is the DHCP server if applicable, but in addition, many test cases use it as “the machine to talk to” in whatever manner the test exercises the protocol stack.

The initialization is invoked by calling the C routine

```
void init_all_network_interfaces(void);
```

Additionally, if the system is configured to support IPv6 then each interface may have an address assigned which is a composite of a 64 bit prefix and the 32 bit IPv4 address for that interface. The prefix is controlled by the CDL setting CYGHWR_NET_DRIVER_ETH0_IPV6_PREFIX for “eth0”, etc. This is a CDL booldata type, allowing this address to be suppressed if not desired.

Alternatively, the system can configure its IPv6 address using router solicitation. When the CDL option CYGOPT_NET_IPV6_ROUTING_THREAD is enabled, `init_all_network_interface` will start a thread which sends out router solicit messages, process router advertisements and thus configure an IPv6 address to the interface.

Refer to the test cases, `.../packages/net/common/VERSION/tests/ftp_test.c` for example usage, and the source files in `.../packages/net/common/VERSION/src/bootp_support.c` and `network_support.c` to see what that call does.

This assumes that the MAC address (also known as ESA or Ethernet Station Address) is already defined in the serial EEPROM or however the particular target implements this; support for setting the MAC address is hardware dependent.

DHCP support is active by default, and there are configuration options to control it. Firstly, in the top level of the “Networking” configuration tree, “Use full DHCP instead of BOOTP” enables DHCP, and it contains an option to have the system provide a thread to renew DHCP leases and manage lease expiry. Secondly, the individual interfaces “eth0” and “eth1” each have new options within the “Use BOOTP/DHCP to initialize ‘ethX’” to select whether to use DHCP rather than BOOTP.

Note that you are completely at liberty to ignore this startup code and its configuration in building your application. `init_all_network_interfaces()` is provided for three main purposes:

- For use by Red Hat’s own test programs.
- As an easy “get you going” utility for newcomers to eCos.

- As readable example code from which further development might start.

If your application has different requirements for bringing up available network interfaces, setting up routes, determining IP addresses and the like from the defaults that the example code provides, you can write your own initialization code to use whatever sequence of `ioctl()` function calls carries out the desired setup. Analogously, in larger systems, a sequence of “ifconfig” invocations is used; these mostly map to `ioctl()` calls to manipulate the state of the interface in question.

Chapter 36. Tests and Demonstrations

Loopback tests

By default, only tests which can execute on any target will be built. These therefore do not actually use external network interfaces (though they may configure and initialize them) but are limited to testing via the loopback interface.

```
ping_lo_test - ping test of the loopback address
tcp_lo_select - simple test of select with TCP via loopback
tcp_lo_test - trivial TCP test via loopback
udp_lo_test - trivial UDP test via loopback
multi_lo_select - test of multiple select() calls simultaneously
```

Building the Network Tests

To build further network tests, ensure that the configuration option `CYGPKG_NET_BUILD_TESTS` is set in your build and then make the tests in the usual way. Alternatively (with that option set) use

```
make -C net/common/VERSION/ tests
```

after building the eCos library, if you wish to build *only* the network tests.

This should give test executables in `install/tests/net/common/VERSION/tests` including the following:

```
socket_test - trivial test of socket creation API
mbuf_test - trivial test of mbuf allocation API
ftp_test - simple FTP test, connects to "server"
ping_test - pings "server" and non-existent host to test timeout
dhcp_test - ping test, but also relinquishes and
               reacquires DHCP leases periodically
flood - a flood ping test; use with care
tcp_echo - data forwarding program for performance test
nc_test_master - network characterization master
nc_test_slave - network characterization slave
server_test - a very simple server example
tftp_client_test - performs a tftp get and put from/to "server"
tftp_server_test - runs a tftp server for a short while
set_mac_address - set MAC address(es) of interfaces in NVRAM
bridge - contributed network bridge code
nc6_test_master - IPv4/IPv6 network characterization master
nc6_test_slave - IPv4/IPv6 network characterization slave
ga_server_test - a very simple IPv4/IPv6 server example
```

Standalone Tests

```
socket_test - trivial test of socket creation API
mbuf_test - trivial test of mbuf allocation API
```

These two do not communicate over the net; they just perform simple API tests then exit.

```
ftp_test      - simple FTP test, connects to "server"
```

This test initializes the interface(s) then connects to the FTP server on the "server" machine for for each active interface in turn, confirms that the connection was successful, disconnects and exits. This tests interworking with the server.

```
ping_test     - pings "server" and non-existent host to test timeout
```

This test initializes the interface(s) then pings the server machine in the standard way, then pings address "32 up" from the server in the expectation that there is no machine there. This confirms that the successful ping is not a false positive, and tests the receive timeout. If there is such a machine, of course the 2nd set of pings succeeds, confirming that we can talk to a machine not previously mentioned by configuration or by bootp. It then does the same thing on the other interface, eth1.

If IPv6 is enabled, the program will also ping to the address it last received a router advertisement from. Also a ping will be made to that address plus 32, in a similar way the the IPv4 case.

```
dhcp_test    - ping test, but also manipulates DHCP leases
```

This test is very similar to the ping test, but in addition, provided the network package is not configured to do this automatically, it manually relinquishes and reclaims DHCP leases for all available interfaces. This tests the external API to DHCP. See section below describing this.

```
flood        - a flood ping test; use with care
```

This test performs pings on all interfaces as quickly as possible, and only prints status information periodically. Flood pinging is bad for network performance; so do not use this test on general purpose networks unless protected by a switch.

Performance Test

```
tcp_echo     - data forwarding program for performance test
```

tcp_echo is one part of the standard performance test we use. The other parts are host programs `tcp_source` and `tcp_sink`. To make these (under your *HOST* system) cd to the tests source directory in the eCos repository and type "make -f make.host" - this should build `tcp_source` and `tcp_sink`.

The host program "tcp_source" sends data to the target. On the target, "tcp_echo" sends it onwards to "tcp_sink" running on your host. So the target must receive and send on all the data that `tcp_source` sends it; the time taken for this is measured and the data rate is calculated.

To invoke the test, first start `tcp_echo` on the target board and wait for it to become quiescent - it will report work to calibrate a CPU load which can be used to simulate real operating conditions for the stack.

Then on your host machine, in one terminal window, invoke `tcp_sink` giving it the IP address (or hostname) of one interface of the target board. For example "tcp_sink 10.130.39.66". `tcp_echo` on the target will print something like "SINK connection from 10.130.39.13:1143" when `tcp_sink` is correctly invoked.

Next, in another host terminal window, invoke `tcp_source`, giving it the IP address (or hostname) of an interface of the target board, and optionally a background load to apply to the target while the test runs. For example, "tcp_source 194.130.39.66" to run the test with no additional target CPU load, or "tcp_source 194.130.39.66 85" to load it up to 85% used. The target load must be a multiple of 5. `tcp_echo` on the target will print something like "SOURCE connection from 194.130.39.13:1144" when `tcp_source` is correctly invoked.

You can connect `tcp_sink` to one target interface and `tcp_source` to another, or both to the same interface. Similarly, you can run `tcp_sink` and `tcp_source` on the same host machine or different ones. TCP/IP and ARP look after them finding one another, as intended.

```
nc_test_master - network characterization master
nc_test_slave - network characterization slave
```

These tests talk to each other to measure network performance. They can each run on either a test target or a host computer given some customization to your local environment. As provided, `nc_test_slave` must run on the test target, and `nc_test_master` must be run on a host computer, and be given the test target's IP address or hostname.

The tests print network performance for various packet sizes over UDP and TCP, versus various additional CPU loads on the target.

The programs

```
nc6_test_slave
nc6_test_master
```

are additional forms which support both IPv4 and IPv6 addressing.

Interactive Tests

```
server_test - a very simple server example
```

This test simply awaits a connection on port 7734 and after accepting a connection, gets a packet (with a timeout of a few seconds) and prints it.

The connection is then closed. We then loop to await the next connection, and so on. To use it, telnet to the target on port 7734 then type something (quickly!)

```
% telnet 172.16.19.171 7734
Hello target board
```

and the test program will print something like:

```
connection from 172.16.19.13:3369
buf = "Hello target board"
```

```
ga_server_test - another very simple server example
```

This is a variation on the `ga_server_test` test with the difference being that it uses the `getaddrinfo` function to set up its addresses. On a system with IPv6 enabled, it will listen on port 7734 for a TCP connection via either IPv4 or IPv6.

```
tftp_client_test - performs a tftp get and put from/to "server"
```

This is only partially interactive. You need to set things up on the "server" in order for this to work, and you will need to look at the server afterwards to confirm that all was well.

For each interface in turn, this test attempts to read by tftp from the server, a file called `tftp_get` and prints the status and contents it read (if any). It then writes the same data to a file called `tftp_put` on the same server.

In order for this to succeed, both files must already exist. The TFTP protocol does not require that a WRQ request `_create_` a file, just that it can write it. The TFTP server on Linux certainly will only allow writes to an existing file, given the appropriate permission. Thus, you need to have these files in place, with proper permission, before running the test.

The conventional place for the tftp server to operate in LINUX is /tftpboot/; you will likely need root privileges to create files there. The data contents of `tftp_get` can be anything you like, but anything very large will waste lots of time printing it on the test's stdout, and anything above 32kB will cause a buffer overflow and unpredictable failure.

Creating an empty `tftp_put` file (eg. by copying /dev/null to it) is neatest. So before the test you should have something like:

```
-rw-rw-rw- 1 root      1076 May  1 11:39 tftp_get
-rw-rw-rw- 1 root         0 May  1 15:52 tftp_put
```

note that both files have public permissions wide open. After running the test, `tftp_put` should be a copy of `tftp_get`.

```
-rw-rw-rw- 1 root      1076 May  1 11:39 tftp_get
-rw-rw-rw- 1 root     1076 May  1 15:52 tftp_put
```

If the configuration contains IPv6 support, the test program will also use IPv6. It will attempt to put/get the files listed above from the address it last received a routers solicit from.

`tftp_server_test` - runs a tftp server for a short while

This test is truly interactive, in that you can use a standard tftp application to get and put files from the server, during the 5 minutes that it runs. The dummy filesystem which underlies the server initially contains one file, called "uu" which contains part of a familiar text and some padding. It also accommodates creation of 3 further files of up to 1Mb in size and names of up to 256 bytes. Exceeding these limits will cause a buffer overflow and unpredictable failure.

The dummy filesystem is an implementation of the generic API which allows a true filesystem to be attached to the tftp server in the network stack.

We have been testing the tftp server by running the test on the target board, then using two different host computers connecting to the different target interfaces, putting a file from each, getting the "uu" file, and getting the file from the other computer. This verifies that data is preserved during the transfer as well as interworking with standard tftp applications.

Maintenance Tools

`set_mac_address` - set MAC address(es) of interfaces in NVRAM

This program makes an example `ioctl()` call `SIOCSIFHWADDR` "Socket IO Set InterFace HardWare AD-Dress" to set the MAC address on targets where this is supported and enabled in the configuration. You must edit the source to choose a MAC address and further edit it to allow this very dangerous operation. Not all ethernet drivers support this operation, because most ethernet hardware does not support it — or it comes pre-set from the factory. *Do not use this program.*

Chapter 37. Support Features

TFTP

The TFTP client and server are described in `tftp_support.h`;

The TFTP client has a new and an older, deprecated, API. The new API works for both IPv4 and IPv6 whereas the deprecated API is IPv4 only.

The new API is as follows:

```
int tftp_client_get(const char * const filename,
                   const char * const server,
                   const int port,
                   char *buf,
                   int len,
                   const int mode,
                   int * const err);

int tftp_client_put(const char * const filename,
                   const char * const server,
                   const int port,
                   const char *buf,
                   int len,
                   const int mode,
                   int *const err);
```

Currently `server` can only be a numeric IPv4 or IPv6 address. The resolver is currently not used, but it is planned to add this feature (patches welcome). If `port` is zero the client connects to the default TFTP port on the server. Otherwise the specified port is used.

The deprecated API is:

```
int tftp_get(const char * const filename,
             const struct sockaddr_in * const server,
             char * buf,
             int len,
             const int mode,
             int * const error);

int tftp_put(const char * const filename,
             const struct sockaddr_in * const server,
             const char * buffer,
             int len,
             const int mode,
             int * const err);
```

The `server` should contain the address of the server to contact. If the `sin_port` member of the structure is zero the default TFTP port is used. Otherwise the specified port is used.

Both APIs report errors in the same way. The functions return a value of -1 and `*err` will be set to one of the following values:

```

#define TFTP_ENOTFOUND 1 /* file not found */
#define TFTP_EACCESS 2 /* access violation */
#define TFTP_ENOSPACE 3 /* disk full or allocation exceeded */
#define TFTP_EBADOP 4 /* illegal TFTP operation */
#define TFTP_EBADID 5 /* unknown transfer ID */
#define TFTP_EEXISTS 6 /* file already exists */
#define TFTP_ENOUSER 7 /* no such user */
#define TFTP_TIMEOUT 8 /* operation timed out */
#define TFTP_NETERR 9 /* some sort of network error */
#define TFTP_INVALID 10 /* invalid parameter */
#define TFTP_PROTOCOL 11 /* protocol violation */
#define TFTP_TOOLARGE 12 /* file is larger than buffer */

```

If there are no errors the return value is the number of bytes transferred.

The server is more complex. It requires a filesystem implementation to be supplied by the user, and attached to the tftp server by means of a vector of function pointers:

```

struct tftpd_fileops {
    int (*open)(const char *, int);
    int (*close)(int);
    int (*write)(int, const void *, int);
    int (*read)(int, void *, int);
};

```

These functions have the obvious semantics. The structure describing the filesystem is an argument to the `tftpd_start`:

```

int tftpd_start(int port,
               struct tftpd_fileops *ops);

```

The first argument is the port to use for the server. If this port number is zero, the default TFTP port number will be used. The return value from `tftpd_start` is a handle which can be passed to `tftpd_stop`. This will kill the tftpd thread. Note that this is not a clean shutdown. The thread will simply be killed. `tftpd_stop` will attempt to close the sockets the thread was listening on and free some of its allocated memory. But if the thread was actively transferring data at the time `tftpd_stop` is called, it is quite likely some memory and a socket will be leaked. Use this function with caution (or implement a clean shutdown and please contribute the code back :-).

There are two CDL configuration options that control how many servers on how many different ports tftp can be started. `CYGSEM_NET_TFTPD_MULTITHREADED`, when enabled, allows multiple tftpd threads to operate on the same port number. With only one thread, while the thread is active transferring data, new requests for transfers will not be served until the active transfer is complete. When multiple threads are started on the same port, multiple transfers can take place simultaneous, up to the number of threads started. However a semaphore is required to synchronise the threads. This semaphore is required per port. The CDL option `CYGNUM_NET_TFTPD_MULTITHREADED_PORTS` controls how many different port numbers multithreaded servers can service.

If `CYGSEM_NET_TFTPD_MULTITHREADED` is not enabled, only one thread may be run per port number. But this removes the need for a semaphore and so `CYGNUM_NET_TFTPD_MULTITHREADED_PORTS` is not required and unlimited number of ports can be used.

It should be noted that the TFTP does not perform any form of file locking. When multiple servers are active, it is assumed the underlying filesystem will refuse to open the same file multiple times, operate correctly with simultaneous read/writes to the same file, or if you are unlucky, corrupt itself beyond all repair.

When IPv6 is enabled the tftpd thread will listen for requests from both IPv4 and IPv6 addresses.

As discussed in the description of the `tftp_server_test` above, an example filesystem is provided in `net/common/VERSION/src/tftp_dummy_file.c` for use by the tftp server test. The dummy filesystem is not a supported part of the network stack, it exists purely for demonstration purposes.

DHCP

This API publishes a routine to maintain DHCP state, and a semaphore that is signalled when a lease requires attention: this is your clue to call the aforementioned routine.

The intent with this API is that a simple DHCP client thread, which maintains the state of the interfaces, can go as follows: (after `init_all_network_interfaces()` is called from elsewhere)

```
while ( 1 ) {
    while ( 1 ) {
        cyg_semaphore_wait( &dhcp_needs_attention );
        if ( ! dhcp_bind() ) // a lease expired
            break; // If we need to re-bind
    }
    dhcp_down(); // tear down unbound interfaces
    init_all_network_interfaces(); // re-initialize
}
```

and if the application does not want to suffer the overhead of a separate thread and its stack for this, this functionality can be placed in the app's server loop in an obvious fashion. That is the goal of breaking out these internal elements. For example, some server might be arranged to poll DHCP from time to time like this:

```
while ( 1 ) {
    init_all_network_interfaces();
    open-my-listen-sockets();
    while ( 1 ) {
        serve-one-request();
        // sleeps if no connections, but not forever;
        // so this loop is polled a few times a minute...
        if ( cyg_semaphore_trywait( &dhcp_needs_attention ) ) {
            if ( ! dhcp_bind() ) {
                close-my-listen-sockets();
                dhcp_down();
                break;
            }
        }
    }
}
```

If the configuration option `CYGOPT_NET_DHCP_DHCP_THREAD` is defined, then eCos provides a thread as described initially. Independent of this option, initialization of the interfaces still occurs in `init_all_network_interfaces()` and your startup code can call that. It will start the DHCP management thread if configured. If a lease fails to be renewed, the management thread will shut down all interfaces and attempt to initialize all the interfaces again from scratch. This may cause chaos in the app, which is why managing the DHCP state in an application aware thread is actually better, just far less convenient for testing.

If the configuration option `CYGOPT_NET_DHCP_OPTION_HOST_NAME` is defined, then the `TAG_HOST_NAME` DHCP option will be included in any DHCP lease requests. The text for the hostname is set by calling `dhcp_set_hostname()`. Any DHCP lease requests made prior to calling `dhcp_set_hostname()` will not include the `TAG_HOST_NAME` DHCP option. The configuration option `CYGNUM_NET_DHCP_OPTION_HOST_NAME_LEN` controls the maximum length allowed for the

hostname. This permits the hostname text to be determined at run-time. Setting the hostname to the empty string will have the effect of disabling the TAG_HOST_NAME DHCP option.

If the configuration option CYGOPT_NET_DHCP_OPTION_DHCP_CLIENTID_MAC is defined, then the TAG_DHCP_CLIENTID DHCP option will be included in any DHCP lease requests. The client ID used will be the current MAC address of the network interface.

The option CYGOPT_NET_DHCP_PARM_REQ_LIST_ADDITIONAL allows additional DHCP options to be added to the request sent to the DHCP server. This option should be set to a comma separated list of options.

The option CYGOPT_NET_DHCP_PARM_REQ_LIST_REPLACE is similar to CYGOPT_NET_DHCP_PARM_REQ_LIST_ADDITIONAL but in this case it completely replaces the default list of options with the configured set of comma separated options.

Chapter 38. TCP/IP Library Reference

getdomainname

GETDOMAINNAME(3) BSD Library Functions Manual GETDOMAINNAME(3)

NAME

getdomainname, setdomainname - get/set YP domain name of current host

SYNOPSIS

```
#include <unistd.h>
```

```
int
getdomainname(char *name, size_t namelen);
```

```
int
setdomainname(const char *name, size_t namelen);
```

DESCRIPTION

The `getdomainname()` function returns the YP domain name for the current processor, as previously set by `setdomainname()`. The parameter `namelen` specifies the size of the name array. If insufficient space is provided, the returned name is truncated. The returned name is always null terminated.

`setdomainname()` sets the domain name of the host machine to be `name`, which has length `namelen`. This call is restricted to the superuser and is normally used only when the system is bootstrapped.

RETURN VALUES

If the call succeeds a value of 0 is returned. If the call fails, a value of -1 is returned and an error code is placed in the global variable `errno`.

ERRORS

The following errors may be returned by these calls:

[EFAULT]	The name or <code>namelen</code> parameter gave an invalid address.
[EPERM]	The caller tried to set the domain name and was not the superuser.

SEE ALSO

`domainname(1)`, `gethostid(3)`, `gethostname(3)`, `sysctl(3)`, `sysctl(8)`, `yp(8)`

BUGS

Domain names are limited to `MAXHOSTNAMELEN` (from `<sys/param.h>`) characters, currently 256. This includes the terminating NUL character.

If the buffer passed to `getdomainname()` is too small, other operating systems may not guarantee termination with NUL.

HISTORY

The `getdomainname` function call appeared in SunOS 3.x.

gethostname

GETHOSTNAME(3)

BSD Library Functions Manual

GETHOSTNAME(3)

NAME

gethostname, sethostname - get/set name of current host

SYNOPSIS

```
#include <unistd.h>
```

```
int
gethostname(char *name, size_t namelen);
```

```
int
sethostname(const char *name, size_t namelen);
```

DESCRIPTION

The `gethostname()` function returns the standard host name for the current processor, as previously set by `sethostname()`. The parameter `namelen` specifies the size of the name array. If insufficient space is provided, the returned name is truncated. The returned name is always null terminated.

`sethostname()` sets the name of the host machine to be `name`, which has length `namelen`. This call is restricted to the superuser and is normally used only when the system is bootstrapped.

RETURN VALUES

If the call succeeds a value of 0 is returned. If the call fails, a value of -1 is returned and an error code is placed in the global variable `errno`.

ERRORS

The following errors may be returned by these calls:

[EFAULT]	The name or <code>namelen</code> parameter gave an invalid address.
[EPERM]	The caller tried to set the hostname and was not the superuser.

SEE ALSO

`hostname(1)`, `getdomainname(3)`, `gethostid(3)`, `sysctl(3)`, `sysctl(8)`, `yp(8)`

STANDARDS

The `gethostname()` function call conforms to X/Open Portability Guide Issue 4.2 ("XPG4.2").

HISTORY

The `gethostname()` function call appeared in 4.2BSD.

BUGS

Host names are limited to `MAXHOSTNAMELEN` (from `<sys/param.h>`) characters, currently 256. This includes the terminating NUL character.

If the buffer passed to `gethostname()` is smaller than `MAXHOSTNAMELEN`,

other operating systems may not guarantee termination with NUL.

BSD

June 4, 1993

BSD

byteorder

BYTEORDER(3)

BSD Library Functions Manual

BYTEORDER(3)

NAME

htonl, htons, ntohl, ntohs, htobe32, htobe16, betoh32, betoh16, htole32, htole16, letoh32, letoh16, swap32, swap16 - convert values between different byte orderings

SYNOPSIS

```
#include <sys/types.h>
#include <machine/endian.h>
```

```
u_int32_t
htonl(u_int32_t host32);
```

```
u_int16_t
htons(u_int16_t host16);
```

```
u_int32_t
ntohl(u_int32_t net32);
```

```
u_int16_t
ntohs(u_int16_t net16);
```

```
u_int32_t
htobe32(u_int32_t host32);
```

```
u_int16_t
htobe16(u_int16_t host16);
```

```
u_int32_t
betoh32(u_int32_t big32);
```

```
u_int16_t
betoh16(u_int16_t big16);
```

```
u_int32_t
htole32(u_int32_t host32);
```

```
u_int16_t
htole16(u_int16_t host16);
```

```
u_int32_t
letoh32(u_int32_t little32);
```

```
u_int16_t
letoh16(u_int16_t little16);
```

```
u_int32_t
swap32(u_int32_t val32);
```

```
u_int16_t
```

```
swap16(u_int16_t val16);
```

DESCRIPTION

These routines convert 16- and 32-bit quantities between different byte orderings. The "swap" functions reverse the byte ordering of the given quantity, the others converts either from/to the native byte order used by the host to/from either little- or big-endian (a.k.a network) order.

Apart from the swap functions, the names can be described by this form: {src-order}to{dst-order}{size}. Both {src-order} and {dst-order} can take the following forms:

- h Host order.
- n Network order (big-endian).
- be Big-endian (most significant byte first).
- le Little-endian (least significant byte first).

One of the specified orderings must be 'h'. {size} will take these forms:

- l Long (32-bit, used in conjunction with forms involving 'n').
- s Short (16-bit, used in conjunction with forms involving 'n').
- 16 16-bit.
- 32 32-bit.

The swap functions are of the form: swap{size}.

Names involving 'n' convert quantities between network byte order and host byte order. The last letter ('s' or 'l') is a mnemonic for the traditional names for such quantities, short and long, respectively. Today, the C concept of short and long integers need not coincide with this traditional misunderstanding. On machines which have a byte order which is the same as the network order, routines are defined as null macros.

The functions involving either "be", "le", or "swap" use the numbers 16 and 32 for specifying the bitwidth of the quantities they operate on. Currently all supported architectures are either big- or little-endian so either the "be" or "le" variants are implemented as null macros.

The routines mentioned above which have either {src-order} or {dst-order} set to 'n' are most often used in conjunction with Internet addresses and ports as returned by gethostbyname(3) and getservent(3).

SEE ALSO

gethostbyname(3), getservent(3)

HISTORY

The byteorder functions appeared in 4.2BSD.

BUGS

On the vax, alpha, i386, and so far mips, bytes are handled backwards from most everyone else in the world. This is not expected to be fixed in the near future.

BSD

June 4, 1993

BSD

ethers

ETHERS(3)

BSD Library Functions Manual

ETHERS(3)

NAME

ether_aton, ether_ntoa, ether_addr, ether_ntohost, ether_hostton,
ether_line - get ethers entry

SYNOPSIS

```
#include <netinet/if_ether.h>
```

```
char *  
ether_ntoa(struct ether_addr *e);
```

```
struct ether_addr *  
ether_aton(char *s);
```

```
int  
ether_ntohost(char *hostname, struct ether_addr *e);
```

```
int  
ether_hostton(char *hostname, struct ether_addr *e);
```

```
int  
ether_line(char *l, struct ether_addr *e, char *hostname);
```

DESCRIPTION

Ethernet addresses are represented by the following structure:

```
struct ether_addr {  
    u_int8_t  ether_addr_octet[6];  
};
```

The ether_ntoa() function converts this structure into an ASCII string of the form "xx:xx:xx:xx:xx:xx", consisting of 6 hexadecimal numbers separated by colons. It returns a pointer to a static buffer that is reused for each call. The ether_aton() converts an ASCII string of the same form and to a structure containing the 6 octets of the address. It returns a pointer to a static structure that is reused for each call.

The ether_ntohost() and ether_hostton() functions interrogate the database mapping host names to Ethernet addresses, /etc/ethers. The ether_ntohost() function looks up the given Ethernet address and writes the associated host name into the character buffer passed. This buffer should be MAXHOSTNAMELEN characters in size. The ether_hostton() function looks up the given host name and writes the associated Ethernet address into the structure passed. Both functions return zero if they find the requested host name or address, and -1 if not.

Each call reads /etc/ethers from the beginning; if a '+' appears alone on a line in the file, then ether_hostton() will consult the ethers.byname YP map, and ether_ntohost() will consult the ethers.byaddr YP map.

The ether_line() function parses a line from the /etc/ethers file and fills in the passed struct ether_addr and character buffer with the Ethernet address and host name on the line. It returns zero if the line was successfully parsed and -1 if not. The character buffer should be MAXHOSTNAMELEN characters in size.

FILES

/etc/ethers

SEE ALSO

ethers(5)

HISTORY

The `ether_ntoa()`, `ether_aton()`, `ether_ntohost()`, `ether_hostton()`, and `ether_line()` functions were adopted from SunOS and appeared in NetBSD 0.9 b.

BUGS

The data space used by these functions is static; if future use requires the data, it should be copied before any subsequent calls to these functions overwrite it.

BSD

December 16, 1993

BSD

getaddrinfo

GETADDRINFO(3)

BSD Library Functions Manual

GETADDRINFO(3)

NAME

`getaddrinfo`, `freeaddrinfo`, `gai_strerror` - nodename-to-address translation in protocol-independent manner

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
```

```
int
getaddrinfo(const char *nodename, const char *servname,
            const struct addrinfo *hints, struct addrinfo **res);
```

```
void
freeaddrinfo(struct addrinfo *ai);
```

```
char *
gai_strerror(int ecode);
```

DESCRIPTION

The `getaddrinfo()` function is defined for protocol-independent nodename-to-address translation. It performs the functionality of `gethostbyname(3)` and `getservbyname(3)`, but in a more sophisticated manner.

The `addrinfo` structure is defined as a result of including the `<netdb.h>` header:

```
struct addrinfo {
    int     ai_flags;      /* AI_PASSIVE, AI_CANONNAME, AI_NUMERICHOST */
    int     ai_family;    /* PF_xxx */
    int     ai_socktype;   /* SOCK_xxx */
    int     ai_protocol;   /* 0 or IPPROTO_xxx for IPv4 and IPv6 */
    size_t  ai_addrlen;    /* length of ai_addr */
    char    *ai_canonname; /* canonical name for nodename */
    struct sockaddr *ai_addr; /* binary address */
    struct addrinfo *ai_next; /* next structure in linked list */
};
```

```
};
```

The `nodename` and `servname` arguments are pointers to NUL-terminated strings or NULL. One or both of these two arguments must be a non-null pointer. In the normal client scenario, both the `nodename` and `servname` are specified. In the normal server scenario, only the `servname` is specified. A non-null `nodename` string can be either a node name or a numeric host address string (i.e., a dotted-decimal IPv4 address or an IPv6 hex address). A non-null `servname` string can be either a service name or a decimal port number.

The caller can optionally pass an `addrinfo` structure, pointed to by the third argument, to provide hints concerning the type of socket that the caller supports. In this hints structure all members other than `ai_flags`, `ai_family`, `ai_socktype`, and `ai_protocol` must be zero or a null pointer. A value of `PF_UNSPEC` for `ai_family` means the caller will accept any protocol family. A value of 0 for `ai_socktype` means the caller will accept any socket type. A value of 0 for `ai_protocol` means the caller will accept any protocol. For example, if the caller handles only TCP and not UDP, then the `ai_socktype` member of the hints structure should be set to `SOCK_STREAM` when `getaddrinfo()` is called. If the caller handles only IPv4 and not IPv6, then the `ai_family` member of the hints structure should be set to `PF_INET` when `getaddrinfo()` is called. If the third argument to `getaddrinfo()` is a null pointer, this is the same as if the caller had filled in an `addrinfo` structure initialized to zero with `ai_family` set to `PF_UNSPEC`.

Upon successful return a pointer to a linked list of one or more `addrinfo` structures is returned through the final argument. The caller can process each `addrinfo` structure in this list by following the `ai_next` pointer, until a null pointer is encountered. In each returned `addrinfo` structure the three members `ai_family`, `ai_socktype`, and `ai_protocol` are the corresponding arguments for a call to the `socket()` function. In each `addrinfo` structure the `ai_addr` member points to a filled-in socket address structure whose length is specified by the `ai_addrlen` member.

If the `AI_PASSIVE` bit is set in the `ai_flags` member of the hints structure, then the caller plans to use the returned socket address structure in a call to `bind()`. In this case, if the `nodename` argument is a null pointer, then the IP address portion of the socket address structure will be set to `INADDR_ANY` for an IPv4 address or `IN6ADDR_ANY_INIT` for an IPv6 address.

If the `AI_PASSIVE` bit is not set in the `ai_flags` member of the hints structure, then the returned socket address structure will be ready for a call to `connect()` (for a connection-oriented protocol) or either `connect()`, `sendto()`, or `sendmsg()` (for a connectionless protocol). In this case, if the `nodename` argument is a null pointer, then the IP address portion of the socket address structure will be set to the loop-back address.

If the `AI_CANONNAME` bit is set in the `ai_flags` member of the hints structure, then upon successful return the `ai_canonname` member of the first `addrinfo` structure in the linked list will point to a NUL-terminated string containing the canonical name of the specified `nodename`.

If the `AI_NUMERICHOST` bit is set in the `ai_flags` member of the hints structure, then a non-null `nodename` string must be a numeric host address string. Otherwise an error of `EAI_NONAME` is returned. This flag prevents any type of name resolution service (e.g., the DNS) from being called.

The arguments to `getaddrinfo()` must sufficiently be consistent and unambiguous. Here are pitfall cases you may encounter:

- o `getaddrinfo()` will raise an error if members of the hints structure are not consistent. For example, for internet address families, `getaddrinfo()` will raise an error if you specify `SOCK_STREAM` to `ai_socktype` while you specify `IPPROTO_UDP` to `ai_protocol`.
- o If you specify a servname which is defined only for certain `ai_socktype`, `getaddrinfo()` will raise an error because the arguments are not consistent. For example, `getaddrinfo()` will raise an error if you ask for "tftp" service on `SOCK_STREAM`.
- o For internet address families, if you specify servname while you set `ai_socktype` to `SOCK_RAW`, `getaddrinfo()` will raise an error, because service names are not defined for the internet `SOCK_RAW` space.
- o If you specify a numeric servname, while leaving `ai_socktype` and `ai_protocol` unspecified, `getaddrinfo()` will raise an error. This is because the numeric servname does not identify any socket type, and `getaddrinfo()` is not allowed to glob the argument in such case.

All of the information returned by `getaddrinfo()` is dynamically allocated: the `addrinfo` structures, the socket address structures, and canonical node name strings pointed to by the `addrinfo` structures. To return this information to the system the function `freeaddrinfo()` is called. The `addrinfo` structure pointed to by the `ai` argument is freed, along with any dynamic storage pointed to by the structure. This operation is repeated until a `NULL` `ai_next` pointer is encountered.

To aid applications in printing error messages based on the `EAI_XXX` codes returned by `getaddrinfo()`, `gai_strerror()` is defined. The argument is one of the `EAI_XXX` values defined earlier and the return value points to a string describing the error. If the argument is not one of the `EAI_XXX` values, the function still returns a pointer to a string whose contents indicate an unknown error.

Extension for scoped IPv6 address

The implementation allows experimental numeric IPv6 address notation with scope identifier. By appending the percent character and scope identifier to addresses, you can fill `sin6_scope_id` field for addresses. This would make management of scoped address easier, and allows cut-and-paste input of scoped address.

At this moment the code supports only link-local addresses with the format. Scope identifier is hardcoded to name of hardware interface associated with the link. (such as `ne0`). Example would be like `"fe80::1%ne0"`, which means "fe80::1 on the link associated with ne0 interface".

The implementation is still very experimental and non-standard. The current implementation assumes one-by-one relationship between interface and link, which is not necessarily true from the specification.

EXAMPLES

The following code tries to connect to "www.kame.net" service "http" via stream socket. It loops through all the addresses available, regardless from address family. If the destination resolves to IPv4 address, it will use `AF_INET` socket. Similarly, if it resolves to IPv6, `AF_INET6` socket is used. Observe that there is no hardcoded reference to particu-

lar address family. The code works even if `getaddrinfo` returns addresses that are not IPv4/v6.

```

struct addrinfo hints, *res, *res0;
int error;
int s;
const char *cause = NULL;

memset(&hints, 0, sizeof(hints));
hints.ai_family = PF_UNSPEC;
hints.ai_socktype = SOCK_STREAM;
error = getaddrinfo("www.kame.net", "http", &hints, &res0);
if (error) {
    errx(1, "%s", gai_strerror(error));
    /*NOTREACHED*/
}
s = -1;
for (res = res0; res; res = res->ai_next) {
    s = socket(res->ai_family, res->ai_socktype,
               res->ai_protocol);
    if (s < 0) {
        cause = "socket";
        continue;
    }

    if (connect(s, res->ai_addr, res->ai_addrlen) < 0) {
        cause = "connect";
        close(s);
        s = -1;
        continue;
    }

    break; /* okay we got one */
}
if (s < 0) {
    err(1, cause);
    /*NOTREACHED*/
}
freeaddrinfo(res0);

```

The following example tries to open a wildcard listening socket onto service "http", for all the address families available.

```

struct addrinfo hints, *res, *res0;
int error;
int s[MAXSOCK];
int nsock;
const char *cause = NULL;

memset(&hints, 0, sizeof(hints));
hints.ai_family = PF_UNSPEC;
hints.ai_socktype = SOCK_STREAM;
hints.ai_flags = AI_PASSIVE;
error = getaddrinfo(NULL, "http", &hints, &res0);
if (error) {
    errx(1, "%s", gai_strerror(error));
    /*NOTREACHED*/
}
nsock = 0;
for (res = res0; res && nsock < MAXSOCK; res = res->ai_next) {
    s[nsock] = socket(res->ai_family, res->ai_socktype,

```

```

        res->ai_protocol);
    if (s[nsock] < 0) {
        cause = "socket";
        continue;
    }

    if (bind(s[nsock], res->ai_addr, res->ai_addrlen) < 0) {
        cause = "bind";
        close(s[nsock]);
        continue;
    }
    (void) listen(s[nsock], 5);

    nsock++;
}
if (nsock == 0) {
    err(1, cause);
    /*NOTREACHED*/
}
freeaddrinfo(res0);

```

DIAGNOSTICS

Error return status from `getaddrinfo()` is zero on success and non-zero on errors. Non-zero error codes are defined in `<netdb.h>`, and as follows:

<code>EAI_ADDRFAMILY</code>	Address family for nodename not supported.
<code>EAI_AGAIN</code>	Temporary failure in name resolution.
<code>EAI_BADFLAGS</code>	Invalid value for <code>ai_flags</code> .
<code>EAI_FAIL</code>	Non-recoverable failure in name resolution.
<code>EAI_FAMILY</code>	<code>ai_family</code> not supported.
<code>EAI_MEMORY</code>	Memory allocation failure.
<code>EAI_NODATA</code>	No address associated with nodename.
<code>EAI_NONAME</code>	nodename nor servname provided, or not known.
<code>EAI_SERVICE</code>	servname not supported for <code>ai_socktype</code> .
<code>EAI_SOCKTYPE</code>	<code>ai_socktype</code> not supported.
<code>EAI_SYSTEM</code>	System error returned in <code>errno</code> .

If called with proper argument, `gai_strerror()` returns a pointer to a string describing the given error code. If the argument is not one of the `EAI_xxx` values, the function still returns a pointer to a string whose contents indicate an unknown error.

SEE ALSO

`getnameinfo(3)`, `gethostbyname(3)`, `getservbyname(3)`, `hosts(5)`, `resolv.conf(5)`, `services(5)`, `hostname(7)`, `named(8)`

R. Gilligan, S. Thomson, J. Bound, and W. Stevens, Basic Socket Interface Extensions for IPv6, RFC2553, March 1999.

Tatsuya Jinmei and Atsushi Onoe, An Extension of Format for IPv6 Scoped Addresses, internet draft, draft-ietf-ipngwg-scopedaddr-format-02.txt, work in progress material.

Craig Metz, "Protocol Independence Using the Sockets API", Proceedings of the freenix track: 2000 USENIX annual technical conference, June 2000.

HISTORY

The implementation first appeared in WIDE Hydrangea IPv6 protocol stack kit.

STANDARDS

The `getaddrinfo()` function is defined in IEEE POSIX 1003.1g draft specification, and documented in "Basic Socket Interface Extensions for IPv6" (RFC2553).

BUGS

The current implementation is not thread-safe.

The text was shamelessly copied from RFC2553.

BSD

May 25, 1995

BSD

gethostbyname

GETHOSTBYNAME(3)

BSD Library Functions Manual

GETHOSTBYNAME(3)

NAME

`gethostbyname`, `gethostbyname2`, `gethostbyaddr`, `gethostent`, `sethostent`, `endhostent`, `hstrerror`, `herror` - get network host entry

SYNOPSIS

```
#include <netdb.h>
extern int h_errno;

struct hostent *
gethostbyname(const char *name);

struct hostent *
gethostbyname2(const char *name, int af);

struct hostent *
gethostbyaddr(const char *addr, int len, int af);

struct hostent *
gethostent(void);

void
sethostent(int stayopen);

void
endhostent(void);

void
herror(const char *string);

const char *
hstrerror(int err);
```

DESCRIPTION

The `gethostbyname()` and `gethostbyaddr()` functions each return a pointer to an object with the following structure describing an internet host referenced by name or by address, respectively. This structure contains either information obtained from the name server (i.e., `resolver(3)` and `named(8)`), broken-out fields from a line in `/etc/hosts`, or database entries supplied by the `yp(8)` system. `resolv.conf(5)` describes how the particular database is chosen.

```
struct hostent {
```

```

    char    *h_name;           /* official name of host */
    char    **h_aliases;       /* alias list */
    int      h_addrtype;       /* host address type */
    int      h_length;         /* length of address */
    char    **h_addr_list;     /* list of addresses from name server */
};
#define h_addr h_addr_list[0] /* address, for backward compatibility */

```

The members of this structure are:

<code>h_name</code>	Official name of the host.
<code>h_aliases</code>	A zero-terminated array of alternate names for the host.
<code>h_addrtype</code>	The type of address being returned.
<code>h_length</code>	The length, in bytes, of the address.
<code>h_addr_list</code>	A zero-terminated array of network addresses for the host. Host addresses are returned in network byte order.
<code>h_addr</code>	The first address in <code>h_addr_list</code> ; this is for backward compatibility.

The function `gethostbyname()` will search for the named host in the current domain and its parents using the search lookup semantics detailed in `resolv.conf(5)` and `hostname(7)`.

`gethostbyname2()` is an advanced form of `gethostbyname()` which allows lookups in address families other than `AF_INET`, for example `AF_INET6`.

The `gethostbyaddr()` function will search for the specified address of length `len` in the address family `af`. The only address family currently supported is `AF_INET`.

The `sethostent()` function may be used to request the use of a connected TCP socket for queries. If the `stayopen` flag is non-zero, this sets the option to send all queries to the name server using TCP and to retain the connection after each call to `gethostbyname()` or `gethostbyaddr()`. Otherwise, queries are performed using UDP datagrams.

The `endhostent()` function closes the TCP connection.

The `herror()` function prints an error message describing the failure. If its argument `string` is non-null, it is prepended to the message string and separated from it by a colon (':') and a space. The error message is printed with a trailing newline. The contents of the error message is the same as that returned by `hstrerror()` with argument `h_errno`.

FILES

```

/etc/hosts
/etc/resolv.conf

```

DIAGNOSTICS

Error return status from `gethostbyname()`, `gethostbyname2()`, and `gethostbyaddr()` is indicated by return of a null pointer. The external integer `h_errno` may then be checked to see whether this is a temporary failure or an invalid or unknown host.

The variable `h_errno` can have the following values:

HOST_NOT_FOUND No such host is known.

TRY_AGAIN This is usually a temporary error and means that the local server did not receive a response from an authoritative server. A retry at some later time may succeed.

NO_RECOVERY Some unexpected server failure was encountered. This is a non-recoverable error.

NO_DATA The requested name is valid but does not have an IP address; this is not a temporary error. This means that the name is known to the name server but there is no address associated with this name. Another type of request to the name server using this domain name will result in an answer; for example, a mail-forwarder may be registered for this domain.

SEE ALSO

resolver(3), getaddrinfo(3), getnameinfo(3), hosts(5), resolv.conf(5),
hostname(7), named(8)

CAVEAT

If the search routines in resolv.conf(5) decide to read the /etc/hosts file, gethostent() and other functions will read the next line of the file, re-opening the file if necessary.

The sethostent() function opens and/or rewinds the file /etc/hosts. If the stayopen argument is non-zero, the file will not be closed after each call to gethostbyname(), gethostbyname2(), or gethostbyaddr().

The endhostent() function closes the file.

HISTORY

The herror() function appeared in 4.3BSD. The endhostent(), gethostbyaddr(), gethostbyname(), gethostent(), and sethostent() functions appeared in 4.2BSD.

BUGS

These functions use static data storage; if the data is needed for future use, it should be copied before any subsequent calls overwrite it. Only the Internet address formats are currently understood.

YP does not support any address families other than AF_INET and uses the traditional database format.

BSD

March 13, 1997

BSD

getifaddrs

GETIFADDRS(3)

BSD Library Functions Manual

GETIFADDRS(3)

NAME

getifaddrs - get interface addresses

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
#include <ifaddrs.h>

int
getifaddrs(struct ifaddrs **ifap);

void
freeifaddrs(struct ifaddrs *ifap);
```

DESCRIPTION

The `getifaddrs()` function stores a reference to a linked list of the network interfaces on the local machine in the memory referenced by `ifap`. The list consists of `ifaddrs` structures, as defined in the include file `<ifaddrs.h>`. The `ifaddrs` structure contains at least the following entries:

```
struct ifaddrs  *ifa_next;          /* Pointer to next struct */
char            *ifa_name;          /* Interface name */
u_int          *ifa_flags;          /* Interface flags */
struct sockaddr *ifa_addr;          /* Interface address */
struct sockaddr *ifa_netmask;       /* Interface netmask */
struct sockaddr *ifa_broadaddr;     /* Interface broadcast address */
struct sockaddr *ifa_dstaddr;       /* P2P interface destination */
void            *ifa_data;          /* Address specific data */
```

`ifa_next`

Contains a pointer to the next structure on the list. This field is set to `NULL` in last structure on the list.

`ifa_name`

Contains the interface name.

`ifa_flags`

Contains the interface flags, as set by `ifconfig(8)`.

`ifa_addr`

References either the address of the interface or the link level address of the interface, if one exists, otherwise it is `NULL`. (The `sa_family` field of the `ifa_addr` field should be consulted to determine the format of the `ifa_addr` address.)

`ifa_netmask`

References the netmask associated with `ifa_addr`, if one is set, otherwise it is `NULL`.

`ifa_broadaddr`

This field, which should only be referenced for non-P2P interfaces, references the broadcast address associated with `ifa_addr`, if one exists, otherwise it is `NULL`.

`ifa_dstaddr`

References the destination address on a P2P interface, if one exists, otherwise it is `NULL`.

`ifa_data`

References address family specific data. For `AF_LINK` addresses it contains a pointer to the struct `if_data` (as defined in include file `<net/if.h>`) which contains various interface attributes and statistics. For all other address families, it contains a pointer to the struct `ifa_data` (as defined in include file `<net/if.h>`) which contains per-address interface statistics.

The data returned by `getifaddrs()` is dynamically allocated and should be freed using `freeifaddrs()` when no longer needed.

RETURN VALUES

Upon successful completion, a value of 0 is returned. Otherwise, a value of -1 is returned and `errno` is set to indicate the error.

ERRORS

The `getifaddrs()` may fail and set `errno` for any of the errors specified for the library routines `ioctl(2)`, `socket(2)`, `malloc(3)`, or `sysctl(3)`.

BUGS

If both `<net/if.h>` and `<ifaddrs.h>` are being included, `<net/if.h>` must be included before `<ifaddrs.h>`.

SEE ALSO

`ioctl(2)`, `socket(2)`, `sysctl(3)`, `networking(4)`, `ifconfig(8)`

HISTORY

The `getifaddrs()` function first appeared in BSDI BSD/OS. The function is supplied on OpenBSD since OpenBSD 2.7.

BSD

October 13, 2005

BSD

getnameinfo

GETNAMEINFO(3)

BSD Library Functions Manual

GETNAMEINFO(3)

NAME

`getnameinfo` - address-to-nodename translation in protocol-independent manner

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
```

```
int
getnameinfo(const struct sockaddr *sa, socklen_t salen, char *host,
             size_t hostlen, char *serv, size_t servlen, int flags);
```

DESCRIPTION

The `getnameinfo()` function is defined for protocol-independent address-to-nodename translation. Its functionality is a reverse conversion of `getaddrinfo(3)`, and implements similar functionality with `gethostbyaddr(3)` and `getservbyport(3)` in more sophisticated manner.

This function looks up an IP address and port number provided by the caller in the DNS and system-specific database, and returns text strings for both in buffers provided by the caller. The function indicates successful completion by a zero return value; a non-zero return value indicates failure.

The first argument, `sa`, points to either a `sockaddr_in` structure (for IPv4) or a `sockaddr_in6` structure (for IPv6) that holds the IP address and port number. The `salen` argument gives the length of the `sockaddr_in` or `sockaddr_in6` structure.

The function returns the nodename associated with the IP address in the buffer pointed to by the host argument. The caller provides the size of this buffer via the hostlen argument. The service name associated with the port number is returned in the buffer pointed to by serv, and the servlen argument gives the length of this buffer. The caller specifies not to return either string by providing a zero value for the hostlen or servlen arguments. Otherwise, the caller must provide buffers large enough to hold the nodename and the service name, including the terminating null characters.

Unfortunately most systems do not provide constants that specify the maximum size of either a fully-qualified domain name or a service name. Therefore to aid the application in allocating buffers for these two returned strings the following constants are defined in <netdb.h>:

```
#define NI_MAXHOST    MAXHOSTNAMELEN
#define NI_MAXSERV    32
```

The first value is actually defined as the constant MAXDNAME in recent versions of BIND's <arpa/nameser.h> header (older versions of BIND define this constant to be 256) and the second is a guess based on the services listed in the current Assigned Numbers RFC.

The final argument is a flag that changes the default actions of this function. By default the fully-qualified domain name (FQDN) for the host is looked up in the DNS and returned. If the flag bit NI_NOFQDN is set, only the nodename portion of the FQDN is returned for local hosts.

If the flag bit NI_NUMERICHOST is set, or if the host's name cannot be located in the DNS, the numeric form of the host's address is returned instead of its name (e.g., by calling inet_ntop() instead of gethostbyaddr()). If the flag bit NI_NAMEREQD is set, an error is returned if the host's name cannot be located in the DNS.

If the flag bit NI_NUMERICSERV is set, the numeric form of the service address is returned (e.g., its port number) instead of its name. The two NI_NUMERICxxx flags are required to support the -n flag that many commands provide.

A fifth flag bit, NI_DGRAM, specifies that the service is a datagram service, and causes getservbyport() to be called with a second argument of "udp" instead of its default of "tcp". This is required for the few ports (512-514) that have different services for UDP and TCP.

These NI_xxx flags are defined in <netdb.h>.

Extension for scoped IPv6 address

The implementation allows experimental numeric IPv6 address notation with scope identifier. IPv6 link-local address will appear as string like "fe80::1%ne0", if NI_WITHSCOPEID bit is enabled in flags argument. Refer to getaddrinfo(3) for the notation.

EXAMPLES

The following code tries to get numeric hostname, and service name, for given socket address. Observe that there is no hardcoded reference to particular address family.

```
struct sockaddr *sa;    /* input */
char hbuf[NI_MAXHOST], sbuf[NI_MAXSERV];
```

```

    if (getnameinfo(sa, sa->sa_len, hbuf, sizeof(hbuf), sbuf,
        sizeof(sbuf), NI_NUMERICHOST | NI_NUMERICSERV)) {
        errx(1, "could not get numeric hostname");
        /*NOTREACHED*/
    }
    printf("host=%s, serv=%s\n", hbuf, sbuf);

```

The following version checks if the socket address has reverse address mapping.

```

    struct sockaddr *sa;    /* input */
    char hbuf[NI_MAXHOST];

    if (getnameinfo(sa, sa->sa_len, hbuf, sizeof(hbuf), NULL, 0,
        NI_NAMEREQD)) {
        errx(1, "could not resolve hostname");
        /*NOTREACHED*/
    }
    printf("host=%s\n", hbuf);

```

DIAGNOSTICS

The function indicates successful completion by a zero return value; a non-zero return value indicates failure. Error codes are as below:

EAI_AGAIN	The name could not be resolved at this time. Future attempts may succeed.
EAI_BADFLAGS	The flags had an invalid value.
EAI_FAIL	A non-recoverable error occurred.
EAI_FAMILY	The address family was not recognized or the address length was invalid for the specified family.
EAI_MEMORY	There was a memory allocation failure.
EAI_NONAME	The name does not resolve for the supplied parameters. NI_NAMEREQD is set and the host's name cannot be located, or both nodename and servname were null.
EAI_SYSTEM	A system error occurred. The error code can be found in errno.

SEE ALSO

getaddrinfo(3), gethostbyaddr(3), getservbyport(3), hosts(5), resolv.conf(5), services(5), hostname(7), named(8)

R. Gilligan, S. Thomson, J. Bound, and W. Stevens, Basic Socket Interface Extensions for IPv6, RFC2553, March 1999.

Tatsuya Jinmei and Atsushi Onoe, An Extension of Format for IPv6 Scoped Addresses, internet draft, draft-ietf-ipngwg-scopedaddr-format-02.txt, work in progress material.

Craig Metz, "Protocol Independence Using the Sockets API", Proceedings of the freenix track: 2000 USENIX annual technical conference, June 2000.

HISTORY

The implementation first appeared in WIDE Hydrangea IPv6 protocol stack kit.

STANDARDS

The `getaddrinfo()` function is defined IEEE POSIX 1003.1g draft specification, and documented in "Basic Socket Interface Extensions for IPv6" (RFC2553).

BUGS

The current implementation is not thread-safe.

The text was shamelessly copied from RFC2553.

OpenBSD intentionally uses different `NI_MAXHOST` value from what RFC2553 suggests, to avoid buffer length handling mistakes.

BSD

May 25, 1995

BSD

getnetent

GETNETENT(3)

BSD Library Functions Manual

GETNETENT(3)

NAME

`getnetent`, `getnetbyaddr`, `getnetbyname`, `setnetent`, `endnetent` - get network entry

SYNOPSIS

```
#include <netdb.h>

struct netent *
getnetent(void);

struct netent *
getnetbyname(char *name);

struct netent *
getnetbyaddr(in_addr_t net, int type);

void
setnetent(int stayopen);

void
endnetent(void);
```

DESCRIPTION

The `getnetent()`, `getnetbyname()`, and `getnetbyaddr()` functions each return a pointer to an object with the following structure containing the broken-out fields of a line in the network database, `/etc/networks`.

```
struct netent {
    char      *n_name;      /* official name of net */
    char      **n_aliases;  /* alias list */
    int       n_addrtype;   /* net number type */
    in_addr_t n_net;        /* net number */
};
```

The members of this structure are:

`n_name` The official name of the network.

`n_aliases` A zero-terminated list of alternate names for the network.

`n_addrtype` The type of the network number returned; currently only `AF_INET`.

`n_net` The network number. Network numbers are returned in machine byte order.

The `getnetent()` function reads the next line of the file, opening the file if necessary.

The `setnetent()` function opens and rewinds the file. If the `stayopen` flag is non-zero, the net database will not be closed after each call to `getnetbyname()` or `getnetbyaddr()`.

The `endnetent()` function closes the file.

The `getnetbyname()` and `getnetbyaddr()` functions search the domain name server if the system is configured to use one. If the search fails, or no name server is configured, they sequentially search from the beginning of the file until a matching net name or net address and type is found, or until EOF is encountered. Network numbers are supplied in host order.

FILES

`/etc/networks`

DIAGNOSTICS

Null pointer (0) returned on EOF or error.

SEE ALSO

`resolver(3)`, `networks(5)`

HISTORY

The `getnetent()`, `getnetbyaddr()`, `getnetbyname()`, `setnetent()`, and `endnetent()` functions appeared in 4.2BSD.

BUGS

The data space used by these functions is static; if future use requires the data, it should be copied before any subsequent calls to these functions overwrite it. Only Internet network numbers are currently understood. Expecting network numbers to fit in no more than 32 bits is naive.

BSD

March 13, 1997

BSD

getprotoent

GETPROTOENT(3)

BSD Library Functions Manual

GETPROTOENT(3)

NAME

`getprotoent`, `getprotobynumber`, `getprotobyname`, `setprotoent`, `endprotoent` -
get protocol entry

SYNOPSIS

```
#include <netdb.h>
```

```
struct protoent *
```

```
getprotoent(void);

struct protoent *
getprotobyname(char *name);

struct protoent *
getprotobynumber(int proto);

void
setprotoent(int stayopen);

void
endprotoent(void);
```

DESCRIPTION

The `getprotoent()`, `getprotobyname()`, and `getprotobynumber()` functions each return a pointer to an object with the following structure containing the broken-out fields of a line in the network protocol database, `/etc/protocols`.

```
struct protoent {
    char    *p_name;        /* official name of protocol */
    char    **p_aliases;    /* alias list */
    int     p_proto;        /* protocol number */
};
```

The members of this structure are:

`p_name` The official name of the protocol.

`p_aliases` A zero-terminated list of alternate names for the protocol.

`p_proto` The protocol number.

The `getprotoent()` function reads the next line of the file, opening the file if necessary.

The `setprotoent()` function opens and rewinds the file. If the `stayopen` flag is non-zero, the net database will not be closed after each call to `getprotobyname()` or `getprotobynumber()`.

The `endprotoent()` function closes the file.

The `getprotobyname()` and `getprotobynumber()` functions sequentially search from the beginning of the file until a matching protocol name or protocol number is found, or until EOF is encountered.

RETURN VALUES

Null pointer (0) returned on EOF or error.

FILES

`/etc/protocols`

SEE ALSO

`protocols(5)`

HISTORY

The `getprotoent()`, `getprotobynumber()`, `getprotobyname()`, `setprotoent()`, and `endprotoent()` functions appeared in 4.2BSD.

BUGS

These functions use a static data space; if the data is needed for future use, it should be copied before any subsequent calls overwrite it. Only the Internet protocols are currently understood.

BSD

June 4, 1993

BSD

getrrsetbyname

GETRRSETBYNAME(3)

BSD Library Functions Manual

GETRRSETBYNAME(3)

NAME

getrrsetbyname - retrieve DNS records

SYNOPSIS

```
#include <netdb.h>
```

```
int
getrrsetbyname(const char *hostname, unsigned int rdclass,
               unsigned int rdtype, unsigned int flags, struct rrsetinfo **res);

int
freerrset(struct rrsetinfo **rrset);
```

DESCRIPTION

getrrsetbyname() gets a set of resource records associated with a hostname, class and type. hostname is a pointer to a null-terminated string. The flags field is currently unused and must be zero.

After a successful call to getrrsetbyname(), *res is a pointer to an rrsetinfo structure, containing a list of one or more rdatainfo structures containing resource records and potentially another list of rdatainfo structures containing SIG resource records associated with those records. The members rri_rdclass and rri_rdtype are copied from the parameters. rri_ttl and rri_name are properties of the obtained rrset. The resource records contained in rri_rdatas and rri_sigs are in uncompressed DNS wire format. Properties of the rdataset are represented in the rri_flags bitfield. If the RRSET_VALIDATED bit is set, the data has been DNSSEC validated and the signatures verified.

The following structures are used:

```
struct rdatainfo {
    unsigned int    rdi_length;    /* length of data */
    unsigned char   *rdi_data;     /* record data */
};

struct rrsetinfo {
    unsigned int    rri_flags;     /* RRSET_VALIDATED ... */
    unsigned int    rri_rdclass;   /* class number */
    unsigned int    rri_rdtype;   /* RR type number */
    unsigned int    rri_ttl;      /* time to live */
    unsigned int    rri_nrdatas;   /* size of rdatas array */
    unsigned int    rri_nsigs;    /* size of sigs array */
    char            *rri_name;     /* canonical name */
    struct rdatainfo *rri_rdatas; /* individual records */
    struct rdatainfo *rri_sigs;   /* individual signatures */
};
```

```
};
```

All of the information returned by `getrrsetbyname()` is dynamically allocated: the `rrsetinfo` and `rdatainfo` structures, and the canonical host name strings pointed to by the `rrsetinfo` structure. Memory allocated for the dynamically allocated structures created by a successful call to `getrrsetbyname()` is released by `freerrset()`. `rrset` is a pointer to a struct `rrset` created by a call to `getrrsetbyname()`.

If the EDNS0 option is activated in `resolv.conf(3)`, `getrrsetbyname()` will request DNSSEC authentication using the EDNS0 DNSSEC OK (DO) bit.

RETURN VALUES

`getrrsetbyname()` returns zero on success, and one of the following error codes if an error occurred:

<code>ERRSET_NONAME</code>	the name does not exist
<code>ERRSET_NODATA</code>	the name exists, but does not have data of the desired type
<code>ERRSET_NOMEMORY</code>	memory could not be allocated
<code>ERRSET_INVALID</code>	a parameter is invalid
<code>ERRSET_FAIL</code>	other failure

SEE ALSO

`resolver(3)`, `resolv.conf(5)`, `named(8)`

AUTHORS

Jakob Schlyter <jakob@openbsd.org>

HISTORY

`getrrsetbyname()` first appeared in OpenBSD 3.0. The API first appeared in ISC BIND version 9.

BUGS

The data in `*rdi_data` should be returned in uncompressed wire format. Currently, the data is in compressed format and the caller can't uncompress since it doesn't have the full message.

CAVEATS

The `RRSET_VALIDATED` flag in `rri_flags` is set if the AD (authenticated data) bit in the DNS answer is set. This flag should not be trusted unless the transport between the nameserver and the resolver is secure (e.g. IPsec, trusted network, loopback communication).

BSD

Oct 18, 2000

BSD

getservent

GETSERVENT(3)

BSD Library Functions Manual

GETSERVENT(3)

NAME

`getservent`, `getservbyport`, `getservbyname`, `setservent`, `endservent` - get service entry

SYNOPSIS

```
#include <netdb.h>
```

```

struct servent *
getservent(void);

struct servent *
getservbyname(char *name, char *proto);

struct servent *
getservbyport(int port, char *proto);

void
setservent(int stayopen);

void
endservent(void);

```

DESCRIPTION

The `getservent()`, `getservbyname()`, and `getservbyport()` functions each return a pointer to an object with the following structure containing the broken-out fields of a line in the network services database, `/etc/services`.

```

struct servent {
    char    *s_name;           /* official name of service */
    char    **s_aliases;       /* alias list */
    int     s_port;            /* port service resides at */
    char    *s_proto;          /* protocol to use */
};

```

The members of this structure are:

`s_name` The official name of the service.

`s_aliases` A zero-terminated list of alternate names for the service.

`s_port` The port number at which the service resides. Port numbers are returned in network byte order.

`s_proto` The name of the protocol to use when contacting the service.

The `getservent()` function reads the next line of the file, opening the file if necessary.

The `setservent()` function opens and rewinds the file. If the `stayopen` flag is non-zero, the net database will not be closed after each call to `getservbyname()` or `getservbyport()`.

The `endservent()` function closes the file.

The `getservbyname()` and `getservbyport()` functions sequentially search from the beginning of the file until a matching protocol name or port number (specified in network byte order) is found, or until EOF is encountered. If a protocol name is also supplied (non-null), searches must also match the protocol.

FILES

`/etc/services`

DIAGNOSTICS

Null pointer (0) returned on EOF or error.

SEE ALSO

```
getprotoent(3), services(5)
```

HISTORY

The `getservent()`, `getservbyport()`, `getservbyname()`, `setservent()`, and `endservent()` functions appeared in 4.2BSD.

BUGS

These functions use static data storage; if the data is needed for future use, it should be copied before any subsequent calls overwrite it. Expecting port numbers to fit in a 32-bit quantity is probably naive.

BSD

January 12, 1994

BSD

if_nametoindex

IF_NAMETOINDEX(3)

BSD Library Functions Manual

IF_NAMETOINDEX(3)

NAME

`if_nametoindex`, `if_indextoname`, `if_nameindex`, `if_freenameindex` - convert interface index to name, and vice versa

SYNOPSIS

```
#include <net/if.h>
```

```
unsigned int
if_nametoindex(const char *ifname);
```

```
char *
if_indextoname(unsigned int ifindex, char *ifname);
```

```
struct if_nameindex *
if_nameindex(void);
```

```
void
if_freenameindex(struct if_nameindex *ptr);
```

DESCRIPTION

These functions map interface indexes to interface names (such as "lo0"), and vice versa.

The `if_nametoindex()` function converts an interface name specified by the `ifname` argument to an interface index (positive integer value). If the specified interface does not exist, 0 will be returned.

`if_indextoname()` converts an interface index specified by the `ifindex` argument to an interface name. The `ifname` argument must point to a buffer of at least `IF_NAMESIZE` bytes into which the interface name corresponding to the specified index is returned. (`IF_NAMESIZE` is also defined in `<net/if.h>` and its value includes a terminating null byte at the end of the interface name.) This pointer is also the return value of the function. If there is no interface corresponding to the specified index, `NULL` is returned.

`if_nameindex()` returns an array of `if_nameindex` structures. `if_nametoindex` is also defined in `<net/if.h>`, and is as follows:

```
struct if_nameindex {
```

```

    unsigned int    if_index; /* 1, 2, ... */
    char            *if_name; /* null terminated name: "le0", ... */
};

```

The end of the array of structures is indicated by a structure with an `if_index` of 0 and an `if_name` of `NULL`. The function returns a null pointer on error. The memory used for this array of structures along with the interface names pointed to by the `if_name` members is obtained dynamically. This memory is freed by the `if_freenameindex()` function.

`if_freenameindex()` takes a pointer that was returned by `if_nameindex()` as argument (`ptr`), and it reclaims the region allocated.

DIAGNOSTICS

`if_nametoindex()` returns 0 on error, positive integer on success.
`if_indextoname()` and `if_nameindex()` return `NULL` on errors.

SEE ALSO

R. Gilligan, S. Thomson, J. Bound, and W. Stevens, "Basic Socket Interface Extensions for IPv6," RFC2553, March 1999.

STANDARDS

These functions are defined in "Basic Socket Interface Extensions for IPv6" (RFC2533).

BSD

May 21, 1998

BSD

inet

INET(3)

BSD Library Functions Manual

INET(3)

NAME

`inet_addr`, `inet_aton`, `inet_lnaof`, `inet_makeaddr`, `inet_netof`,
`inet_network`, `inet_ntoa`, `inet_ntop`, `inet_pton` - Internet address manipulation routines

SYNOPSIS

```

#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>

```

```

in_addr_t
inet_addr(const char *cp);

```

```

int
inet_aton(const char *cp, struct in_addr *addr);

```

```

in_addr_t
inet_lnaof(struct in_addr in);

```

```

struct in_addr
inet_makeaddr(unsigned long net, unsigned long lna);

```

```

in_addr_t
inet_netof(struct in_addr in);

```

```

in_addr_t

```

```

inet_network(const char *cp);

char *
inet_ntoa(struct in_addr in);

const char *
inet_ntop(int af, const void *src, char *dst, size_t size);

int
inet_pton(int af, const char *src, void *dst);

```

DESCRIPTION

The routines `inet_aton()`, `inet_addr()` and `inet_network()` interpret character strings representing numbers expressed in the Internet standard ‘.’ notation. The `inet_pton()` function converts a presentation format address (that is, printable form as held in a character string) to network format (usually a `struct in_addr` or some other internal binary representation, in network byte order). It returns 1 if the address was valid for the specified address family, or 0 if the address wasn’t parseable in the specified address family, or -1 if some system error occurred (in which case `errno` will have been set). This function is presently valid for `AF_INET` and `AF_INET6`. The `inet_aton()` routine interprets the specified character string as an Internet address, placing the address into the structure provided. It returns 1 if the string was successfully interpreted, or 0 if the string was invalid. The `inet_addr()` and `inet_network()` functions return numbers suitable for use as Internet addresses and Internet network numbers, respectively.

The function `inet_ntop()` converts an address from network format (usually a `struct in_addr` or some other binary form, in network byte order) to presentation format (suitable for external display purposes). It returns `NULL` if a system error occurs (in which case, `errno` will have been set), or it returns a pointer to the destination string. The routine `inet_ntoa()` takes an Internet address and returns an ASCII string representing the address in ‘.’ notation. The routine `inet_makeaddr()` takes an Internet network number and a local network address and constructs an Internet address from it. The routines `inet_netof()` and `inet_lnaof()` break apart Internet host addresses, returning the network number and local network address part, respectively.

All Internet addresses are returned in network order (bytes ordered from left to right). All network numbers and local address parts are returned as machine format integer values.

INTERNET ADDRESSES (IP VERSION 4)

Values specified using the ‘.’ notation take one of the following forms:

```

a.b.c.d
a.b.c
a.b
a

```

When four parts are specified, each is interpreted as a byte of data and assigned, from left to right, to the four bytes of an Internet address. Note that when an Internet address is viewed as a 32-bit integer quantity on a system that uses little-endian byte order (such as the Intel 386, 486 and Pentium processors) the bytes referred to above appear as “d.c.b.a”. That is, little-endian bytes are ordered from right to left.

When a three part address is specified, the last part is interpreted as a

16-bit quantity and placed in the rightmost two bytes of the network address. This makes the three part address format convenient for specifying Class B network addresses as "128.net.host".

When a two part address is supplied, the last part is interpreted as a 24-bit quantity and placed in the rightmost three bytes of the network address. This makes the two part address format convenient for specifying Class A network addresses as "net.host".

When only one part is given, the value is stored directly in the network address without any byte rearrangement.

All numbers supplied as "parts" in a '.' notation may be decimal, octal, or hexadecimal, as specified in the C language (i.e., a leading 0x or 0X implies hexadecimal; otherwise, a leading 0 implies octal; otherwise, the number is interpreted as decimal).

INTERNET ADDRESSES (IP VERSION 6)

In order to support scoped IPv6 addresses, `getaddrinfo(3)` and `getnameinfo(3)` are recommended rather than the functions presented here.

The presentation format of an IPv6 address is given in [RFC1884 2.2]:

There are three conventional forms for representing IPv6 addresses as text strings:

1. The preferred form is x:x:x:x:x:x:x:x, where the 'x's are the hexadecimal values of the eight 16-bit pieces of the address. Examples:

```
FEDC:BA98:7654:3210:FEDC:BA98:7654:3210
1080:0:0:0:8:800:200C:417A
```

Note that it is not necessary to write the leading zeros in an individual field, but there must be at least one numeral in every field (except for the case described in 2.).

2. Due to the method of allocating certain styles of IPv6 addresses, it will be common for addresses to contain long strings of zero bits. In order to make writing addresses

containing zero bits easier a special syntax is available to compress the zeros. The use of "::" indicates multiple groups of 16 bits of zeros. The "::" can only appear once in an address. The "::" can also be used to compress the leading and/or trailing zeros in an address.

For example the following addresses:

```
1080:0:0:0:8:800:200C:417A  a unicast address
FF01:0:0:0:0:0:0:43        a multicast address
0:0:0:0:0:0:0:1            the loopback address
0:0:0:0:0:0:0:0            the unspecified addresses
```

may be represented as:

```
1080::8:800:200C:417A      a unicast address
FF01::43                   a multicast address
::1                         the loopback address
::                          the unspecified addresses
```

3. An alternative form that is sometimes more convenient when dealing with a mixed environment of IPv4 and IPv6 nodes is `x:x:x:x:x:x:d.d.d.d`, where the 'x's are the hexadecimal values of the six high-order 16-bit pieces of the address, and the 'd's are the decimal values of the four low-order 8-bit pieces of the address (standard IPv4 representation). Examples:

```
0:0:0:0:0:0:13.1.68.3
0:0:0:0:0:FFFF:129.144.52.38
```

or in compressed form:

```
::13.1.68.3
::FFFF:129.144.52.38
```

DIAGNOSTICS

The constant `INADDR_NONE` is returned by `inet_addr()` and `inet_network()` for malformed requests.

SEE ALSO

`byteorder(3)`, `gethostbyname(3)`, `getnetent(3)`, `inet_net(3)`, `hosts(5)`, `networks(5)`

STANDARDS

The `inet_ntop` and `inet_pton` functions conform to the IETF IPv6 BSD API and address formatting specifications. Note that `inet_pton` does not accept 1-, 2-, or 3-part dotted addresses; all four parts must be specified. This is a narrower input set than that accepted by `inet_aton`.

HISTORY

The `inet_addr`, `inet_network`, `inet_makeaddr`, `inet_lnaof` and `inet_netof` functions appeared in 4.2BSD. The `inet_aton` and `inet_ntoa` functions appeared in 4.3BSD. The `inet_pton` and `inet_ntop` functions appeared in BIND 4.9.4.

BUGS

The value `INADDR_NONE` (`0xffffffff`) is a valid broadcast address, but `inet_addr()` cannot return that value without indicating failure. Also, `inet_addr()` should have been designed to return a struct `in_addr`. The newer `inet_aton()` function does not share these problems, and almost all existing code should be modified to use `inet_aton()` instead.

The problem of host byte ordering versus network byte ordering is confusing.

The string returned by `inet_ntoa()` resides in a static memory area.

BSD

June 18, 1997

BSD

inet6_option_space

INET6_OPTION_SPACE(3) BSD Library Functions Manual INET6_OPTION_SPACE(3)

NAME

`inet6_option_space`, `inet6_option_init`, `inet6_option_append`,
`inet6_option_alloc`, `inet6_option_next`, `inet6_option_find` - IPv6 Hop-by-Hop and Destination Options manipulation

SYNOPSIS

```
#include <netinet/in.h>

int
inet6_option_space(int nbytes);

int
inet6_option_init(void *bp, struct cmsghdr **cmsg, int type);

int
inet6_option_append(struct cmsghdr *cmsg, const u_int8_t *typep,
                    int multx, int plusy);

u_int8_t *
inet6_option_alloc(struct cmsghdr *cmsg, int datalen, int multx,
                  int plusy);

int
inet6_option_next(const struct cmsghdr *cmsg, u_int8_t **tptrp);

int
inet6_option_find(const struct cmsghdr *cmsg, u_int8_t **tptrp,
                  int type);
```

DESCRIPTION

Building and parsing the Hop-by-Hop and Destination options is complicated due to alignment constraints, padding and ancillary data manipulation. RFC2292 defines a set of functions to help the application. The function prototypes for these functions are all in the `<netinet/in.h>` header.

`inet6_option_space`

`inet6_option_space()` returns the number of bytes required to hold an option when it is stored as ancillary data, including the `cmsghdr` structure at the beginning, and any padding at the end (to make its size a multiple of 8 bytes). The argument is the size of the structure defining the option, which must include any pad bytes at the beginning (the value `y` in the alignment term "`xn + y`"), the type byte, the length byte, and the option data.

Note: If multiple options are stored in a single ancillary data object, which is the recommended technique, this function overestimates the amount of space required by the size of `N-1` `cmsghdr` structures, where `N` is the number of options to be stored in the object. This is of little consequence, since it is assumed that most Hop-by-Hop option headers and Destination option headers carry only one option (appendix B of [RFC-2460]).

`inet6_option_init`

`inet6_option_init()` is called once per ancillary data object that will contain either Hop-by-Hop or Destination options. It returns 0 on success or -1 on an error.

`bp` is a pointer to previously allocated space that will contain the ancillary data object. It must be large enough to contain all the individual options to be added by later calls to `inet6_option_append()` and `inet6_option_alloc()`.

`cmsgp` is a pointer to a pointer to a `cmsghdr` structure. `*cmsgp` is initialized by this function to point to the `cmsghdr` structure constructed

by this function in the buffer pointed to by `bp`.

`type` is either `IPV6_HOPOPTS` or `IPV6_DSTOPTS`. This type is stored in the `cmsg_type` member of the `cmsghdr` structure pointed to by `*cmsgp`.

`inet6_option_append`

This function appends a Hop-by-Hop option or a Destination option into an ancillary data object that has been initialized by `inet6_option_init()`. This function returns 0 if it succeeds or -1 on an error.

`cmsg` is a pointer to the `cmsghdr` structure that must have been initialized by `inet6_option_init()`.

`typep` is a pointer to the 8-bit option type. It is assumed that this field is immediately followed by the 8-bit option data length field, which is then followed immediately by the option data. The caller initializes these three fields (the type-length-value, or TLV) before calling this function.

The option type must have a value from 2 to 255, inclusive. (0 and 1 are reserved for the Pad1 and PadN options, respectively.)

The option data length must have a value between 0 and 255, inclusive, and is the length of the option data that follows.

`multx` is the value `x` in the alignment term "`xn + y`". It must have a value of 1, 2, 4, or 8.

`plusy` is the value `y` in the alignment term "`xn + y`". It must have a value between 0 and 7, inclusive.

`inet6_option_alloc`

This function appends a Hop-by-Hop option or a Destination option into an ancillary data object that has been initialized by `inet6_option_init()`. This function returns a pointer to the 8-bit option type field that starts the option on success, or NULL on an error.

The difference between this function and `inet6_option_append()` is that the latter copies the contents of a previously built option into the ancillary data object while the current function returns a pointer to the space in the data object where the option's TLV must then be built by the caller.

`cmsg` is a pointer to the `cmsghdr` structure that must have been initialized by `inet6_option_init()`.

`datalen` is the value of the option data length byte for this option. This value is required as an argument to allow the function to determine if padding must be appended at the end of the option. (The `inet6_option_append()` function does not need a data length argument since the option data length must already be stored by the caller.)

`multx` is the value `x` in the alignment term "`xn + y`". It must have a value of 1, 2, 4, or 8.

`plusy` is the value `y` in the alignment term "`xn + y`". It must have a value between 0 and 7, inclusive.

`inet6_option_next`

This function processes the next Hop-by-Hop option or Destination option in an ancillary data object. If another option remains to be processed,

the return value of the function is 0 and `*tptrp` points to the 8-bit option type field (which is followed by the 8-bit option data length, followed by the option data). If no more options remain to be processed, the return value is -1 and `*tptrp` is NULL. If an error occurs, the return value is -1 and `*tptrp` is not NULL.

`msg` is a pointer to `cmsghdr` structure of which `msg_level` equals `IPPROTO_IPV6` and `msg_type` equals either `IPV6_HOPOPTS` or `IPV6_DSTOPTS`.

`tptrp` is a pointer to a pointer to an 8-bit byte and `*tptrp` is used by the function to remember its place in the ancillary data object each time the function is called. The first time this function is called for a given ancillary data object, `*tptrp` must be set to NULL.

Each time this function returns success, `*tptrp` points to the 8-bit option type field for the next option to be processed.

`inet6_option_find`

This function is similar to the previously described `inet6_option_next()` function, except this function lets the caller specify the option type to be searched for, instead of always returning the next option in the ancillary data object. `msg` is a pointer to `cmsghdr` structure of which `msg_level` equals `IPPROTO_IPV6` and `msg_type` equals either `IPV6_HOPOPTS` or `IPV6_DSTOPTS`.

`tptrp` is a pointer to a pointer to an 8-bit byte and `*tptrp` is used by the function to remember its place in the ancillary data object each time the function is called. The first time this function is called for a given ancillary data object, `*tptrp` must be set to NULL. ~ This function starts searching for an option of the specified type beginning after the value of `*tptrp`. If an option of the specified type is located, this function returns 0 and `*tptrp` points to the 8-bit option type field for the option of the specified type. If an option of the specified type is not located, the return value is -1 and `*tptrp` is NULL. If an error occurs, the return value is -1 and `*tptrp` is not NULL.

DIAGNOSTICS

`inet6_option_init()` and `inet6_option_append()` return 0 on success or -1 on an error.

`inet6_option_alloc()` returns NULL on an error.

On errors, `inet6_option_next()` and `inet6_option_find()` return -1 setting `*tptrp` to non NULL value.

EXAMPLES

RFC2292 gives comprehensive examples in chapter 6.

SEE ALSO

W. Stevens and M. Thomas, Advanced Sockets API for IPv6, RFC2292, February 1998.

S. Deering and R. Hinden, Internet Protocol, Version 6 (IPv6) Specification, RFC2460, December 1998.

HISTORY

The implementation first appeared in KAME advanced networking kit.

STANDARDS

The functions are documented in "Advanced Sockets API for IPv6" (RFC2292).

BUGS

The text was shamelessly copied from RFC2292.

BSD

December 10, 1999

BSD

inet6_rthdr_space

INET6_RTHDR_SPACE(3) BSD Library Functions Manual INET6_RTHDR_SPACE(3)

NAME

inet6_rthdr_space, inet6_rthdr_init, inet6_rthdr_add,
inet6_rthdr_lasthop, inet6_rthdr_reverse, inet6_rthdr_segments,
inet6_rthdr_getaddr, inet6_rthdr_getflags - IPv6 Routing Header Options
manipulation

SYNOPSIS

```
#include <netinet/in.h>

size_t
inet6_rthdr_space(int type, int segments);

struct cmsghdr *
inet6_rthdr_init(void *bp, int type);

int
inet6_rthdr_add(struct cmsghdr *cmsg, const struct in6_addr *addr,
               unsigned int flags);

int
inet6_rthdr_lasthop(struct cmsghdr *cmsg, unsigned int flags);

int
inet6_rthdr_reverse(const struct cmsghdr *in, struct cmsghdr *out);

int
inet6_rthdr_segments(const struct cmsghdr *cmsg);

struct in6_addr *
inet6_rthdr_getaddr(struct cmsghdr *cmsg, int index);

int
inet6_rthdr_getflags(const struct cmsghdr *cmsg, int index);
```

DESCRIPTION

RFC2292 IPv6 advanced API defines eight functions that the application calls to build and examine a Routing header. Four functions build a Routing header:

inet6_rthdr_space() return #bytes required for ancillary data

inet6_rthdr_init() initialize ancillary data for Routing header

inet6_rthdr_add() add IPv6 address & flags to Routing header

inet6_rthdr_lasthop() specify the flags for the final hop

Four functions deal with a returned Routing header:

`inet6_rthdr_reverse()` reverse a Routing header

`inet6_rthdr_segments()` return #segments in a Routing header

`inet6_rthdr_getaddr()` fetch one address from a Routing header

`inet6_rthdr_getflags()` fetch one flag from a Routing header

The function prototypes for these functions are all in the `<netinet/in.h>` header.

`inet6_rthdr_space`

This function returns the number of bytes required to hold a Routing header of the specified type containing the specified number of segments (addresses). For an IPv6 Type 0 Routing header, the number of segments must be between 1 and 23, inclusive. The return value includes the size of the `cmsghdr` structure that precedes the Routing header, and any required padding.

If the return value is 0, then either the type of the Routing header is not supported by this implementation or the number of segments is invalid for this type of Routing header.

Note: This function returns the size but does not allocate the space required for the ancillary data. This allows an application to allocate a larger buffer, if other ancillary data objects are desired, since all the ancillary data objects must be specified to `sendmsg(2)` as a single `msg_control` buffer.

`inet6_rthdr_init`

This function initializes the buffer pointed to by `bp` to contain a `cmsghdr` structure followed by a Routing header of the specified type. The `cmsghdr` member of the `cmsghdr` structure is initialized to the size of the structure plus the amount of space required by the Routing header. The `cmsghdr_level` and `cmsghdr_type` members are also initialized as required.

The caller must allocate the buffer and its size can be determined by calling `inet6_rthdr_space()`.

Upon success the return value is the pointer to the `cmsghdr` structure, and this is then used as the first argument to the next two functions. Upon an error the return value is `NULL`.

`inet6_rthdr_add`

This function adds the address pointed to by `addr` to the end of the Routing header being constructed and sets the type of this hop to the value of `flags`. For an IPv6 Type 0 Routing header, `flags` must be either `IPV6_RTHDR_LOOSE` or `IPV6_RTHDR_STRICT`.

If successful, the `cmsghdr` member of the `cmsghdr` structure is updated to account for the new address in the Routing header and the return value of the function is 0. Upon an error the return value of the function is -1.

`inet6_rthdr_lasthop`

This function specifies the Strict/Loose flag for the final hop of a Routing header. For an IPv6 Type 0 Routing header, `flags` must be either `IPV6_RTHDR_LOOSE` or `IPV6_RTHDR_STRICT`.

The return value of the function is 0 upon success, or -1 upon an error.

Notice that a Routing header specifying *N* intermediate nodes requires *N*+1 Strict/Loose flags. This requires *N* calls to `inet6_rthdr_add()` followed by one call to `inet6_rthdr_lasthop()`.

`inet6_rthdr_reverse`

This function takes a Routing header that was received as ancillary data (pointed to by the first argument, *in*) and writes a new Routing header that sends datagrams along the reverse of that route. Both arguments are allowed to point to the same buffer (that is, the reversal can occur in place).

The return value of the function is 0 on success, or -1 upon an error.

`inet6_rthdr_segments`

This function returns the number of segments (addresses) contained in the Routing header described by *cmsg*. On success the return value is between 1 and 23, inclusive. The return value of the function is -1 upon an error.

`inet6_rthdr_getaddr`

This function returns a pointer to the IPv6 address specified by *index* (which must have a value between 1 and the value returned by `inet6_rthdr_segments()`) in the Routing header described by *cmsg*. An application should first call `inet6_rthdr_segments()` to obtain the number of segments in the Routing header.

Upon an error the return value of the function is NULL.

`inet6_rthdr_getflags`

This function returns the flags value specified by *index* (which must have a value between 0 and the value returned by `inet6_rthdr_segments()`) in the Routing header described by *cmsg*. For an IPv6 Type 0 Routing header the return value will be either `IPV6_RTHDR_LOOSE` or `IPV6_RTHDR_STRICT`.

Upon an error the return value of the function is -1.

Note: Addresses are indexed starting at 1, and flags starting at 0, to maintain consistency with the terminology and figures in RFC2460.

DIAGNOSTICS

`inet6_rthdr_space()` returns 0 on errors.

`inet6_rthdr_add()`, `inet6_rthdr_lasthop()` and `inet6_rthdr_reverse()` return 0 on success, and returns -1 on error.

`inet6_rthdr_init()` and `inet6_rthdr_getaddr()` return NULL on error.

`inet6_rthdr_segments()` and `inet6_rthdr_getflags()` return -1 on error.

EXAMPLES

RFC2292 gives comprehensive examples in chapter 8.

SEE ALSO

W. Stevens and M. Thomas, *Advanced Sockets API for IPv6*, RFC2292, February 1998.

S. Deering and R. Hinden, *Internet Protocol, Version 6 (IPv6) Specification*, RFC2460, December 1998.

HISTORY

The implementation first appeared in KAME advanced networking kit.

STANDARDS

The functions are documented in "Advanced Sockets API for IPv6" (RFC2292).

BUGS

The text was shamelessly copied from RFC2292.

`inet6_rthdr_reverse()` is not implemented yet.

BSD

December 10, 1999

BSD

inet_net

INET_NET(3)

BSD Library Functions Manual

INET_NET(3)

NAME

`inet_net_ntop`, `inet_net_pton` - Internet network number manipulation routines

SYNOPSIS

```
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
```

```
char *
inet_net_ntop(int af, const void *src, int bits, char *dst, size_t size);
```

```
int
inet_net_pton(int af, const char *src, void *dst, size_t size);
```

DESCRIPTION

The `inet_net_ntop()` function converts an Internet network number from network format (usually a struct `in_addr` or some other binary form, in network byte order) to CIDR presentation format (suitable for external display purposes). `bits` is the number of bits in `src` that are the network number. It returns `NULL` if a system error occurs (in which case, `errno` will have been set), or it returns a pointer to the destination string.

The `inet_net_pton()` function converts a presentation format Internet network number (that is, printable form as held in a character string) to network format (usually a struct `in_addr` or some other internal binary representation, in network byte order). It returns the number of bits (either computed based on the class, or specified with `/CIDR`), or `-1` if a failure occurred (in which case `errno` will have been set. It will be set to `ENOENT` if the Internet network number was not valid).

The only value for `af` currently supported is `AF_INET`. `size` is the size of the result buffer `dst`.

NETWORK NUMBERS (IP VERSION 4)

Internet network numbers may be specified in one of the following forms:

```
a.b.c.d/bits
a.b.c.d
```

```
a.b.c
a.b
a
```

When four parts are specified, each is interpreted as a byte of data and assigned, from left to right, to the four bytes of an Internet network number. Note that when an Internet network number is viewed as a 32-bit integer quantity on a system that uses little-endian byte order (such as the Intel 386, 486, and Pentium processors) the bytes referred to above appear as "d.c.b.a". That is, little-endian bytes are ordered from right to left.

When a three part number is specified, the last part is interpreted as a 16-bit quantity and placed in the rightmost two bytes of the Internet network number. This makes the three part number format convenient for specifying Class B network numbers as "128.net.host".

When a two part number is supplied, the last part is interpreted as a 24-bit quantity and placed in the rightmost three bytes of the Internet network number. This makes the two part number format convenient for specifying Class A network numbers as "net.host".

When only one part is given, the value is stored directly in the Internet network number without any byte rearrangement.

All numbers supplied as "parts" in a '.' notation may be decimal, octal, or hexadecimal, as specified in the C language (i.e., a leading 0x or 0X implies hexadecimal; otherwise, a leading 0 implies octal; otherwise, the number is interpreted as decimal).

SEE ALSO

byteorder(3), inet(3), networks(5)

HISTORY

The inet_net_ntop and inet_net_pton functions first appeared in BIND 4.9.4.

BSD

June 18, 1997

BSD

ipx

IPX(3)

BSD Library Functions Manual

IPX(3)

NAME

ipx_addr, ipx_ntoa - IPX address conversion routines

SYNOPSIS

```
#include <sys/types.h>
#include <netipx/ipx.h>

struct ipx_addr
ipx_addr(const char *cp);

char *
ipx_ntoa(struct ipx_addr ipx);
```

DESCRIPTION

The routine `ipx_addr()` interprets character strings representing IPX addresses, returning binary information suitable for use in system calls. The routine `ipx_ntoa()` takes IPX addresses and returns ASCII strings representing the address in a notation in common use:

```
<network number>.<host number>.<port number>
```

Trailing zero fields are suppressed, and each number is printed in hexadecimal, in a format suitable for input to `ipx_addr()`. Any fields lacking super-decimal digits will have a trailing 'H' appended.

An effort has been made to ensure that `ipx_addr()` be compatible with most formats in common use. It will first separate an address into 1 to 3 fields using a single delimiter chosen from period ('.'), colon (':'), or pound-sign ('#'). Each field is then examined for byte separators (colon or period). If there are byte separators, each subfield separated is taken to be a small hexadecimal number, and the entirety is taken as a network-byte-ordered quantity to be zero extended in the high-network-order bytes. Next, the field is inspected for hyphens, in which case the field is assumed to be a number in decimal notation with hyphens separating the millenia. Next, the field is assumed to be a number: It is interpreted as hexadecimal if there is a leading '0x' (as in C), a trailing 'H' (as in Mesa), or there are any super-decimal digits present. It is interpreted as octal if there is a leading '0' and there are no super-octal digits. Otherwise, it is converted as a decimal number.

RETURN VALUES

None. (See BUGS.)

SEE ALSO

`ns(4)`, `hosts(5)`, `networks(5)`

HISTORY

The precursor `ns_addr()` and `ns_ntoa()` functions appeared in 4.3BSD.

BUGS

The string returned by `ipx_ntoa()` resides in a static memory area. The function `ipx_addr()` should diagnose improperly formed input, and there should be an unambiguous way to recognize this.

BSD

June 4, 1993

BSD

iso_addr

ISO_ADDR(3)

BSD Library Functions Manual

ISO_ADDR(3)

NAME

`iso_addr`, `iso_ntoa` - network address conversion routines for Open System Interconnection

SYNOPSIS

```
#include <sys/types.h>
#include <netiso/iso.h>
```

```
struct iso_addr *
iso_addr(char *cp);
```

```
char *
iso_ntoa(struct iso_addr *isoa);
```

DESCRIPTION

The routine `iso_addr()` interprets character strings representing OSI addresses, returning binary information suitable for use in system calls. The routine `iso_ntoa()` takes OSI addresses and returns ASCII strings representing NSAPs (network service access points) in a notation inverse to that accepted by `iso_addr()`.

Unfortunately, no universal standard exists for representing OSI network addresses.

The format employed by `iso_addr()` is a sequence of hexadecimal "digits" (optionally separated by periods), of the form:

<hex digits>.<hex digits>.<hex digits>

Each pair of hexadecimal digits represents a byte with the leading digit indicating the higher-ordered bits. A period following an even number of bytes has no effect (but may be used to increase legibility). A period following an odd number of bytes has the effect of causing the byte of address being translated to have its higher order bits filled with zeros.

RETURN VALUES

`iso_ntoa()` always returns a null terminated string. `iso_addr()` always returns a pointer to a struct `iso_addr`. (See BUGS.)

SEE ALSO

`iso(4)`

HISTORY

The `iso_addr()` and `iso_ntoa()` functions appeared in 4.3BSD-Reno.

BUGS

The returned values reside in a static memory area.

The function `iso_addr()` should diagnose improperly formed input, and there should be an unambiguous way to recognize this.

BSD

June 4, 1993

BSD

link_addr

LINK_ADDR(3)

BSD Library Functions Manual

LINK_ADDR(3)

NAME

`link_addr`, `link_ntoa` - elementary address specification routines for link level access

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
#include <net/if_dl.h>
```

```
void
link_addr(const char *addr, struct sockaddr_dl *sdl);
```

```
char *
link_ntoa(const struct sockaddr_dl *sdl);
```

DESCRIPTION

The `link_addr()` function interprets character strings representing link-level addresses, returning binary information suitable for use in system calls. `link_ntoa()` takes a link-level address and returns an ASCII string representing some of the information present, including the link level address itself, and the interface name or number, if present. This facility is experimental and is still subject to change.

For `link_addr()`, the string `addr` may contain an optional network interface identifier of the form "name unit-number", suitable for the first argument to `ifconfig(8)`, followed in all cases by a colon and an interface address in the form of groups of hexadecimal digits separated by periods. Each group represents a byte of address; address bytes are filled left to right from low order bytes through high order bytes.

Thus `le0:8.0.9.13.d.30` represents an Ethernet address to be transmitted on the first Lance Ethernet interface.

RETURN VALUES

`link_ntoa()` always returns a null-terminated string. `link_addr()` has no return value. (See **BUGS**.)

SEE ALSO

`iso(4)`, `ifconfig(8)`

HISTORY

The `link_addr()` and `link_ntoa()` functions appeared in 4.3BSD-Reno.

BUGS

The returned values for `link_ntoa` reside in a static memory area.

The function `link_addr()` should diagnose improperly formed input, and there should be an unambiguous way to recognize this.

If the `sdl_len` field of the link socket address `sdl` is 0, `link_ntoa()` will not insert a colon before the interface address bytes. If this translated address is given to `link_addr()` without inserting an initial colon, the latter will not interpret it correctly.

BSD

July 28, 1993

BSD

net_addrcmp

NET_ADDRCMP(3)

BSD Library Functions Manual

NET_ADDRCMP(3)

NAME

`net_addrcmp` - compare socket address structures

SYNOPSIS

```
#include <netdb.h>
```

```
int
```

```
net_addrcmp(struct sockaddr *sa1, struct sockaddr *sa2);
```

DESCRIPTION

The `net_addrcmp()` function compares two socket address structures, `sa1` and `sa2`.

RETURN VALUES

If `sa1` and `sa2` are for the same address, `net_addrcmp()` returns 0.

The `sa_len` fields are compared first. If they do not match, `net_addrcmp()` returns -1 or 1 if `sa1->sa_len` is less than or greater than `sa2->sa_len`, respectively.

Next, the `sa_family` members are compared. If they do not match, `net_addrcmp()` returns -1 or 1 if `sa1->sa_family` is less than or greater than `sa2->sa_family`, respectively.

Lastly, if each socket address structure's `sa_len` and `sa_family` fields match, the protocol-specific data (the `sa_data` field) is compared. If there's a match, both `sa1` and `sa2` must refer to the same address, and 0 is returned; otherwise, a value >0 or <0 is returned.

HISTORY

A `net_addrcmp()` function was added in OpenBSD 2.5.

BSD	July 3, 1999	BSD
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ns

NS(3)	BSD Library Functions Manual	NS(3)
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NAME

`ns_addr`, `ns_ntoa` - Xerox NS(tm) address conversion routines

SYNOPSIS

```
#include <sys/types.h>
#include <netns/ns.h>
```

```
struct ns_addr
ns_addr(char *cp);
```

```
char *
ns_ntoa(struct ns_addr ns);
```

DESCRIPTION

The routine `ns_addr()` interprets character strings representing XNS addresses, returning binary information suitable for use in system calls. The routine `ns_ntoa()` takes XNS addresses and returns ASCII strings representing the address in a notation in common use in the Xerox Development Environment:

<network number>.<host number>.<port number>

Trailing zero fields are suppressed, and each number is printed in hexadecimal, in a format suitable for input to `ns_addr()`. Any fields lacking super-decimal digits will have a trailing 'H' appended.

Unfortunately, no universal standard exists for representing XNS

addresses. An effort has been made to ensure that `ns_addr()` be compatible with most formats in common use. It will first separate an address into 1 to 3 fields using a single delimiter chosen from period ('.'), colon (':'), or pound-sign '#'. Each field is then examined for byte separators (colon or period). If there are byte separators, each sub-field separated is taken to be a small hexadecimal number, and the entirety is taken as a network-byte-ordered quantity to be zero extended in the high-network-order bytes. Next, the field is inspected for hyphens, in which case the field is assumed to be a number in decimal notation with hyphens separating the millenia. Next, the field is assumed to be a number: It is interpreted as hexadecimal if there is a leading '0x' (as in C), a trailing 'H' (as in Mesa), or there are any super-decimal digits present. It is interpreted as octal if there is a leading '0' and there are no super-octal digits. Otherwise, it is converted as a decimal number.

RETURN VALUES

None. (See BUGS.)

SEE ALSO

`hosts(5)`, `networks(5)`

HISTORY

The `ns_addr()` and `ns_toa()` functions appeared in 4.3BSD.

BUGS

The string returned by `ns_ntoa()` resides in a static memory area. The function `ns_addr()` should diagnose improperly formed input, and there should be an unambiguous way to recognize this.

BSD

June 4, 1993

BSD

resolver

RESOLVER(3)

BSD Library Functions Manual

RESOLVER(3)

NAME

`res_query`, `res_search`, `res_mkquery`, `res_send`, `res_init`, `dn_comp`,
`dn_expand` - resolver routines

SYNOPSIS

```
#include <sys/types.h>
#include <netinet/in.h>
#include <arpa/nameser.h>
#include <resolv.h>

int
res_query(char *dname, int class, int type, u_char *answer, int anslen);

int
res_search(char *dname, int class, int type, u_char *answer, int anslen);

int
res_mkquery(int op, char *dname, int class, int type, char *data,
            int datalen, struct rrec *newrr, char *buf, int buflen);

int
```

```

res_send(char *msg, int msglen, char *answer, int anslen);

int
res_init(void);

int
dn_comp(char *exp_dn, char *comp_dn, int length, char **dnptrs,
        char **lastdnptr);

int
dn_expand(u_char *msg, u_char *eomorig, u_char *comp_dn, u_char *exp_dn,
        int length);

```

DESCRIPTION

These routines are used for making, sending, and interpreting query and reply messages with Internet domain name servers.

Global configuration and state information that is used by the resolver routines is kept in the structure `_res`. Most of the values have reasonable defaults and can be ignored. Options stored in `_res.options` are defined in `<resolv.h>` and are as follows. Options are stored as a simple bit mask containing the bitwise OR of the options enabled.

RES_INIT	True if the initial name server address and default domain name are initialized (i.e., <code>res_init()</code> has been called).
RES_DEBUG	Print debugging messages.
RES_AAONLY	Accept authoritative answers only. With this option, <code>res_send()</code> should continue until it finds an authoritative answer or finds an error. Currently this is not implemented.
RES_USEVC	Use TCP connections for queries instead of UDP datagrams.
RES_STAYOPEN	Used with <code>RES_USEVC</code> to keep the TCP connection open between queries. This is useful only in programs that regularly do many queries. UDP should be the normal mode used.
RES_IGNTC	Unused currently (ignore truncation errors, i.e., don't retry with TCP).
RES_RECURSE	Set the recursion-desired bit in queries. This is the default. (<code>res_send()</code> does not do iterative queries and expects the name server to handle recursion.)
RES_DEFNAMES	If set, <code>res_search()</code> will append the default domain name to single-component names (those that do not contain a dot). This option is enabled by default.
RES_DNSRCH	If this option is set, <code>res_search()</code> will search for host names in the current domain and in parent domains; see <code>hostname(7)</code> . This is used by the standard host lookup routine <code>gethostbyname(3)</code> . This option is enabled by default.
RES_USE_INET6	Enables support for IPv6-only applications. This causes IPv4 addresses to be returned as an IPv4 mapped address. For example, 10.1.1.1 will be returned as <code>::ffff:10.1.1.1</code> . The option is not meaningful on OpenBSD.

The `res_init()` routine reads the configuration file (if any; see `resolv.conf(5)`) to get the default domain name, search list, and the Internet address of the local name server(s). If no server is configured, the host running the resolver is tried. The current domain name is defined by the hostname if not specified in the configuration file; it can be overridden by the environment variable `LOCALDOMAIN`. This environment variable may contain several blank-separated tokens if you wish to override the search list on a per-process basis. This is similar to the search command in the configuration file. Another environment variable `RES_OPTIONS` can be set to override certain internal resolver options which are otherwise set by changing fields in the `_res` structure or are inherited from the configuration file's options command. The syntax of the `RES_OPTIONS` environment variable is explained in `resolv.conf(5)`. Initialization normally occurs on the first call to one of the following routines.

The `res_query()` function provides an interface to the server query mechanism. It constructs a query, sends it to the local server, awaits a response, and makes preliminary checks on the reply. The query requests information of the specified type and class for the specified fully qualified domain name `dname`. The reply message is left in the answer buffer with length `anslen` supplied by the caller.

The `res_search()` routine makes a query and awaits a response like `res_query()`, but in addition, it implements the default and search rules controlled by the `RES_DEFNAMES` and `RES_DNSRCH` options. It returns the first successful reply.

The remaining routines are lower-level routines used by `res_query()`. The `res_mkquery()` function constructs a standard query message and places it in `buf`. It returns the size of the query, or `-1` if the query is larger than `buflen`. The query type `op` is usually `QUERY`, but can be any of the query types defined in `<arpa/nameser.h>`. The domain name for the query is given by `dname`. `newrr` is currently unused but is intended for making update messages.

The `res_send()` routine sends a pre-formatted query and returns an answer. It will call `res_init()` if `RES_INIT` is not set, send the query to the local name server, and handle timeouts and retries. The length of the reply message is returned, or `-1` if there were errors.

The `dn_comp()` function compresses the domain name `exp_dn` and stores it in `comp_dn`. The size of the compressed name is returned or `-1` if there were errors. The size of the array pointed to by `comp_dn` is given by `length`. The compression uses an array of pointers `dnptrs` to previously compressed names in the current message. The first pointer points to the beginning of the message and the list ends with `NULL`. The limit to the array is specified by `lastdnptr`. A side effect of `dn_comp()` is to update the list of pointers for labels inserted into the message as the name is compressed. If `dnptr` is `NULL`, names are not compressed. If `lastdnptr` is `NULL`, the list of labels is not updated.

The `dn_expand()` entry expands the compressed domain name `comp_dn` to a full domain name. The compressed name is contained in a query or reply message; `msg` is a pointer to the beginning of the message. The uncompressed name is placed in the buffer indicated by `exp_dn` which is of size `length`. The size of compressed name is returned or `-1` if there was an error.

FILES

/etc/resolv.conf configuration file see resolv.conf(5).

SEE ALSO

gethostbyname(3), resolv.conf(5), hostname(7), named(8)

RFC1032, RFC1033, RFC1034, RFC1035, RFC1535, RFC974

Name Server Operations Guide for BIND.

HISTORY

The res_query function appeared in 4.3BSD.

BSD

June 4, 1993

BSD

accept

ACCEPT(2)

BSD System Calls Manual

ACCEPT(2)

NAME

accept - accept a connection on a socket

SYNOPSIS

```
#include <sys/types.h>
```

```
#include <sys/socket.h>
```

```
int
```

```
accept(int s, struct sockaddr *addr, socklen_t *addrlen);
```

DESCRIPTION

The argument *s* is a socket that has been created with `socket(2)`, bound to an address with `bind(2)`, and is listening for connections after a `listen(2)`. The `accept()` argument extracts the first connection request on the queue of pending connections, creates a new socket with the same properties of *s*, and allocates a new file descriptor for the socket. If no pending connections are present on the queue, and the socket is not marked as non-blocking, `accept()` blocks the caller until a connection is present. If the socket is marked non-blocking and no pending connections are present on the queue, `accept()` returns an error as described below. The accepted socket may not be used to accept more connections. The original socket *s* remains open.

The argument *addr* is a result parameter that is filled in with the address of the connecting entity as known to the communications layer. The exact format of the *addr* parameter is determined by the domain in which the communication is occurring. The *addrlen* is a value-result parameter; it should initially contain the amount of space pointed to by *addr*; on return it will contain the actual length (in bytes) of the address returned. This call is used with connection-based socket types, currently with `SOCK_STREAM`.

It is possible to `select(2)` or `poll(2)` a socket for the purposes of doing an `accept()` by selecting it for read.

For certain protocols which require an explicit confirmation, such as ISO or DATAKIT, `accept()` can be thought of as merely dequeuing the next connection request and not implying confirmation. Confirmation can be implied by a normal read or write on the new file descriptor, and `reject`

tion can be implied by closing the new socket.

One can obtain user connection request data without confirming the connection by issuing a `recvmsg(2)` call with an `msg_iovlen` of 0 and a non-zero `msg_controllen`, or by issuing a `getsockopt(2)` request. Similarly, one can provide user connection rejection information by issuing a `sendmsg(2)` call with providing only the control information, or by calling `setsockopt(2)`.

RETURN VALUES

The call returns -1 on error. If it succeeds, it returns a non-negative integer that is a descriptor for the accepted socket.

ERRORS

The `accept()` will fail if:

[EBADF]	The descriptor is invalid.
[ENOTSOCK]	The descriptor references a file, not a socket.
[EOPNOTSUPP]	The referenced socket is not of type <code>SOCK_STREAM</code> .
[EINVAL]	The referenced socket is not listening for connections (that is, <code>listen(2)</code> has not yet been called).
[EFAULT]	The <code>addr</code> parameter is not in a writable part of the user address space.
[EWOULDBLOCK]	The socket is marked non-blocking and no connections are present to be accepted.
[EMFILE]	The per-process descriptor table is full.
[ENFILE]	The system file table is full.
[ECONNABORTED]	A connection has been aborted.

SEE ALSO

`bind(2)`, `connect(2)`, `listen(2)`, `poll(2)`, `select(2)`, `poll(2)`, `socket(2)`

HISTORY

The `accept()` function appeared in 4.2BSD.

BSD

February 15, 1999

BSD

bind

BIND(2)

BSD System Calls Manual

BIND(2)

NAME

`bind` - bind a name to a socket

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
int
```

```
bind(int s, const struct sockaddr *name, socklen_t namelen);
```

DESCRIPTION

`bind()` assigns a name to an unnamed socket. When a socket is created with `socket(2)` it exists in a name space (address family) but has no name assigned. `bind()` requests that name be assigned to the socket.

NOTES

Binding a name in the UNIX domain creates a socket in the file system that must be deleted by the caller when it is no longer needed (using `unlink(2)`).

The rules used in name binding vary between communication domains. Consult the manual entries in section 4 for detailed information.

RETURN VALUES

If the `bind` is successful, a 0 value is returned. A return value of -1 indicates an error, which is further specified in the global `errno`.

ERRORS

The `bind()` call will fail if:

[EBADF]	S is not a valid descriptor.
[ENOTSOCK]	S is not a socket.
[EADDRNOTAVAIL]	The specified address is not available from the local machine.
[EADDRINUSE]	The specified address is already in use.
[EINVAL]	The socket is already bound to an address.
[EINVAL]	The family of the socket and that requested in <code>name->sa_family</code> are not equivalent.
[EACCES]	The requested address is protected, and the current user has inadequate permission to access it.
[EFAULT]	The name parameter is not in a valid part of the user address space.

The following errors are specific to binding names in the UNIX domain.

[ENOTDIR]	A component of the path prefix is not a directory.
[ENAMETOOLONG]	A component of a pathname exceeded {NAME_MAX} characters, or an entire path name exceeded {PATH_MAX} characters.
[ENOENT]	A prefix component of the path name does not exist.
[ELOOP]	Too many symbolic links were encountered in translating the pathname.
[EIO]	An I/O error occurred while making the directory entry or allocating the inode.
[EROFS]	The name would reside on a read-only file system.
[EISDIR]	An empty pathname was specified.

SEE ALSO

connect(2), getsockname(2), listen(2), socket(2)

HISTORY

The bind() function call appeared in 4.2BSD.

BSD

February 15, 1999

BSD

connect

CONNECT(2)

BSD System Calls Manual

CONNECT(2)

NAME

connect - initiate a connection on a socket

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
int
```

```
connect(int s, const struct sockaddr *name, socklen_t namelen);
```

DESCRIPTION

The parameter *s* is a socket. If it is of type `SOCK_DGRAM`, this call specifies the peer with which the socket is to be associated; this address is that to which datagrams are to be sent, and the only address from which datagrams are to be received. If the socket is of type `SOCK_STREAM`, this call attempts to make a connection to another socket. The other socket is specified by *name*, which is an address in the communications space of the socket. Each communications space interprets the *name* parameter in its own way. Generally, stream sockets may successfully connect() only once; datagram sockets may use connect() multiple times to change their association. Datagram sockets may dissolve the association by connecting to an invalid address, such as a null address.

RETURN VALUES

If the connection or binding succeeds, 0 is returned. Otherwise a -1 is returned, and a more specific error code is stored in *errno*.

ERRORS

The connect() call fails if:

[EBADF]	<i>S</i> is not a valid descriptor.
[ENOTSOCK]	<i>S</i> is a descriptor for a file, not a socket.
[EADDRNOTAVAIL]	The specified address is not available on this machine.
[EAFNOSUPPORT]	Addresses in the specified address family cannot be used with this socket.
[EISCONN]	The socket is already connected.
[ETIMEDOUT]	Connection establishment timed out without establishing a connection.

[EINVAL]	A TCP connection with a local broadcast, the all-ones or a multicast address as the peer was attempted.
[ECONNREFUSED]	The attempt to connect was forcefully rejected.
[EINTR]	A connect was interrupted before it succeeded by the delivery of a signal.
[ENETUNREACH]	The network isn't reachable from this host.
[EADDRINUSE]	The address is already in use.
[EFAULT]	The name parameter specifies an area outside the process address space.
[EINPROGRESS]	The socket is non-blocking and the connection cannot be completed immediately. It is possible to select(2) or poll(2) for completion by selecting the socket for writing, and also use getsockopt(2) with SO_ERROR to check for error conditions.
[EALREADY]	The socket is non-blocking and a previous connection attempt has not yet been completed.

The following errors are specific to connecting names in the UNIX domain. These errors may not apply in future versions of the UNIX IPC domain.

[ENOTDIR]	A component of the path prefix is not a directory.
[ENAMETOOLONG]	A component of a pathname exceeded {NAME_MAX} characters, or an entire path name exceeded {PATH_MAX} characters.
[ENOENT]	The named socket does not exist.
[EACCES]	Search permission is denied for a component of the path prefix.
[EACCES]	Write access to the named socket is denied.
[ELOOP]	Too many symbolic links were encountered in translating the pathname.

SEE ALSO

accept(2), getsockname(2), getsockopt(2), poll(2), select(2), socket(2)

HISTORY

The connect() function call appeared in 4.2BSD.

BSD

February 15, 1999

BSD

getpeername

GETPEERNAME(2)

BSD System Calls Manual

GETPEERNAME(2)

NAME

getpeername - get name of connected peer

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
int
getpeername(int s, struct sockaddr *name, socklen_t *namelen);
```

DESCRIPTION

getpeername() returns the address information of the peer connected to socket *s*. One common use occurs when a process inherits an open socket, such as TCP servers forked from *inetd*(8). In this scenario, getpeername() is used to determine the connecting client's IP address.

getpeername() takes three parameters:

s Contains the file descriptor of the socket whose peer should be looked up.

name Points to a *sockaddr* structure that will hold the address information for the connected peer. Normal use requires one to use a structure specific to the protocol family in use, such as *sockaddr_in* (IPv4) or *sockaddr_in6* (IPv6), cast to a *(struct sockaddr *)*.

For greater portability, especially with the newer protocol families, the new *struct sockaddr_storage* should be used. *sockaddr_storage* is large enough to hold any of the other *sockaddr_** variants. On return, it can be cast to the correct *sockaddr* type, based the protocol family contained in its *ss_family* field.

namelen Indicates the amount of space pointed to by *name*, in bytes.

If address information for the local end of the socket is required, the *getsockname*(2) function should be used instead.

If *name* does not point to enough space to hold the entire socket address, the result will be truncated to *namelen* bytes.

RETURN VALUES

If the call succeeds, a 0 is returned and *namelen* is set to the actual size of the socket address returned in *name*. Otherwise, *errno* is set and a value of -1 is returned.

ERRORS

On failure, *errno* is set to one of the following:

[EBADF]	The argument <i>s</i> is not a valid descriptor.
[ENOTSOCK]	The argument <i>s</i> is a file, not a socket.
[ENOTCONN]	The socket is not connected.
[ENOBUFS]	Insufficient resources were available in the system to perform the operation.

[EFAULT]	The name parameter points to memory not in a valid part of the process address space.
SEE ALSO	accept(2), bind(2), getsockname(2), getpeereid(2), socket(2)
HISTORY	The getpeername() function call appeared in 4.2BSD.
BSD	July 17, 1999
	BSD

getsockname

GETSOCKNAME(2) BSD System Calls Manual GETSOCKNAME(2)

NAME
getsockname - get socket name

```
SYNOPSIS
#include <sys/types.h>
#include <sys/socket.h>
```

```
int  
getsockname(int s, struct sockaddr *name, socklen_t *namelen);
```

DESCRIPTION
<p>getsockname() returns the locally bound address information for a specified socket.</p>

Common uses of this function are as follows:

- o When `bind(2)` is called with a port number of 0 (indicating the kernel should pick an ephemeral port) `getsockname()` is used to retrieve the kernel-assigned port number.
- o When a process calls `bind(2)` on a wildcard IP address, `getsockname()` is used to retrieve the local IP address for the connection.
- o When a function wishes to know the address family of a socket, `getsockname()` can be used.

getsockname() takes three parameters:

s, Contains the file desriptor for the socket to be looked up.

name points to a `sockaddr` structure which will hold the resulting address information. Normal use requires one to use a structure specific to the protocol family in use, such as `sockaddr_in` (IPv4) or `sockaddr_in6` (IPv6), cast to a `(struct sockaddr *)`.

For greater portability (such as newer protocol families) the new structure `sockaddr_storage` exists. `sockaddr_storage` is large enough to hold any of the other `sockaddr_*` variants. On return, it should be cast to the correct `sockaddr` type, according to the current protocol family.

namelen Indicates the amount of space pointed to by name, in bytes. Upon return, namelen is set to the actual size of the returned address infor-

mation.

If the address of the destination socket for a given socket connection is needed, the `getpeername(2)` function should be used instead.

If `name` does not point to enough space to hold the entire socket address, the result will be truncated to `namelen` bytes.

RETURN VALUES

On success, `getsockname()` returns a 0, and `namelen` is set to the actual size of the socket address returned in `name`. Otherwise, `errno` is set, and a value of -1 is returned.

ERRORS

If `getsockname()` fails, `errno` is set to one of the following:

[EBADF]	The argument <code>s</code> is not a valid descriptor.
[ENOTSOCK]	The argument <code>s</code> is a file, not a socket.
[ENOBUFS]	Insufficient resources were available in the system to perform the operation.
[EFAULT]	The name parameter points to memory not in a valid part of the process address space.

SEE ALSO

`accept(2)`, `bind(2)`, `getpeername(2)`, `getpeereid(2)`, `socket(2)`

BUGS

Names bound to sockets in the UNIX domain are inaccessible; `getsockname` returns a zero length name.

HISTORY

The `getsockname()` function call appeared in 4.2BSD.

BSD

July 17, 1999

BSD

getsockopt

GETSOCKOPT(2)

BSD System Calls Manual

GETSOCKOPT(2)

NAME

`getsockopt`, `setsockopt` - get and set options on sockets

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
int
getsockopt(int s, int level, int optname, void *optval,
           socklen_t *optlen);
```

```
int
setsockopt(int s, int level, int optname, const void *optval,
           socklen_t optlen);
```

DESCRIPTION

`getsockopt()` and `setsockopt()` manipulate the options associated with a socket. Options may exist at multiple protocol levels; they are always present at the uppermost "socket" level.

When manipulating socket options the level at which the option resides and the name of the option must be specified. To manipulate options at the socket level, level is specified as `SOL_SOCKET`. To manipulate options at any other level the protocol number of the appropriate protocol controlling the option is supplied. For example, to indicate that an option is to be interpreted by the TCP protocol, level should be set to the protocol number of TCP; see `getprotoent(3)`.

The parameters `optval` and `optlen` are used to access option values for `setsockopt()`. For `getsockopt()` they identify a buffer in which the value for the requested option(s) are to be returned. For `getsockopt()`, `optlen` is a value-result parameter, initially containing the size of the buffer pointed to by `optval`, and modified on return to indicate the actual size of the value returned. If no option value is to be supplied or returned, `optval` may be `NULL`.

`optname` and any specified options are passed uninterpreted to the appropriate protocol module for interpretation. The include file `<sys/socket.h>` contains definitions for socket level options, described below. Options at other protocol levels vary in format and name; consult the appropriate entries in section 4 of the manual.

Most socket-level options utilize an `int` parameter for `optval`. For `setsockopt()`, the parameter should be non-zero to enable a boolean option, or zero if the option is to be disabled. `SO_LINGER` uses a struct `linger` parameter, defined in `<sys/socket.h>`, which specifies the desired state of the option and the linger interval (see below). `SO_SNDTIMEO` and `SO_RCVTIMEO` use a struct `timeval` parameter, defined in `<sys/time.h>`.

The following options are recognized at the socket level. Except as noted, each may be examined with `getsockopt()` and set with `setsockopt()`.

<code>SO_DEBUG</code>	enables recording of debugging information
<code>SO_REUSEADDR</code>	enables local address reuse
<code>SO_REUSEPORT</code>	enables duplicate address and port bindings
<code>SO_KEEPAIVE</code>	enables keep connections alive
<code>SO_DONTROUTE</code>	enables routing bypass for outgoing messages
<code>SO_LINGER</code>	linger on close if data present
<code>SO_BROADCAST</code>	enables permission to transmit broadcast messages
<code>SO_OOBINLINE</code>	enables reception of out-of-band data in band
<code>SO_SNDBUF</code>	set buffer size for output
<code>SO_RCVBUF</code>	set buffer size for input
<code>SO_SNDLOWAT</code>	set minimum count for output
<code>SO_RCVLOWAT</code>	set minimum count for input
<code>SO_SNDTIMEO</code>	set timeout value for output
<code>SO_RCVTIMEO</code>	set timeout value for input
<code>SO_TYPE</code>	get the type of the socket (get only)
<code>SO_ERROR</code>	get and clear error on the socket (get only)

`SO_DEBUG` enables debugging in the underlying protocol modules.

`SO_REUSEADDR` indicates that the rules used in validating addresses supplied in a `bind(2)` call should allow reuse of local addresses.

`SO_REUSEPORT` allows completely duplicate bindings by multiple processes if they all set `SO_REUSEPORT` before binding the port. This option permits multiple instances of a program to each receive UDP/IP multicast or broadcast datagrams destined for the bound port. `SO_KEEPAIVE` enables

the periodic transmission of messages on a connected socket. Should the connected party fail to respond to these messages, the connection is considered broken and processes using the socket are notified via a SIGPIPE signal when attempting to send data. `SO_DONTROUTE` indicates that outgoing messages should bypass the standard routing facilities. Instead, messages are directed to the appropriate network interface according to the network portion of the destination address.

`SO_LINGER` controls the action taken when unsent messages are queued on socket and a `close(2)` is performed. If the socket promises reliable delivery of data and `SO_LINGER` is set, the system will block the process on the `close(2)` attempt until it is able to transmit the data or until it decides it is unable to deliver the information (a timeout period measured in seconds, termed the linger interval, is specified in the `setsockopt()` call when `SO_LINGER` is requested). If `SO_LINGER` is disabled and a `close(2)` is issued, the system will process the close in a manner that allows the process to continue as quickly as possible.

The option `SO_BROADCAST` requests permission to send broadcast datagrams on the socket. Broadcast was a privileged operation in earlier versions of the system. With protocols that support out-of-band data, the `SO_OOBINLINE` option requests that out-of-band data be placed in the normal data input queue as received; it will then be accessible with `recv(2)` or `read(2)` calls without the `MSG_OOB` flag. Some protocols always behave as if this option is set. `SO_SNDBUF` and `SO_RCVBUF` are options to adjust the normal buffer sizes allocated for output and input buffers, respectively. The buffer size may be increased for high-volume connections, or may be decreased to limit the possible backlog of incoming data. The system places an absolute limit on these values.

`SO_SNDLOWAT` is an option to set the minimum count for output operations. Most output operations process all of the data supplied by the call, delivering data to the protocol for transmission and blocking as necessary for flow control. Nonblocking output operations will process as much data as permitted subject to flow control without blocking, but will process no data if flow control does not allow the smaller of the low water mark value or the entire request to be processed. A `select(2)` or `poll(2)` operation testing the ability to write to a socket will return true only if the low water mark amount could be processed. The default value for `SO_SNDLOWAT` is set to a convenient size for network efficiency, often 1024. `SO_RCVLOWAT` is an option to set the minimum count for input operations. In general, receive calls will block until any (non-zero) amount of data is received, then return with the smaller of the amount available or the amount requested. The default value for `SO_RCVLOWAT` is 1. If `SO_RCVLOWAT` is set to a larger value, blocking receive calls normally wait until they have received the smaller of the low water mark value or the requested amount. Receive calls may still return less than the low water mark if an error occurs, a signal is caught, or the type of data next in the receive queue is different than that returned.

`SO_SNDTIMEO` is an option to set a timeout value for output operations. It accepts a struct `timeval` parameter with the number of seconds and microseconds used to limit waits for output operations to complete. If a send operation has blocked for this much time, it returns with a partial count or with the error `EWOULDBLOCK` if no data was sent. In the current implementation, this timer is restarted each time additional data are delivered to the protocol, implying that the limit applies to output portions ranging in size from the low water mark to the high water mark for output. `SO_RCVTIMEO` is an option to set a timeout value for input operations. It accepts a struct `timeval` parameter with the number of seconds and microseconds used to limit waits for input operations to complete.

In the current implementation, this timer is restarted each time additional data are received by the protocol, and thus the limit is in effect an inactivity timer. If a receive operation has been blocked for this much time without receiving additional data, it returns with a short count or with the error `EWOULDBLOCK` if no data were received.

Finally, `SO_TYPE` and `SO_ERROR` are options used only with `getsockopt()`. `SO_TYPE` returns the type of the socket, such as `SOCK_STREAM`; it is useful for servers that inherit sockets on startup. `SO_ERROR` returns any pending error on the socket and clears the error status. It may be used to check for asynchronous errors on connected datagram sockets or for other asynchronous errors.

RETURN VALUES

A 0 is returned if the call succeeds, -1 if it fails.

ERRORS

The call succeeds unless:

<code>[EBADF]</code>	The argument <code>s</code> is not a valid descriptor.
<code>[ENOTSOCK]</code>	The argument <code>s</code> is a file, not a socket.
<code>[ENOPROTOOPT]</code>	The option is unknown at the level indicated.
<code>[EFAULT]</code>	The address pointed to by <code>optval</code> is not in a valid part of the process address space. For <code>getsockopt()</code> , this error may also be returned if <code>optlen</code> is not in a valid part of the process address space.

SEE ALSO

`connect(2)`, `ioctl(2)`, `poll(2)`, `select(2)`, `poll(2)`, `socket(2)`, `getprotoent(3)`, `protocols(5)`

BUGS

Several of the socket options should be handled at lower levels of the system.

HISTORY

The `getsockopt()` system call appeared in 4.2BSD.

BSD

February 15, 1999

BSD

ioctl

IOCTL(2)

BSD System Calls Manual

IOCTL(2)

NAME

`ioctl` - control device

SYNOPSIS

```
#include <sys/ioctl.h>
```

```
int
```

```
ioctl(int d, unsigned long request, ...);
```

DESCRIPTION

The `ioctl()` function manipulates the underlying device parameters of special files. In particular, many operating characteristics of character special files (e.g., terminals) may be controlled with `ioctl()` requests.

The argument `d` must be an open file descriptor. The third argument is called `arg` and contains additional information needed by this device to perform the requested function. `arg` is either an `int` or a pointer to a device-specific data structure, depending upon the given request.

An `ioctl` request has encoded in it whether the argument is an "in" parameter or "out" parameter, and the size of the third argument (`arg`) in bytes. Macros and defines used in specifying an `ioctl` request are located in the file `<sys/ioctl.h>`.

RETURN VALUES

If an error has occurred, a value of `-1` is returned and `errno` is set to indicate the error.

ERRORS

`ioctl()` will fail if:

[EBADF]	<code>d</code> is not a valid descriptor.
[ENOTTY]	<code>d</code> is not associated with a character special device.
[ENOTTY]	The specified request does not apply to the kind of object that the descriptor <code>d</code> references.
[EINVAL]	request or <code>arg</code> is not valid.
[EFAULT]	<code>arg</code> points outside the process's allocated address space.

SEE ALSO

`cdio(1)`, `chio(1)`, `mt(1)`, `execve(2)`, `fcntl(2)`, `intro(4)`, `tty(4)`

HISTORY

An `ioctl()` function call appeared in Version 7 AT&T UNIX.

BSD December 11, 1993 BSD

poll

POLL(2) BSD System Calls Manual POLL(2)

NAME

`poll` - synchronous I/O multiplexing

SYNOPSIS

```
#include <poll.h>
```

```
int
poll(struct pollfd *fds, int nfds, int timeout);
```

DESCRIPTION

`poll()` provides a mechanism for reporting I/O conditions across a set of file descriptors.

The arguments are as follows:

fds Points to an array of pollfd structures, which are defined as:

```
struct pollfd {
    int fd;
    short events;
    short revents;
};
```

The fd member is an open file descriptor. The events and revents members are bitmasks of conditions to monitor and conditions found, respectively.

nfds The number of pollfd structures in the array.

timeout Maximum interval to wait for the poll to complete, in milliseconds. If this value is 0, then poll() will return immediately. If this value is INFTIM (-1), poll() will block indefinitely until a condition is found.

The calling process sets the events bitmask and poll() sets the revents bitmask. Each call to poll() resets the revents bitmask for accuracy. The condition flags in the bitmasks are defined as:

POLLIN	Data is available on the file descriptor for reading.
POLLNORM	Same as POLLIN.
POLLPRI	Same as POLLIN.
POLLOUT	Data can be written to the file descriptor without blocking.
POLLERR	This flag is not used in this implementation and is provided only for source code compatibility.
POLLHUP	The file descriptor was valid before the polling process and invalid after. Presumably, this means that the file descriptor was closed sometime during the poll.
POLLNVAL	The corresponding file descriptor is invalid.
POLLRDNORM	Same as POLLIN.
POLLRDBAND	Same as POLLIN.
POLLWRNORM	Same as POLLOUT.
POLLWRBAND	Same as POLLOUT.
POLLMSG	This flag is not used in this implementation and is provided only for source code compatibility.

All flags except POLLIN, POLLOUT, and their synonyms are for use only in the revents member of the pollfd structure. An attempt to set any of these flags in the events member will generate an error condition.

In addition to I/O multiplexing, poll() can be used to generate simple timeouts. This functionality may be achieved by passing a null pointer for fds.

WARNINGS

The POLLHUP flag is only a close approximation and may not always be accurate.

RETURN VALUES

Upon error, poll() returns a -1 and sets the global variable errno to indicate the error. If the timeout interval was reached before any events occurred, a 0 is returned. Otherwise, poll() returns the number of file descriptors for which revents is non-zero.

ERRORS

poll() will fail if:

- [EINVAL] nfds was either a negative number or greater than the number of available file descriptors.
- [EINVAL] An invalid flags was set in the events member of the pollfd structure.
- [EINVAL] The timeout passed to poll() was too large.
- [EAGAIN] Resource allocation failed inside of poll(). Subsequent calls to poll() may succeed.
- [EINTR] poll() caught a signal during the polling process.

SEE ALSO

poll(2), select(2), sysconf(3)

HISTORY

A poll() system call appeared in AT&T System V UNIX.

BSD

December 13, 1994

BSD

select

SELECT(2)

BSD System Calls Manual

SELECT(2)

NAME

select - synchronous I/O multiplexing

SYNOPSIS

```
#include <sys/types.h>
#include <sys/time.h>
#include <unistd.h>

int
select(int nfds, fd_set *readfds, fd_set *writefds, fd_set *exceptfds,
       struct timeval *timeout);

FD_SET(fd, &fdset);

FD_CLR(fd, &fdset);

FD_ISSET(fd, &fdset);
```

```
FD_ZERO(&fdset);
```

DESCRIPTION

`select()` examines the I/O descriptor sets whose addresses are passed in `readfds`, `writefds`, and `exceptfds` to see if some of their descriptors are ready for reading, are ready for writing, or have an exceptional condition pending, respectively. The first `nfds` descriptors are checked in each set; i.e., the descriptors from 0 through `nfds-1` in the descriptor sets are examined. On return, `select()` replaces the given descriptor sets with subsets consisting of those descriptors that are ready for the requested operation. `select()` returns the total number of ready descriptors in all the sets.

The descriptor sets are stored as bit fields in arrays of integers. The following macros are provided for manipulating such descriptor sets: `FD_ZERO(&fdset)` initializes a descriptor set `fdset` to the null set. `FD_SET(fd, &fdset)` includes a particular descriptor `fd` in `fdset`. `FD_CLR(fd, &fdset)` removes `fd` from `fdset`. `FD_ISSET(fd, &fdset)` is non-zero if `fd` is a member of `fdset`, zero otherwise. The behavior of these macros is undefined if a descriptor value is less than zero or greater than or equal to `FD_SETSIZE`, which is normally at least equal to the maximum number of descriptors supported by the system.

If `timeout` is a non-null pointer, it specifies a maximum interval to wait for the selection to complete. If `timeout` is a null pointer, the `select` blocks indefinitely. To effect a poll, the `timeout` argument should be non-null, pointing to a zero-valued `timeval` structure. `timeout` is not changed by `select()`, and may be reused on subsequent calls; however, it is good style to re-initialize it before each invocation of `select()`.

Any of `readfds`, `writefds`, and `exceptfds` may be given as null pointers if no descriptors are of interest.

RETURN VALUES

`select()` returns the number of ready descriptors that are contained in the descriptor sets, or -1 if an error occurred. If the time limit expires, `select()` returns 0. If `select()` returns with an error, including one due to an interrupted call, the descriptor sets will be unmodified.

ERRORS

An error return from `select()` indicates:

[EFAULT]	One or more of <code>readfds</code> , <code>writefds</code> , or <code>exceptfds</code> points outside the process's allocated address space.
[EBADF]	One of the descriptor sets specified an invalid descriptor.
[EINTR]	A signal was delivered before the time limit expired and before any of the selected events occurred.
[EINVAL]	The specified time limit is invalid. One of its components is negative or too large.

SEE ALSO

`accept(2)`, `connect(2)`, `gettimeofday(2)`, `poll(2)`, `read(2)`, `recv(2)`, `send(2)`, `write(2)`, `getdtablesize(3)`

BUGS

Although the provision of `getdtablesize(3)` was intended to allow user

programs to be written independent of the kernel limit on the number of open files, the dimension of a sufficiently large bit field for select remains a problem. The default bit size of `fd_set` is based on the symbol `FD_SETSIZE` (currently 256), but that is somewhat smaller than the current kernel limit to the number of open files. However, in order to accommodate programs which might potentially use a larger number of open files with select, it is possible to increase this size within a program by providing a larger definition of `FD_SETSIZE` before the inclusion of `<sys/types.h>`. The kernel will cope, and the userland libraries provided with the system are also ready for large numbers of file descriptors.

Alternatively, to be really safe, it is possible to allocate `fd_set` bit-arrays dynamically. The idea is to permit a program to work properly even if it is `execve(2)`'d with 4000 file descriptors pre-allocated. The following illustrates the technique which is used by userland libraries:

```
fd_set *fdsr;
int max = fd;

fdsr = (fd_set *)calloc(howmany(max+1, NFDDBITS),
    sizeof(fd_mask));
if (fdsr == NULL) {
    ...
    return (-1);
}
FD_SET(fd, fdsr);
n = select(max+1, fdsr, NULL, NULL, &tv);
...
free(fdsr);
```

Alternatively, it is possible to use the `poll(2)` interface. `poll(2)` is more efficient when the size of `select()`'s `fd_set` bit-arrays are very large, and for fixed numbers of file descriptors one need not size and dynamically allocate a memory object.

`select()` should probably have been designed to return the time remaining from the original timeout, if any, by modifying the time value in place. Even though some systems stupidly act in this different way, it is unlikely this semantic will ever be commonly implemented, as the change causes massive source code compatibility problems. Furthermore, recent new standards have dictated the current behaviour. In general, due to the existence of those brain-damaged non-conforming systems, it is unwise to assume that the timeout value will be unmodified by the `select()` call, and the caller should reinitialize it on each invocation. Calculating the delta is easily done by calling `gettimeofday(2)` before and after the call to `select()`, and using `timersub()` (as described in `getitimer(2)`).

Internally to the kernel, `select()` works poorly if multiple processes wait on the same file descriptor. Given that, it is rather surprising to see that many daemons are written that way (i.e., `httpd(8)`).

HISTORY

The `select()` function call appeared in 4.2BSD.

BSD

March 25, 1994

BSD

send

SEND(2)

BSD System Calls Manual

SEND(2)

NAME

send, sendto, sendmsg - send a message from a socket

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>

ssize_t
send(int s, const void *msg, size_t len, int flags);

ssize_t
sendto(int s, const void *msg, size_t len, int flags,
        const struct sockaddr *to, socklen_t tolen);

ssize_t
sendmsg(int s, const struct msghdr *msg, int flags);
```

DESCRIPTION

send(), sendto(), and sendmsg() are used to transmit a message to another socket. send() may be used only when the socket is in a connected state, while sendto() and sendmsg() may be used at any time.

The address of the target is given by to with tolen specifying its size. The length of the message is given by len. If the message is too long to pass atomically through the underlying protocol, the error EMSGSIZE is returned, and the message is not transmitted.

No indication of failure to deliver is implicit in a send(). Locally detected errors are indicated by a return value of -1.

If no messages space is available at the socket to hold the message to be transmitted, then send() normally blocks, unless the socket has been placed in non-blocking I/O mode. The select(2) or poll(2) system calls may be used to determine when it is possible to send more data.

The flags parameter may include one or more of the following:

```
#define MSG_OOB      0x1  /* process out-of-band data */
#define MSG_DONTROUTE 0x4  /* bypass routing, use direct interface */
```

The flag MSG_OOB is used to send "out-of-band" data on sockets that support this notion (e.g., SOCK_STREAM); the underlying protocol must also support "out-of-band" data. MSG_DONTROUTE is usually used only by diagnostic or routing programs.

See recv(2) for a description of the msghdr structure.

RETURN VALUES

The call returns the number of characters sent, or -1 if an error occurred.

ERRORS

send(), sendto(), and sendmsg() fail if:

[EBADF]	An invalid descriptor was specified.
[ENOTSOCK]	The argument s is not a socket.

[EFAULT]	An invalid user space address was specified for a parameter.
[EMSGSIZE]	The socket requires that message be sent atomically, and the size of the message to be sent made this impossible.
[EAGAIN]	The socket is marked non-blocking and the requested operation would block.
[ENOBUFFS]	The system was unable to allocate an internal buffer. The operation may succeed when buffers become available.
[ENOBUFFS]	The output queue for a network interface was full. This generally indicates that the interface has stopped sending, but may be caused by transient congestion.
[EACCES]	The SO_BROADCAST option is not set on the socket, and a broadcast address was given as the destination.
[EHOSTUNREACH]	The destination address specified an unreachable host.
[EINVAL]	The flags parameter is invalid.
[EHOSTDOWN]	The destination address specified a host that is down.
[ENETDOWN]	The destination address specified a network that is down.
[ECONNREFUSED]	The destination host rejected the message (or a previous one). This error can only be returned by connected sockets.
[ENOPROTOOPT]	There was a problem sending the message. This error can only be returned by connected sockets.
[EDESTADDRREQ]	The socket is not connected, and no destination address was specified.
[EISCONN]	The socket is already connected, and a destination address was specified.

In addition, `send()` and `sendto()` may return the following error:

[EINVAL]	<code>len</code> was larger than <code>SSIZE_MAX</code> .
----------	---

Also, `sendmsg()` may return the following errors:

[EINVAL]	The sum of the <code>iov_len</code> values in the <code>msg_iov</code> array overflowed an <code>ssize_t</code> .
[EMSGSIZE]	The <code>msg_iovlen</code> member of <code>msg</code> was less than 0 or larger than <code>IOV_MAX</code> .
[EAFNOSUPPORT]	Addresses in the specified address family cannot be used with this socket.

SEE ALSO

```
fcntl(2), getsockopt(2), poll(2), recv(2), select(2), poll(2), socket(2),
write(2)
```

HISTORY

The `send()` function call appeared in 4.2BSD.

BSD

July 28, 1998

BSD

shutdown

SHUTDOWN(2)

BSD System Calls Manual

SHUTDOWN(2)

NAME

`shutdown` - shut down part of a full-duplex connection

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
int
shutdown(int s, int how);
```

DESCRIPTION

The `shutdown()` call causes all or part of a full-duplex connection on the socket associated with `s` to be shut down. If `how` is `SHUT_RD`, further receives will be disallowed. If `how` is `SHUT_WR`, further sends will be disallowed. If `how` is `SHUT_RDWR`, further sends and receives will be disallowed.

RETURN VALUES

A 0 is returned if the call succeeds, -1 if it fails.

ERRORS

The call succeeds unless:

[EINVAL]	<code>how</code> is not <code>SHUT_RD</code> , <code>SHUT_WR</code> , or <code>SHUT_RDWR</code> .
[EBADF]	<code>s</code> is not a valid descriptor.
[ENOTSOCK]	<code>s</code> is a file, not a socket.
[ENOTCONN]	The specified socket is not connected.

SEE ALSO

`connect(2)`, `socket(2)`

HISTORY

The `shutdown()` function call appeared in 4.2BSD. The `how` arguments used to be simply 0, 1, and 2, but now have named values as specified by X/Open Portability Guide Issue 4 ("XPG4").

BSD

June 4, 1993

BSD

socket

SOCKET(2)

BSD System Calls Manual

SOCKET(2)

NAME

socket - create an endpoint for communication

SYNOPSIS

```
#include <sys/types.h>
#include <sys/socket.h>
```

```
int
socket(int domain, int type, int protocol);
```

DESCRIPTION

socket() creates an endpoint for communication and returns a descriptor.

The domain parameter specifies a communications domain within which communication will take place; this selects the protocol family which should be used. These families are defined in the include file <sys/socket.h>. The currently understood formats are

AF_UNIX	(UNIX internal protocols),
AF_INET	(ARPA Internet protocols),
AF_INET6	(ARPA IPv6 protocols),
AF_ISO	(ISO protocols),
AF_NS	(Xerox Network Systems protocols),
AF_IPX	(Internetwork Packet Exchange), and
AF_IMPLINK	(IMP host at IMP link layer).

The socket has the indicated type, which specifies the semantics of communication. Currently defined types are:

```
SOCK_STREAM
SOCK_DGRAM
SOCK_RAW
SOCK_SEQPACKET
SOCK_RDM
```

A SOCK_STREAM type provides sequenced, reliable, two-way connection based byte streams. An out-of-band data transmission mechanism may be supported. A SOCK_DGRAM socket supports datagrams (connectionless, unreliable messages of a fixed (typically small) maximum length). A SOCK_SEQPACKET socket may provide a sequenced, reliable, two-way connection-based data transmission path for datagrams of fixed maximum length; a consumer may be required to read an entire packet with each read system call. This facility is protocol specific, and presently implemented only for PF_NS. SOCK_RAW sockets provide access to internal network protocols and interfaces. The types SOCK_RAW, which is available only to the superuser, and SOCK_RDM, which is planned, but not yet implemented, are not described here.

The protocol specifies a particular protocol to be used with the socket. Normally only a single protocol exists to support a particular socket type within a given protocol family. However, it is possible that many protocols may exist, in which case a particular protocol must be specified in this manner. The protocol number to use is particular to the communication domain in which communication is to take place; see protocols(5). A value of 0 for protocol will let the system select an appropriate protocol for the requested socket type.

Sockets of type `SOCK_STREAM` are full-duplex byte streams, similar to pipes. A stream socket must be in a connected state before any data may be sent or received on it. A connection to another socket is created with a `connect(2)` call. Once connected, data may be transferred using `read(2)` and `write(2)` calls or some variant of the `send(2)` and `recv(2)` calls. When a session has been completed a `close(2)` may be performed. Out-of-band data may also be transmitted as described in `send(2)` and received as described in `recv(2)`.

The communications protocols used to implement a `SOCK_STREAM` ensure that data is not lost or duplicated. If a piece of data for which the peer protocol has buffer space cannot be successfully transmitted within a reasonable length of time, then the connection is considered broken and calls will indicate an error with `-1` returns and with `ETIMEDOUT` as the specific code in the global variable `errno`. The protocols optionally keep sockets "warm" by forcing transmissions roughly every minute in the absence of other activity. An error is then indicated if no response can be elicited on an otherwise idle connection for an extended period (e.g., 5 minutes). A `SIGPIPE` signal is raised if a process sends on a broken stream; this causes naive processes, which do not handle the signal, to exit.

`SOCK_SEQPACKET` sockets employ the same system calls as `SOCK_STREAM` sockets. The only difference is that `read(2)` calls will return only the amount of data requested, and any remaining in the arriving packet will be discarded.

`SOCK_DGRAM` and `SOCK_RAW` sockets allow sending of datagrams to correspondents named in `send(2)` calls. Datagrams are generally received with `recvfrom(2)`, which returns the next datagram with its return address.

An `fcntl(2)` call can be used to specify a process group to receive a `SIGURG` signal when the out-of-band data arrives. It may also enable non-blocking I/O and asynchronous notification of I/O events via `SIGIO`.

The operation of sockets is controlled by socket level options. These options are defined in the file `<sys/socket.h>`. `setsockopt(2)` and `getsockopt(2)` are used to set and get options, respectively.

RETURN VALUES

A `-1` is returned if an error occurs, otherwise the return value is a descriptor referencing the socket.

ERRORS

The `socket()` call fails if:

[EPROTONOSUPPORT]	The protocol type or the specified protocol is not supported within this domain.
[EMFILE]	The per-process descriptor table is full.
[ENFILE]	The system file table is full.
[EACCES]	Permission to create a socket of the specified type and/or protocol is denied.
[ENOBUFS]	Insufficient buffer space is available. The socket cannot be created until sufficient resources are freed.

SEE ALSO

`accept(2)`, `bind(2)`, `connect(2)`, `getsockname(2)`, `getsockopt(2)`, `ioctl(2)`,
`listen(2)`, `poll(2)`, `read(2)`, `recv(2)`, `select(2)`, `send(2)`, `setsockopt(2)`,
`shutdown(2)`, `socketpair(2)`, `write(2)`, `getprotoent(3)`, `netintro(4)`

An Introductory 4.3 BSD Interprocess Communication Tutorial, reprinted in
UNIX Programmer's Supplementary Documents Volume 1.

BSD Interprocess Communication Tutorial, reprinted in UNIX Programmer's
Supplementary Documents Volume 1.

HISTORY

The `socket()` function call appeared in 4.2BSD.

BSD

June 4, 1993

BSD

XV. FreeBSD TCP/IP Stack port for eCos

TCP/IP Networking for eCos now provides a complete TCP/IP networking stack, based on a recent snapshot of the FreeBSD code, released by the KAME project. The networking support is fully featured and well tested within the eCos environment.

Chapter 39. Networking Stack Features

Since this networking package is based on BSD code, it is very complete and robust. The eCos implementation includes support for the following protocols:

- IPv4
- UDP
- TCP
- ICMP
- raw packet interface
- Multi-cast addressing
- IPv6 (including UDP, ICP, ICMP)

These additional features are also present in the package, but are not supported:

- Berkeley Packet Filter
- Uni-cast support
- Multi-cast routing

Chapter 40. Freebsd TCP/IP stack port

This document describes how to get started with the Freebsd TCP/IP network stack.

Targets

A number of ethernet devices may be supported. The default configuration supports two instances of the interface by default, and you will need to write your own driver instantiation code, and supplemental startup and initialization code, if you should add additional ones.

The target for your board will normally be supplied with an ethernet driver, in which case including the network stack and generic ethernet driver package to your build will automatically enable usage of the ethernet device driver. If your target is not supplied with an ethernet driver, you will need to use loopback (see [the Section called *Loopback tests* in Chapter 36](#)).

Building the Network Stack

Using the *Build->Packages* dialog, add the packages “Networking”, “Freebsd TCP/IP Stack” and “Common Ethernet Support” to your configuration. Their package names are CYGPKG_NET, CYGPKG_NET_FREEBSD_STACK and CYGPKG_NET_ETH_DRIVERS respectively.

A short-cut way to do this is by using the “net” *template* if it is available for your platform.

The platform-specific ethernet device driver for your platform will be added as part of the target selection (in the *Build->Templates* “Hardware” item), along with the PCI I/O subsystem (if relevant) and the appropriate serial device driver.

For example, the PowerPC MBX target selection adds the package PKG_NET_QUICC_ETH_DRIVERS, and the Cirrus Logic EDB7xxx target selection adds the package CYGPKG_NET_EDB7XXX_ETH_DRIVERS. After this, eCos and its tests can be built exactly as usual.

Note: By default, most of the network tests are not built. This is because some of them require manual intervention, i.e. they are to be run “by hand”, and are not suitable for automated testing. To build the full set of network tests, set the configuration option CYGPKG_NET_BUILD_TESTS “Build networking tests (demo programs)” within “Networking support build options”.

Chapter 41. APIs

Standard networking

The APIs for the standard networking calls such as `socket()`, `recv()` and so on, are in header files relative to the top-level include directory, within the standard subdirectories as conventionally found in `/usr/include`. For example:

```
install/include/arpa/tftp.h
install/include/netinet/tcpip.h
install/include/sys/socket.h
install/include/sys/socketvar.h
install/include/sys/sockio.h
```

`network.h` at the top level defines various extensions, for example the API `init_all_network_interfaces(void)` described above. We advise including `network.h` whether you use these features or not.

In general, using the networking code may require definition of two symbols: `_KERNEL` and `__ECOS`. `_KERNEL` is not normally required; `__ECOS` is normally required. So add this to your compile lines for files which use the network stack:

```
-D__ECOS
```

To expand a little, it's like this because this is a port of a standard distribution external to eCos. One goal is to perturb the sources as little as possible, so that upgrading and maintenance from the external distribution is simplified. The `__ECOS` symbol marks out the eCos additions in making the port. The `_KERNEL` symbol is traditional UNIX practice: it distinguishes a compilation which is to be linked into the kernel from one which is part of an application. eCos applications are fully linked, so this distinction does not apply. `_KERNEL` can however be used to control the visibility of the internals of the stack, so depending on what features your application uses, it may or may not be necessary.

The include file `network.h` undefines `_KERNEL` unconditionally, to provide an application-like compilation environment. If you were writing code which, for example, enumerates the stack's internal structures, that is a kernel-like compilation environment, so you would need to define `_KERNEL` (in addition to `__ECOS`) and avoid including `network.h`.

Enhanced Select()

The network stack supports an extension to the standard select semantics which allows all threads that are waiting to be restarted even if the select conditions are not satisfied.

The standard `select()` API:

```
int
select(int nfd,
       fd_set *in, fd_set *out, fd_set *ex,
       struct timeval *tv);
```

does not support the restart.

The additional API:

```
int
cyg_select_with_abort(int nfd,
    fd_set *in, fd_set *out, fd_set *ex,
    struct timeval *tv)
```

behaves exactly as `select()` with the additional feature that a call to

```
void cyg_select_abort(void)
```

will cause all threads waiting in any `cyg_select_with_abort()` call to cease waiting and continue execution.

XVI. DNS for eCos and RedBoot

eCos and RedBoot can both use the DNS package to perform network name lookups.

Chapter 42. DNS

DNS API

The DNS client uses the normal BSD API for performing lookups: `gethostbyname()`, `gethostbyaddr()`, `getaddrinfo()`, `getnameinfo()`.

There are a few restrictions:

- If the DNS server returns multiple authoritative records for a host name to `gethostbyname`, the hostent will only contain a record for the first entry. If multiple records are desired, use `getaddrinfo`, which will return multiple results.
- The code has been made thread safe. ie multiple threads may call `gethostbyname()` without causing problems to the hostent structure returned. What is not safe is one thread using both `gethostbyname()` and `gethostbyaddr()`. A call to one will destroy the results from the previous call to the other function. `getaddrinfo()` and `getnameinfo()` are thread safe and so these are the preferred interfaces. They are also address family independent so making it easier to port code to IPv6.
- The DNS client will only return IPv4 addresses to RedBoot. At the moment this is not really a limitation, since RedBoot only supports IPv4 and not IPv6.

To initialise the DNS client the following function must be called:

```
#include <network.h>
int cyg_dns_res_start(char * dns_server)
```

Where `dns_server` is the address of the DNS server. The address must be in numeric form and can be either an IPv4 or an IPv6 address.

There also exists a deprecated function to start the DNS client:

```
int cyg_dns_res_init(struct in_addr *dns_server)
```

where `dns_server` is the address of the DNS server the client should query. The address should be in network order and can only be an IPv4 address.

On error both this function returns -1, otherwise 0 for success. If lookups are attempted before this function has been called, they will fail and return NULL, unless numeric host addresses are passed. In this cause, the address will be converted and returned without the need for a lookup.

A default, hard coded, server may be specified in the CDL option `CYGDAT_NS_DNS_DEFAULT_SERVER`. The use of this is controlled by `CYGPKG_NS_DNS_DEFAULT`. If this is enabled, `init_all_network_interfaces()` will initialize the resolver with the hard coded address. The DHCP client or user code may override this address by calling `cyg_dns_res_init` again.

The DNS client understands the concepts of the target being in a domain. By default no domain will be used. Host name lookups should be for fully qualified names. The domain name can be set and retrieved using the functions:

```
int getdomainname(char *name, size_t len);
int setdomainname(const char *name, size_t len);
```

Alternatively, a hard coded domain name can be set using CDL. The boolean `CYGPKG_NS_DNS_DOMAINNAME` enables this and the domain name is taken from `CYGPKG_NS_DNS_DOMAINNAME_NAME`.

Once set, the DNS client will use some simple heuristics when deciding how to use the domainname. If the name given to the client ends with a "." it is assumed to be a FQDN and the domain name will not be used. If the name contains a "." somewhere within it, first a lookup will be performed without the domainname. If that fails the domainname will be appended and looked up. If the name does not contain a ".", the domainname is appended and used for the first query. If that fails, the unadorned name is lookup.

The `getaddrinfo` will return both IPv4 and IPv6 addresses for a given host name, when IPv6 is enabled in the eCos configuration. The CDL option `CYGOPT_NS_DNS_FIRST_FAMILY` controls the order IPv6 and IPv4 addresses are returned in the linked list of `addrinfo` structures. If the value `AF_INET` is used, the IPv4 addresses will be first. If the value `AF_INET6`, which is the default, is used, IPv6 address will be first. This ordering will control how clients attempt to connect to servers, ie using IPv6 or IPv4 first.

DNS Client Testing

The DNS client has a test program, `dns1.c`, which tests many of the features of the DNS client and the functions `gethostbyname()`, `gethostbyaddr()`, `getaddrinfo()`, `getnameinfo()`.

In order for this test to work, a DNS server must be configured with a number of names and addresses. The following is an example forward address resolution database for `bind v9`, which explains the requirements.

```
$TTL      680400
@         IN      SOA      lunn.org.      andrew.lunn.lunn.org (
2003041801 ; serial
10800      ; refresh
1800       ; retry
3600000    ; expire
259200)    ; minimum
IN        NS      londo.lunn.org.

hostnamev4 IN      A       192.168.88.1
cnamev4    IN      CNAME   hostnamev4
hostnamev6 IN      AAAA    fec0::88:4:3:2:1
cnamev6    IN      CNAME   hostnamev6
hostnamev46 IN     A       192.168.88.2
hostnamev46 IN     AAAA    fec0::88:4:3:2:2
cnamev46   IN      CNAME   hostnamev46
```

The actual names and addresses do not matter, since they are configurable in the test. What is important is the relationship between the names and the addresses and there family, ie `hostnamev4` should map to one IPv4 address. `hostnamev46` should map to both an IPv4 and an IPv6 address. `cnamev4` should be a CNAME record for `hostname4`. Reverse lookup information is also needed by the test.

The information placed into the DNS server is also need in the test case. A structure is defined to hold this information:

```
struct test_info_s {
    char * dns_server_v4;
    char * dns_server_v6;
    char * domain_name;
    char * hostname_v4;
    char * cname_v4;
    char * ip_addr_v4;
    char * hostname_v6;
```

```
char * cname_v6;  
char * ip_addr_v6;  
char * hostname_v46;  
char * cname_v46;  
char * ip_addr_v46_v4;  
char * ip_addr_v46_v6;  
};
```

The test program may hold a number of such structures for different DNS server. The test will use each structure in turn to perform the tests. If IPv6 is not enabled in the eCos configuration, the entries which use IPv6 may be assigned to NULL.

XVII. eCos PPP User Guide

This package provides support for PPP (Point-to-Point Protocol) in the eCos FreeBSD TCP/IP networking stack.

Chapter 43. Features

The eCos PPP implementation provides the following features:

- PPP line protocol including VJ compression.
- LCP, IPCP and CCP control protocols.
- PAP and CHAP authentication.
- CHAT subset connection scripting.
- Modem control line support.

Chapter 44. Using PPP

Before going into detail, let's look at a simple example of how the eCos PPP package is used. Consider the following example:

```
static void ppp_up(void)
{
    cyg_ppp_options_t options;
    cyg_ppp_handle_t ppp_handle;

    // Bring up the TCP/IP network
    init_all_network_interfaces();

    // Initialize the options
    cyg_ppp_options_init( &options );

    // Start up PPP
    ppp_handle = cyg_ppp_up( "/dev/ser0", &options );

    // Wait for it to get running
    if( cyg_ppp_wait_up( ppp_handle ) == 0 )
    {
        // Make use of PPP
        use_ppp();

        // Bring PPP link down
        cyg_ppp_down( ppp_handle );

        // Wait for connection to go down.
        cyg_ppp_wait_down( ppp_handle );
    }
}
```

This is a simple example of how to bring up a simple PPP connection to another computer over a directly connected serial line. The other end is assumed to already be running PPP on the line and waiting for a connection.

The first thing this code does is to call `init_all_network_interfaces()` to bring up the TCP/IP stack and initialize any other network interfaces. It then calls `cyg_ppp_options_init()` to initialize the PPP options structure to the defaults. As it happens, the default options are exactly what we want for this example, so we don't need to make any further changes. We go straight on to bring the PPP interface up by calling `cyg_ppp_up()`. The arguments to this function give the name of the serial device to use, in this case `"/dev/ser0"`, and a pointer to the options.

When `cyg_ppp_up()` returns, it passes back a handle to the PPP connection which is to be used in other calls. The PPP link will not necessarily have been fully initialized at this time. There is a certain amount of negotiation that goes on between the ends of a PPP link before it is ready to pass packets. An application can wait until the link is ready by calling `cyg_ppp_wait_up()`, which returns zero if the link is up and running, or -1 if it has gone down or failed to come up.

After a successful return from `cyg_ppp_wait_up()`, the application may make use of the PPP connection. This is represented here by the call to `use_ppp()` but it may, of course, be accessed by any thread. While the connection is up the application may use the standard socket calls to make or accept network connections and transfer data in the normal way.

Once the application has finished with the PPP link, it can bring it down by calling `cyg_ppp_down()`. As with bringing the connection up, this call is asynchronous, it simply informs the PPP subsystem to start bringing the link down. The application can wait for the link to go down fully by calling `cyg_ppp_wait_down()`.

That example showed how to use PPP to connect to a local peer. PPP is more often used to connect via a modem to a remote server, such as an ISP. The following example shows how this works:

```
static char *isp_script[] =
{
    "ABORT"          ,          "BUSY"          ,
    "ABORT"          ,          "NO CARRIER"    ,
    "ABORT"          ,          "ERROR"         ,
    " "              ,          "ATZ"           ,
    "OK"             ,          "AT S7=45 S0=0 L1 V1 X4 &C1 E1 Q0" ,
    "OK"             ,          "ATD" CYGPKG_PPP_DEFAULT_DIALUP_NUMBER ,
    "ogin:--ogin:"   ,          CYGPKG_PPP_AUTH_DEFAULT_USER      ,
    "assword:"       ,          CYGPKG_PPP_AUTH_DEFAULT_PASSWD    ,
    "otocol:"        ,          "ppp"           ,
    "HELLO"          ,          "\\c"           ,
    0
};

static void ppp_up(void)
{
    cyg_ppp_options_t options;
    cyg_ppp_handle_t ppp_handle;

    // Bring up the TCP/IP network
    init_all_network_interfaces();

    // Initialize the options
    cyg_ppp_options_init( &options );

    options.script = isp_script;
    options.modem = 1;

    // Start up PPP
    ppp_handle = cyg_ppp_up( "/dev/ser0", &options );

    // Wait for it to get running
    if( cyg_ppp_wait_up( ppp_handle ) == 0 )
    {
        // Make use of PPP
        use_ppp();

        // Bring PPP link down
        cyg_ppp_down( ppp_handle );

        // Wait for connection to go down.
        cyg_ppp_wait_down( ppp_handle );
    }
}
```

The majority of this code is exactly the same as the previous example. The main difference is in the setting of a couple of options before calling `cyg_ppp_up()`. The *script* option is set to point to a CHAT script to manage the setup of the connection. The *modem* option is set to cause the PPP system to make use of the modem control lines.

During the PPP bring-up a call will be made to `cyg_ppp_chat()` to run the CHAT script (see [Chapter 47](#)). In the example this script sets up various modem options and then dials a number supplied as part of the PPP package configuration (see [Chapter 46](#)). When the connection has been established, the script log on to the server, using a name and password also supplied by the configuration, and then starts PPP on the remote end. If this script succeeds the PPP connection will be brought up and will then function as expected.

The *modem* option causes the PPP system to make use of the modem control lines. In particular it waits for `Carrier Detect` to be asserted, and will bring the link down if it is lost. See [cyg_ppp_options_init\(\)](#) for more details.

Chapter 45. PPP Interface

cyg_ppp_options_init()

Name

cyg_ppp_options_init — Initialize PPP link options

Synopsis

```
#include <cyg/ppp/ppp.h>

cyg_int32 cyg_ppp_options_init(cyg_ppp_options_t *options);
```

Description

This function initializes the PPP options, pointed to by the *options* parameter, to the default state. Once the defaults have been initialized, application code may adjust them by assigning new values to the the fields of the `cyg_ppp_options_t` structure.

This function returns zero if the options were initialized successfully. It returns -1 if the *options* argument is NULL, or the options could not be initialized.

The option fields, their functions and default values are as follows:

debug

If set to 1 this enables the reporting of debug messages from the PPP system. These will be generated using `diag_printf()` and will appear on the standard debug channel. Note that `diag_printf()` disables interrupts during output: this may cause the PPP link device to overrun and miss characters. It is quite possible for this option to cause errors and even make the PPP link fail completely. Consequently, this option should be used with care.

Default value: 0

kdebugflag

This five bit field enables low level debugging messages from the PPP device layer in the TCP/IP stack. As with the *debug* option, this may result in missed characters and cause errors. The bits of the field have the following meanings:

Bit	BSD Name	Description
0x01	SC_DEBUG	Enable debug messages

cyg_ppp_options_init()

Bit	BSD Name	Description
0x02	SC_LOG_INPKT	Log contents of good packets received
0x04	SC_LOG_OUTPKT	Log contents of packets sent
0x08	SC_LOG_RAWIN	Log all characters received
0x10	SC_LOG_FLUSH	Log all characters flushed

Default value: 0

default_route

If set to 1 this option causes the PPP subsystem to install a default route in the TCP/IP stack's routing tables using the peer as the gateway. This entry will be removed when the PPP link is broken. If there is already an existing working network connection, such as an ethernet device, then there may already be a default route established. If this is the case, then this option will have no effect.

Default value: 1

modem

If this option is set to 1, then the modem lines will be used during the connection. Specifically, the PPP subsystem will wait until the `carrier detect` signal is asserted before bringing up the PPP link, and will take the PPP link down if this signal is de-asserted.

Default value: 0

flowctl

This option is used to specify the mechanism used to control data flow across the serial line. It can take one of the following values:

`CYG_PPP_FLOWCTL_DEFAULT`

The flow control mechanism is not changed and is left at whatever value was set before bringing PPP up. This allows a non-standard flow control mechanism to be used, or for it to be chosen and set by some other means.

`CYG_PPP_FLOWCTL_NONE`

Flow control is turned off. It is not recommended that this option be used unless the baud rate is set low or the two communicating machines are particularly fast.

`CYG_PPP_FLOWCTL_HARDWARE`

Use hardware flow control via the RTS/CTS lines. This is the most effective flow control mechanism and should always be used if available. Availability of this mechanism depends on whether the serial device hardware has the ability to control these lines, whether they have been connected to the socket pins and whether the device driver has the necessary support.

`CYG_PPP_FLOWCTL_SOFTWARE`

Use software flow control by embedding XON/XOFF characters in the data stream. This is somewhat less effective than hardware flow control since it is subject to the propagation time of the serial cable

and the latency of the communicating devices. Since it does not rely on any hardware support, this flow control mechanism is always available.

Default value: CYG_PPP_FLOWCTL_HARDWARE

refuse_pap

If this option is set to 1, then the PPP subsystem will not agree to authenticate itself to the peer with PAP. When dialling in to a remote server it is normal to authenticate the client. There are three ways this can be done, using a straightforward login mechanism via the CHAT script, with the Password Authentication Protocol (PAP), or with the Challenge Handshake Authentication Protocol (CHAP). For PAP to work the *user* and *passwd* options must be set to the expected values. If they are not, then this option should be set to force CHAP authentication.

Default value: 0

refuse_chap

If this option is set to 1, then the PPP subsystem will not agree to authenticate itself to the peer with CHAP. CHAP authentication will only work if the *passwd* option has been set to the required CHAP secret for the destination server. Otherwise this option should be disabled.

If both *refuse_pap* and *refuse_chap* are set, then either no authentication will be carried out, or it is the responsibility of the **chat** script to do it. If the peer does not require any authentication, then the setting of these options is irrelevant.

Default value: 0

baud

This option is set to the baud rate at which the serial connection should be run. The default value is the rate at which modems conventionally operate. This field is an instance of the *cyg_serial_baud_rate_t* enum defined in the *serialio.h* header and may only take one of the baud rate constants defined in there.

Default value: CYGNUM_SERIAL_BAUD_115200

idle_time_limit

This is the number of seconds that the PPP connection may be idle before it is shut down automatically.

Default value: 60

maxconnect

This causes the connection to terminate when it has been up for this number of seconds. The default value of zero means that the connection will stay up indefinitely, until either end explicitly brings it down, or the link is lost.

Default value: 0

cyg_ppp_options_init()

`our_address`

This is the IP address, in network byte order, to be attached to the local end of the PPP connection. The default value of `INADDR_ANY` causes the local address to be obtained from the peer.

Default value: `INADDR_ANY`

`his_address`

This is the IP address, in network byte order, to be attached to the remote end of the PPP connection. The default value of `INADDR_ANY` causes the remote address to be obtained from the peer.

Default value: `INADDR_ANY`

`accept_local`

This allows the behaviour described above for `our_address` to be modified. Normally, if `our_address` is set, then the PPPD will insist that this address be used. However, if this option is also set, the PPPD will accept a value supplied by the peer.

Default value: 0

`accept_remote`

This allows the behaviour described above for `his_address` to be modified. Normally, if `his_address` is set, then the PPPD will insist that this address be used. However, if this option is also set, the PPPD will accept a value supplied by the peer.

Default value: 0

`script`

This is a pointer to a CHAT script suitable for passing to `cyg_ppp_chat()`. See [Chapter 47](#) for details of the format and contents of this script.

Default value: `NULL`

`user`

This array contains the user name to be used for PAP authentication. This field is not used for CHAP authentication. By default the value of this option is set from the `CYGPKG_PPP_AUTH_DEFAULT_USER` configuration option.

Default value: `CYGPKG_PPP_AUTH_DEFAULT_USER`

`passwd`

This array contains the password to be used for PAP authentication, or the secret to be used during CHAP authentication. By default the value of this option is set from the `CYGPKG_PPP_AUTH_DEFAULT_PASSWD` configuration option.

Default value: `CYGPKG_PPP_AUTH_DEFAULT_PASSWD`

cyg_ppp_up()

Name

`cyg_ppp_up` — Bring PPP connection up

Synopsis

```
#include <cyg/ppp/ppp.h>

cyg_ppp_handle_t cyg_ppp_up(char *devnam, const cyg_ppp_options_t *options);
```

Description

This function starts up a PPP connection. The *devnam* argument is the name of the device to be used for the connection, typically `/dev/ser0` or `/dev/ser1`. The *options* argument should point to an initialized `cyg_ppp_options_t` object.

The return value will either be zero, indicating a failure, or a `cyg_ppp_handle_t` object that may be used as an argument to other PPP functions.

Note: Although the PPP API is designed to permit several simultaneous connections to co-exist, at present only one PPP connection is actually implemented. Any attempt to create a second connection while there is already one open will fail.

cyg_ppp_up()

cyg_ppp_down()

Name

`cyg_ppp_down` — Bring PPP connection down

Synopsis

```
#include <cyg/ppp/ppp.h>

cyg_int32 cyg_ppp_down(cyg_ppp_handle_t handle);
```

Description

This function brings the PPP connection down. The *handle* argument is the result of a successful call to `cyg_ppp_up()`. This function only signals to the PPP subsystem that the link should be brought down. The link will be terminated asynchronously. If the application needs to wait for the link to terminate, then it should call `cyg_ppp_wait_down()` after calling `cyg_ppp_down()`.

The function returns zero if it was able to start the termination of the PPP connection successfully. It will return -1 if the connection is not running, or if it could not otherwise start the termination.

cyg_ppp_down()

cyg_ppp_wait_up()

Name

cyg_ppp_wait_up — Wait for PPP connection to come up

Synopsis

```
#include <cyg/ppp/ppp.h>

cyg_int32 cyg_ppp_wait_up(cyg_ppp_handle_t handle);
```

Description

This function waits until the PPP connection is running and then returns. This is needed because the actual bring up of the connection happens mostly after the call to `cyg_ppp_up()` returns, and may take some time to complete, especially if dialling a remote server.

The result of this call will be zero when the connection is running, or -1 if the connection failed to start for some reason. If the connection is already running when this call is made it will return immediately with a zero result. If the connection is not in the process of coming up, or has failed, or has terminated, then a result of -1 will be returned immediately. Thus this function may also be used to test that the connection is still running at any point.

cyg_ppp_wait_up()

cyg_ppp_wait_down()

Name

`cyg_ppp_wait_down` — Wait for PPP connection to terminate

Synopsis

```
#include <cyg/ppp/ppp.h>

void cyg_ppp_wait_down(cyg_ppp_handle_t handle);
```

Description

This function waits for the PPP connection to terminate. The link may be terminated with a call to `cyg_ppp_down()`, by the remote end, or by the telephone line being dropped or lost.

This function has no return value. If the PPP connection is not running, or has terminated, it will return. Applications should use `cyg_ppp_wait_up()` to test the link state.

cyg_ppp_wait_down()

cyg_ppp_chat()

Name

cyg_ppp_chat — Execute chat script

Synopsis

```
#include <cyg/ppp/ppp.h>

cyg_int32 cyg_ppp_chat(const char *devname, const char *script[]);
```

Description

This function implements a subset of the automated conversational scripting as defined by the **chat** program. The first argument is the name of the serial device to be used, typically `/dev/ser0` or `/dev/ser1`. The *script* argument is a pointer to a zero terminated array of strings that comprise the chat script. See [Chapter 44](#) for an example script, and [Chapter 47](#) for full detail of the script used.

The return value of this function will be zero if the chat script fails for any reason, such as an ABORT or a timeout. If the end of the script is reached, then the return value will be non-zero.

Under normal use this function is called from the PPP subsystem if the `cyg_ppp_options_t script` field is set to a non-NULL value. This function should only be used directly if the application needs to undertake special processing between running the chat script, and bringing up the PPP connections.

cyg_ppp_chat()

Chapter 46. Installing and Configuring PPP

Including PPP in a Configuration

PPP is contained entirely within a single eCos package. So to include PPP in a configuration all you need to do is add that package.

In the GUI configuration tool use the **Build->Packages** menu item, find the "PPP Support" package in the left-hand pane and use the **Add** button to add it to the list of packages in use in the right-hand pane.

In the command-line tool **ecosconfig**, you can use the following command during the configuration phase to add the PPP package:

```
$ ecosconfig add ppp
```

In addition to the PPP package you will also need to have the "Network" package and the "Serial Device Drivers" package in the configuration. The dependencies and requirements of the networking package are such that it is strongly recommended that you start with the `net` template.

See the eCos User Guide for full details on how to configure and build eCos.

Configuring PPP

The PPP package contains a number of configuration options that may be changed to affect its behaviour.

CYGNUM_PPP_PPPD_THREAD_PRIORITY

The PPP system contains two threads, One is used for receiving data from the link and processing control packets. The other is used to transmit data asynchronously to the link when it cannot be completed synchronously. The receive thread runs at the priority given here, and the transmit thread runs at the next lower priority. The exact priority needed here depends on the importance of the PPP subsystem relative to the rest of the system. The default is to put it in the middle of the priority range to provide reasonable response without impacting genuine high priority threads.

Default value: `CYGNUM_KERNEL_SCHED_PRIORITIES/2`

CYGPKG_PPP_DEBUG_WARN_ONLY

The runtime `debug` option enables logging of high level debug messages. Too many of these can interfere with the PPP device and may result in missed messages. This is because these messages are emitted via the `diag_printf()` mechanism, which disables interrupts while it prints. By default, therefore, we only report errors and warnings, and not all events. Setting this option to zero will enable the logging of all events.

Default value: `1`

CYGPKG_PPP_AUTH_DEFAULT_USER

This option gives the default value for the user name used to initialize the `user` field in the PPP options.

Default value: `"eCos"`

CYGPKG_PPP_AUTH_DEFAULT_PASSWD

This option gives the default value for the password used to initialize the *passwd* field in the PPP options.

Default value: "secret"

CYGPKG_PPP_DEFAULT_DIALUP_NUMBER

This option provides a default dialup number for use in **chat** scripts. This value is not used anywhere in the PPP package, but is provided to complete the information needed, alongside the user name and password, for accessing a typical dialup server.

Default value: "5551234"

CYGPKG_PPP_PAP

This component enables the inclusion of PAP authentication support.

Default value: 1

CYGPKG_PPP_CHAP

This component enables the inclusion of CHAT authentication support.

Default value: 1

CYGPKG_PPP_COMPRESSION

This component provides control over PPP compression features. **WARNING:** at present there are problems with this option, and in any case the compression code needs to allocate large amounts of memory. Hence this option is currently disabled and should remain so.

Default value: 0

PPP_BSDCOMP

This option enables inclusion of BSD compression into the PPP protocol.

Default value: 0

PPP_DEFLATE

This option enables inclusion of ZLIB compression into the PPP protocol.

Default value: 0

CYGPKG_PPP_CHAT

This component enables the inclusion of a simple scripting system to bring up PPP connections. It implements a subset of the **chat** scripting language.

Default value: 1

CYGNUM_PPP_CHAT_ABORTS_MAX

This option defines the maximum number of `ABORT` strings that the `CHAT` system will store.

Default value: 10

CYGNUM_PPP_CHAT_ABORTS_SIZE

This option defines the maximum size of each `ABORT` strings that the **chat** system will store.

Default value: 20

CYGNUM_PPP_CHAT_STRING_LENGTH

This option defines the maximum size of any expect or reply strings that the **chat** system will be given.

Default value: 256

CYGPKG_PPP_TEST_DEVICE

This option defines the serial device to be used for PPP test programs.

Default value: `"/dev/ser0"`

CYGPKG_PPP_TESTS_AUTOMATE

This option enables automated testing features in certain test programs. These programs will interact with a test server at the remote end of the serial link to run a variety of tests in different conditions. Without this option most tests default to running a single test instance and are suitable for being run by hand for debugging purposes.

Default value: 0

CYGDAT_PPP_TEST_BAUD_RATES

This option supplies a list of baud rates at which certain tests will run if the `CYGPKG_PPP_TESTS_AUTOMATE` option is set.

Default value: `"CYGNUM_SERIAL_BAUD_19200,CYGNUM_SERIAL_BAUD_38400,CYGNUM_SERIAL_BAUD_57600,CYGNUM_`

Chapter 47. CHAT Scripts

The automated conversational scripting supported by the eCos PPP package is a subset of the scripting language provided by the **chat** command found on most UNIX and Linux systems.

Unlike the **chat** command, the eCos `cyg_ppp_chat()` function takes as a parameter a zero-terminated array of pointers to strings. In most programs this will be defined by means of an initializer for a static array, although there is nothing to stop the application constructing it at runtime. A simple script would be defined like this:

```
static char *chat_script[] =
{
    "ABORT"          , "BUSY"          ,
    "ABORT"          , "NO CARRIER" ,
    ""              , "ATD5551234"  ,
    "ogin:--ogin:"   , "ppp"        ,
    "ssword:"        , "hithere"     ,
    0
};
```

The following sections have been abstracted from the public domain documentation for the **chat** command.

Chat Script

A script consists of one or more "expect-send" pairs of strings, separated by spaces, with an optional "subexpect- subsend" string pair, separated by a dash as in the following example:

```
"ogin:--ogin:"      , "ppp"          ,
"ssword:"           , "hello2u2"    ,
0
```

This script fragment indicates that the `cyg_ppp_chat()` function should expect the string "ogin:". If it fails to receive a login prompt within the time interval allotted, it is to send a carriage return to the remote and then expect the string "ogin:" again. If the first "ogin:" is received then the carriage return is not generated.

Once it received the login prompt the `cyg_ppp_chat()` function will send the string "ppp" and then expect the prompt "ssword:". When it receives the prompt for the password, it will send the password "hello2u2".

A carriage return is normally sent following the reply string. It is not expected in the "expect" string unless it is specifically requested by using the "\r" character sequence.

The expect sequence should contain only what is needed to identify the string. It should not contain variable information. It is generally not acceptable to look for time strings, network identification strings, or other variable pieces of data as an expect string.

To help correct for characters which may be corrupted during the initial sequence, look for the string "ogin:" rather than "login:". It is possible that the leading "l" character may be received in error and you may never find the string even though it was sent by the system. For this reason, scripts look for "ogin:" rather than "login:" and "ssword:" rather than "password:".

A very simple script might look like this:

```
"ogin:"            , "ppp"          ,
"ssword:"          , "hello2u2"     ,
0
```

In other words, expect "...login:", send "ppp", expect "...ssword:", send "hello2u2".

In actual practice, simple scripts are rare. At the very least, you should include sub-expect sequences should the original string not be received. For example, consider the following script:

```
"login:--login:" , "ppp" ,
"ssword:" , "hello2u2" ,
0
```

This would be a better script than the simple one used earlier. This would look for the same "login:" prompt, however, if one was not received, a single return sequence is sent and then it will look for "login:" again. Should line noise obscure the first login prompt then sending the empty line will usually generate a login prompt again.

ABORT Strings

Many modems will report the status of the call as a string. These strings may be CONNECTED or NO CARRIER or BUSY. It is often desirable to terminate the script should the modem fail to connect to the remote. The difficulty is that a script would not know exactly which modem string it may receive. On one attempt, it may receive BUSY while the next time it may receive NO CARRIER.

These "abort" strings may be specified in the script using the ABORT sequence. It is written in the script as in the following example:

```
"ABORT" , "BUSY" ,
"ABORT" , "NO CARRIER" ,
" " , "ATZ" ,
"OK" , "ATDT5551212" ,
"CONNECT" , ...
```

This sequence will expect nothing; and then send the string ATZ. The expected response to this is the string OK. When it receives OK, it sends the string ATDT5551212 to dial the telephone. The expected string is CONNECT. If the string CONNECT is received the remainder of the script is executed. However, should the modem find a busy telephone, it will send the string BUSY. This will cause the string to match the abort character sequence. The script will then fail because it found a match to the abort string. If it received the string NO CARRIER, it will abort for the same reason. Either string may be received. Either string will terminate the chat script.

TIMEOUT

The initial timeout value is 45 seconds. To change the timeout value for the next expect string, the following example may be used:

```
" " , "ATZ" ,
"OK" , "ATDT5551212" ,
"CONNECT" , "\\c" ,
"TIMEOUT" , "10" ,
"login:--login:" , "ppp" ,
"TIMEOUT" , "5" ,
"assword:" , "hello2u2" ,
0
```

This will change the timeout to 10 seconds when it expects the login: prompt. The timeout is then changed to 5 seconds when it looks for the password prompt.

The timeout, once changed, remains in effect until it is changed again.

Sending EOT

The special reply string of EOT indicates that the chat program should send an EOT character to the remote. This is normally the End-of-file character sequence. A return character is not sent following the EOT. The EOT sequence may be embedded into the send string using the sequence `"\x04"` (i.e. a Control-D character).

Escape Sequences

Most standard **chat** escape sequences can be replaced with standard C string escapes such as `'\r'`, `'\n'`, `'\t'` etc. Additional escape sequences may be embedded in the expect or reply strings by introducing them with *two* backslashes.

`\\c`

Suppresses the newline at the end of the reply string. This is the only method to send a string without a trailing return character. It must be at the end of the send string. For example, the sequence `"hello\\c"` will simply send the characters h, e, l, l, o. (not valid in expect strings.)

Chapter 48. PPP Enabled Device Drivers

For PPP to function fully over a serial device, its driver must implement certain features. At present not all eCos serial drivers implement these features. A driver indicates that it supports a certain feature by including an "implements" line in its CDL for the following interfaces:

CYGINT_IO_SERIAL_FLOW_CONTROL_HW

This interface indicates that the driver implements hardware flow control using the RTS and CTS lines. When data is being transferred over high speed data lines, it is essential that flow control be used to prevent buffer overrun.

The PPP subsystem functions best with hardware flow control. If this is not available, then it can be configured to use software flow control. Since software flow control is implemented by the device independent part of the serial device infrastructure, it is available for all serial devices. However, this will have an effect on the performance and reliability of the PPP link.

CYGINT_IO_SERIAL_LINE_STATUS_HW

This interface indicates that the driver implements a callback interface for indicating the status of various RS232 control lines. Of particular interest here is the ability to detect changes in the Carrier Detect (CD) line. Not all drivers that implement this interface can indicate CD status.

This functionality is only needed if it is important that the link be dropped immediately a telephone connection fails. Without it, a connection will only be dropped after it times out. This may be acceptable in many situations.

At the time of writing, the serial device drivers for the following platforms implement some or all of the required functionality:

- All drivers that use the generic 16x5x driver implement all functions:
 - ARM CerfPDA
 - ARM IQ80321
 - ARM PID
 - ARM IOP310
 - i386 PC
 - MIPS Atlas
 - MIPS Ref4955
 - SH3 SE77x9
- The following drivers implement flow control but either do not support line status callbacks, or do not report CD changes:
 - SH4 SCIF
 - A&M AdderI

- A&M AdderII
- All other drivers can support software flow control only.

Chapter 49. Testing

Test Programs

There are a number of test programs supplied with the PPP subsystem. By default all of these tests use the device configured by `CYGPKG_PPP_TEST_DEVICE` as the PPP link device.

`ppp_up`

This test just brings up the PPP link on `CYGPKG_PPP_TEST_DEVICE` and waits until the remote end brings it back down. No modem lines are used and the program expects a PPP connection to be waiting on the other end of the line. Typically the remote end will test the link using **ping** or access the HTTP system monitor if it is present.

If `CYGPKG_PPP_TESTS_AUTOMATE` is set, then this test attempts to bring PPP up at each of the baud rates specified in `CYGDAT_PPP_TEST_BAUD_RATES`. If it is not set then it will just bring the connection up at 115200 baud.

`ppp_updown`

This test brings the PPP link up on `CYGPKG_PPP_TEST_DEVICE` and attempts to **ping** the remote end of the link. Once the pings have finished, the link is then brought down.

If `CYGPKG_PPP_TESTS_AUTOMATE` is set, then this test attempts to bring PPP up at each of the baud rates specified in `CYGDAT_PPP_TEST_BAUD_RATES`. If it is not set then it will just bring the connection up at 115200 baud.

`chat`

This test does not bring the PPP link up but simply executes a chat script. It expects a server at the remote end of the link to supply the correct responses.

This program expects the **test_server.sh** script to be running on the remote end and attempts several different tests, expecting a variety of different responses for each.

`ppp_auth`

This test attempts to bring up the PPP link under a variety of different authentication conditions. This includes checking that both PAP and CHAP authentication work, and that the connection is rejected when the incorrect authentication protocol or secrets are used.

This test expects the **test_server.sh** script to be running on the remote end. For this test to work the `/etc/ppp/pap-secrets` file on the remote end should contain the following two lines:

```
eCos      *          secret      *
eCosPAP    *          secretPAP   *
```

The `/etc/ppp/chap-secrets` file should contain:

```
eCos      *          secret      *
```

```
eCosCHAP      *      secretCHAP      *

isp
```

This test expects the serial test device to be connected to a Hayes compatible modem. The test dials the telephone number given in `CYGPKG_PPP_DEFAULT_DIALUP_NUMBER` and attempts to log on to an ISP using the user name and password supplied in `CYGPKG_PPP_AUTH_DEFAULT_USER` and `CYGPKG_PPP_AUTH_DEFAULT_PASSWD`. Once the PPP connection has been made, the program then attempts to ping a number of well known addresses.

Since this test is designed to interact with an ISP, it does not run within the automated testing system.

```
tcp_echo
```

This is a version of the standard network **tcp_echo** test that brings up the PPP connection before waiting for the **tcp_sink** and **tcp_source** programs to connect. It is expected that at least one of these programs will connect via the PPP link. However, if another network interface is present, such as an ethernet device, then one may connect via that interface.

While this test is supported by the **test_server.sh** script, it runs for such a long time that it should not normally be used during automated testing.

```
nc_test_slave
```

This is a version of the standard network **nc_test_slave** test that brings up the PPP connection before waiting for the **nc_test_master** program to connect. It is expected that the master will connect via the PPP link.

While this test is supported by the **test_server.sh** script, it runs for such a long time that it should not normally be used during automated testing.

Test Script

The PPP package additionally contains a shell script (**test_server.sh**) that may be used to operate the remote end of a PPP test link.

The script may be invoked with the following arguments:

```
--dev=<devname>
```

This mandatory option gives the name of the device to be used for the PPP link. Typically `"/dev/ttyS0"` or `"/dev/ttyS1"`.

```
--myip=<ipaddress>
```

This mandatory option gives the IP address to be attached to this end of the PPP link.

```
--hisip=<ipaddress>
```

This mandatory option gives the IP address to be attached to the remote (test target) end of the PPP link.

`--baud=<baud_rate>`

This option gives the baud rate at which the PPP link is to be run. If absent then the link will run at the value set for `--redboot-baud`.

`--redboot`

If this option is present then the script will look for a "RedBoot>" prompt between test runs. This is necessary if the serial device being used for testing is also used by RedBoot.

`--redboot-baud=<baud_rate>`

This option gives the baud rate at which the search for the RedBoot prompt will be made. If absent then the link will run at 38400 baud.

`--debug`

If this option is present, then the script will print out some additional debug messages while it runs.

This script operates as follows: If the `--redboot` option is set it sets the device baud rate to the RedBoot baud rate and waits until a "RedBoot>" prompt is encountered. It then sets the baud rate to the value given by the `--baud` option and reads lines from the device until a recognizable test announce string is read. It then executes an appropriate set of commands to satisfy the test. This usually means bringing up the PPP link by running **pppd** and maybe executing various commands. It then either terminates the link itself, or waits for the target to terminate it. It then goes back to looking for another test announce string. If a string of the form "BAUD:XXX" is received then the baud rate is changed depending on the XXX value. If a "FINISH" string is received it returns to waiting for a "RedBoot>" prompt. The script repeats this process until it is terminated with a signal.

XVIII. Ethernet Device Drivers

Chapter 50. Generic Ethernet Device Driver

Generic Ethernet API

This section provides a simple description of how to write a low-level, hardware dependent ethernet driver.

There is a high-level driver (which is only code — with no state of its own) that is part of the stack. There will be one or more low-level drivers tied to the actual network hardware. Each of these drivers contains one or more driver instances. The intent is that the low-level drivers know nothing of the details of the stack that will be using them. Thus, the same driver can be used by the eCos supported TCP/IP stack, RedBoot, or any other, with no changes.

A driver instance is contained within a struct `eth_drv_sc`:

```
struct eth_hwr_funs {
    // Initialize hardware (including startup)
    void (*start)(struct eth_drv_sc *sc,
                  unsigned char *enaddr,
                  int flags);
    // Shut down hardware
    void (*stop)(struct eth_drv_sc *sc);
    // Device control (ioctl pass-thru)
    int (*control)(struct eth_drv_sc *sc,
                  unsigned long key,
                  void *data,
                  int data_length);
    // Query - can a packet be sent?
    int (*can_send)(struct eth_drv_sc *sc);
    // Send a packet of data
    void (*send)(struct eth_drv_sc *sc,
                 struct eth_drv_sg *sg_list,
                 int sg_len,
                 int total_len,
                 unsigned long key);
    // Receive [unload] a packet of data
    void (*recv)(struct eth_drv_sc *sc,
                 struct eth_drv_sg *sg_list,
                 int sg_len);
    // Deliver data to/from device from/to stack memory space
    // (moves lots of memcpy()s out of DSRs into thread)
    void (*deliver)(struct eth_drv_sc *sc);
    // Poll for interrupts/device service
    void (*poll)(struct eth_drv_sc *sc);
    // Get interrupt information from hardware driver
    int (*int_vector)(struct eth_drv_sc *sc);
    // Logical driver interface
    struct eth_drv_funs *eth_drv, *eth_drv_old;
};

struct eth_drv_sc {
    struct eth_hwr_funs *funs;
    void *driver_private;
    const char *dev_name;
    int state;
    struct arpcom sc_arpcom; /* ethernet common */
};
```

Note: If you have two instances of the same hardware, you only need one struct `eth_hwr_funs` shared between them.

There is another structure which is used to communicate with the rest of the stack:

```
struct eth_drv_funs {
    // Logical driver - initialization
    void (*init)(struct eth_drv_sc *sc,
                unsigned char *enaddr);
    // Logical driver - incoming packet notifier
    void (*recv)(struct eth_drv_sc *sc,
                int total_len);
    // Logical driver - outgoing packet notifier
    void (*tx_done)(struct eth_drv_sc *sc,
                   CYG_ADDRESS key,
                   int status);
};
```

Your driver does *not* create an instance of this structure. It is provided for driver code to use in the `eth_drv` member of the function record. Its usage is described below in [the Section called *Upper Layer Functions*](#)

One more function completes the API with which your driver communicates with the rest of the stack:

```
extern void eth_drv_dsr(cyg_vector_t vector,
                      cyg_ucount32 count,
                      cyg_addrword_t data);
```

This function is designed so that it can be registered as the DSR for your interrupt handler. It will awaken the “Network Delivery Thread” to call your deliver routine. See [the Section called *Deliver function*](#).

You create an instance of struct `eth_drv_sc` using the `ETH_DRV_SC()` macro which sets up the structure, including the prototypes for the functions, etc. By doing things this way, if the internal design of the ethernet drivers changes (e.g. we need to add a new low-level implementation function), existing drivers will no longer compile until updated. This is much better than to have all of the definitions in the low-level drivers themselves and have them be (quietly) broken if the interfaces change.

The “magic” which gets the drivers started (and indeed, linked) is similar to what is used for the I/O subsystem. This is done using the `NETDEVTAB_ENTRY()` macro, which defines an initialization function and the basic data structures for the low-level driver.

```
typedef struct cyg_netdevtab_entry {
    const char      *name;
    bool            (*init)(struct cyg_netdevtab_entry *tab);
    void            *device_instance;
    unsigned long    status;
} cyg_netdevtab_entry_t;
```

The `device_instance` entry here would point to the struct `eth_drv_sc` entry previously defined. This allows the network driver setup to work with any class of driver, not just ethernet drivers. In the future, there will surely be serial PPP drivers, etc. These will use the `NETDEVTAB_ENTRY()` setup to create the basic driver, but they will most likely be built on top of other high-level device driver layers.

To instantiate itself, and connect it to the system, a hardware driver will have a template (boilerplate) which looks something like this:

```
#include <cyg/infra/cyg_type.h>
#include <cyg/hal/hal_arch.h>
```

```

#include <cyg/infra/diag.h>
#include <cyg/hal/drv_api.h>
#include <cyg/io/eth/netdev.h>
#include <cyg/io/eth/eth_drv.h>

ETH_DRV_SC(DRV_sc,
           0, // No driver specific data needed
           "eth0", // Name for this interface
           HRDWR_start,
           HRDWR_stop,
           HRDWR_control,
           HRDWR_can_send,
           HRDWR_send,
           HRDWR_recv,
           HRDWR_deliver,
           HRDWR_poll,
           HRDWR_int_vector
);

NETDEVTAB_ENTRY(DRV_netdev,
                "DRV",
                DRV_HRDWR_init,
                &DRV_sc);

```

This, along with the referenced functions, completely define the driver.

Note: If one needed the same low-level driver to handle multiple similar hardware interfaces, you would need multiple invocations of the `ETH_DRV_SC()`/`NETDEVTAB_ENTRY()` macros. You would add a pointer to some instance specific data, e.g. containing base addresses, interrupt numbers, etc, where the

```
0, // No driver specific data
```

is currently.

Review of the functions

Now a brief review of the functions. This discussion will use generic names for the functions — your driver should use hardware-specific names to maintain uniqueness against any other drivers.

Init function

```
static bool DRV_HDWR_init(struct cyg_netdevtab_entry *tab)
```

This function is called as part of system initialization. Its primary function is to decide if the hardware (as indicated via `tab->device_instance`) is working and if the interface needs to be made available in the system. If this is the case, this function needs to finish with a call to the ethernet driver function:

```

struct eth_drv_sc *sc = (struct eth_drv_sc *)tab->device_instance;
....initialization code....
// Initialize upper level driver
(sc->funcs->eth_drv->init)( sc, unsigned char *enaddr );

```

where *enaddr* is a pointer to the ethernet station address for this unit, to inform the stack of this device's readiness and availability.

Note: The ethernet station address (ESA) is supposed to be a world-unique, 48 bit address for this particular ethernet interface. Typically it is provided by the board/hardware manufacturer in ROM.

In many packages it is possible for the ESA to be set from RedBoot, (perhaps from 'fconfig' data), hard-coded from CDL, or from an EPROM. A driver should choose a run-time specified ESA (e.g. from RedBoot) preferentially, otherwise (in order) it should use a CDL specified ESA if one has been set, otherwise an EPROM set ESA, or otherwise fail. See the `cl/cs8900a` ethernet driver for an example.

Start function

```
static void
HRDWR_start(struct eth_drv_sc *sc, unsigned char *enaddr, int flags)
```

This function is called, perhaps much later than system initialization time, when the system (an application) is ready for the interface to become active. The purpose of this function is to set up the hardware interface to start accepting packets from the network and be able to send packets out. The receiver hardware should not be enabled prior to this call.

Note: This function will be called whenever the up/down state of the logical interface changes, e.g. when the IP address changes, or when promiscuous mode is selected by means of an `ioctl()` call in the application. This may occur more than once, so this function needs to be prepared for that case.

Note: In future, the *flags* field (currently unused) may be used to tell the function how to start up, e.g. whether interrupts will be used, alternate means of selecting promiscuous mode etc.

Stop function

```
static void HRDWR_stop(struct eth_drv_sc *sc)
```

This function is the inverse of "start." It should shut down the hardware, disable the receiver, and keep it from interacting with the physical network.

Control function

```
static int
HRDWR_control(
    struct eth_drv_sc *sc, unsigned long key,
    void *data, int len)
```


This function is used to perform low-level “control” operations on the interface. These operations would typically be initiated via `ioctl()` calls in the BSD stack, and would be anything that might require the hardware setup to change (i.e. cannot be performed totally by the platform-independent layers).

The *key* parameter selects the operation, and the *data* and *len* params point describe, as required, some data for the operation in question.

Available Operations:

ETH_DRV_SET_MAC_ADDRESS

This operation sets the ethernet station address (ESA or MAC) for the device. Normally this address is kept in non-volatile memory and is unique in the world. This function must at least set the interface to use the new address. It may also update the NVM as appropriate.

ETH_DRV_GET_IF_STATS_UD

ETH_DRV_GET_IF_STATS

These acquire a set of statistical counters from the interface, and write the information into the memory pointed to by *data*. The “UD” variant explicitly instructs the driver to acquire up-to-date values. This is a separate option because doing so may take some time, depending on the hardware.

The definition of the data structure is in `cyg/io/eth/eth_drv_stats.h`.

This call is typically made by SNMP.

ETH_DRV_SET_MC_LIST

This entry instructs the device to set up multicast packet filtering to receive only packets addressed to the multicast ESAs in the list pointed to by *data*.

The format of the data is a 32-bit count of the ESAs in the list, followed by packed bytes which are the ESAs themselves, thus:

```
#define ETH_DRV_MAX_MC 8
struct eth_drv_mc_list {
    int len;
    unsigned char addr[ETH_DRV_MAX_MC][ETHER_ADDR_LEN];
};
```

ETH_DRV_SET_MC_ALL

This entry instructs the device to receive all multicast packets, and delete any explicit filtering which had been set up.

This function should return zero if the specified operation was completed successfully. It should return non-zero if the operation could not be performed, for any reason.

Can-send function

```
static int HRDWR_can_send(struct eth_drv_sc *sc)
```

This function is called to determine if it is possible to start the transmission of a packet on the interface. Some interfaces will allow multiple packets to be "queued" and this function allows for the highest possible utilization of that mode.

Return the number of packets which could be accepted at this time, zero implies that the interface is saturated/busy.

Send function

```
struct eth_drv_sg {
    CYG_ADDRESS  buf;
    CYG_ADDRWORD len;
};

static void
HRDWR_send(
    struct eth_drv_sc *sc,
    struct eth_drv_sg *sg_list, int sg_len,
    int total_len, unsigned long key)
```

This function is used to send a packet of data to the network. It is the responsibility of this function to somehow hand the data over to the hardware interface. This will most likely require copying, but just the address/length values could be used by smart hardware.

Note: All data in/out of the driver is specified via a "scatter-gather" list. This is just an array of address/length pairs which describe sections of data to move (in the order given by the array), as in the struct eth_drv_sg defined above and pointed to by *sg_list*.

Once the data has been successfully sent by the interface (or if an error occurs), the driver should call `(sc->funcs->eth_drv->tx_done)()` (see [the Section called *Callback Tx-Done function*](#)) using the specified *key*. Only then will the upper layers release the resources for that packet and start another transmission.

Note: In future, this function may be extended so that the data need not be copied by having the function return a "disposition" code (done, send pending, etc). At this point, you should move the data to some "safe" location before returning.

Deliver function

```
static void
HRDWR_deliver(struct eth_drv_sc *sc)
```

This function is called from the "Network Delivery Thread" in order to let the device driver do the time-consuming work associated with receiving a packet — usually copying the entire packet from the hardware or a special memory location into the network stack's memory.

After handling any outstanding incoming packets or pending transmission status, it can unmask the device's interrupts, and free any relevant resources so it can process further packets.

It will be called when the interrupt handler for the network device has called

```
eth_drv_dsr( vector, count, (cyg_addrword_t)sc );
```

to alert the system that “something requires attention.” This `eth_drv_dsr()` call must occur from within the interrupt handler’s DSR (not the ISR) or actually *be* the DSR, whenever it is determined that the device needs attention from the foreground. The third parameter (*data* in the prototype of `eth_drv_dsr()`) *must* be a valid struct `eth_drv_sc` pointer `sc`.

The reason for this slightly convoluted train of events is to keep the DSR (and ISR) execution time as short as possible, so that other activities of higher priority than network servicing are not denied the CPU by network traffic.

To deliver a newly-received packet into the network stack, the deliver routine must call

```
(sc->funcs->eth_drv->recv)(sc, len);
```

which will in turn call the receive function, which we talk about next. See also [the Section called *Callback Receive function*](#) below.

Receive function

```
static void
HRDWR_recv(
    struct eth_drv_sc *sc,
    struct eth_drv_sg *sg_list, int sg_len)
```

This function is a call back, only invoked after the upper-level function

```
(sc->funcs->eth_drv->recv)(struct eth_drv_sc *sc, int total_len)
```

has been called itself from your deliver function when it knows that a packet of data is available on the interface. The `(sc->funcs->eth_drv->recv)()` function then arranges network buffers and structures for the data and then calls `HRDWR_recv()` to actually move the data from the interface.

A scatter-gather list (struct `eth_drv_sg`) is used once more, just like in the send case.

Poll function

```
static void
HRDWR_poll(struct eth_drv_sc *sc)
```

This function is used when in a non-interrupt driven system, e.g. when interrupts are completely disabled. This allows the driver time to check whether anything needs doing either for transmission, or to check if anything has been received, or if any other processing needs doing.

It is perfectly correct and acceptable for the poll function to look like this:

```
static void
HRDWR_poll(struct eth_drv_sc *sc)
{
    my_interrupt_ISR(sc);
    HRDWR_deliver(struct eth_drv_sc *sc);
}
```

provided that both the ISR and the deliver functions are idempotent and harmless if called when there is no attention needed by the hardware. Some devices might not need a call to the ISR here if the deliver function contains all the “intelligence.”

Interrupt-vector function

```
static int
HRDWR_int_vector(struct eth_drv_sc *sc)
```

This function returns the interrupt vector number used for receive interrupts. This is so that the common GDB stubs can detect when to check for incoming “CTRL-C” packets (used to asynchronously halt the application) when debugging over ethernet. The GDB stubs need to know which interrupt the ethernet device uses so that they can mask or unmask that interrupt as required.

Upper Layer Functions

Upper layer functions are called by drivers to deliver received packets or transmission completion status back up into the network stack.

These functions are defined by the hardware independent upper layers of the networking driver support. They are present to hide the interfaces to the actual networking stack so that the hardware drivers may be used by different network stack implementations without change.

These functions require a pointer to a struct `eth_drv_sc` which describes the interface at a logical level. It is assumed that the low level hardware driver will keep track of this pointer so it may be passed “up” as appropriate.

Callback Init function

```
void (sc->funcs->eth_drv->init)(
    struct eth_drv_sc *sc, unsigned char *enaddr)
```

This function establishes the device at initialization time. It should be called once per device instance only, from the initialization function, if all is well (see [the Section called *Init function*](#)). The hardware should be totally initialized (*not* “started”) when this function is called.

Callback Tx-Done function

```
void (sc->funcs->eth_drv->tx_done)(
    struct eth_drv_sc *sc,
    unsigned long key, int status)
```

This function is called when a packet completes transmission on the interface. The *key* value must be one of the keys provided to `HRDWR_send()` above. The value *status* should be non-zero (details currently undefined) to indicate that an error occurred during the transmission, and zero if all was well.

It should be called from the deliver function (see [the Section called *Deliver function*](#)) or poll function (see [the Section called *Poll function*](#)).

Callback Receive function

```
void (sc->funcs->eth_drv->recv)(struct eth_drv_sc *sc, int len)
```

This function is called to indicate that a packet of length *len* has arrived at the interface. The callback *HRDWR_recv()* function described above will be used to actually unload the data from the interface into buffers used by the device independent layers.

It should be called from the deliver function (see [the Section called *Deliver function*](#)) or poll function (see [the Section called *Poll function*](#)).

Calling graph for Transmission and Reception

It may be worth clarifying further the flow of control in the transmit and receive cases, where the hardware driver does use interrupts and so DSRs to tell the “foreground” when something asynchronous has occurred.

Transmission

1. Some foreground task such as the application, SNMP “daemon”, DHCP management thread or whatever, calls into network stack to send a packet, or the stack decides to send a packet in response to incoming traffic such as a “ping” or ARP request.
2. The driver calls the *HRDWR_can_send()* function in the hardware driver.
3. *HRDWR_can_send()* returns the number of available “slots” in which it can store a pending transmit packet. If it cannot send at this time, the packet is queued outside the hardware driver for later; in this case, the hardware is already busy transmitting, so expect an interrupt as described below for completion of the packet currently outgoing.
4. If it can send right now, *HRDWR_send()* is called. *HRDWR_send()* copies the data into special hardware buffers, or instructs the hardware to “send that.” It also remembers the key that is associated with this tx request.
5. These calls return ... time passes ...
6. Asynchronously, the hardware makes an interrupt to say “transmit is done.” The ISR quiets the interrupt source in the hardware and requests that the associated DSR be run.
7. The DSR calls (or *is*) the *eth_drv_dsr()* function in the generic driver.
8. *eth_drv_dsr()* in the generic driver awakens the “Network Delivery Thread” which calls the deliver function *HRDWR_deliver()* in the driver.
9. The deliver function realizes that a transmit request has completed, and calls the callback tx-done function *(sc->funcs->eth_drv->tx_done)()* with the same key that it remembered for this tx.
10. The callback tx-done function uses the key to find the resources associated with this transmit request; thus the stack knows that the transmit has completed and its resources can be freed.
11. The callback tx-done function also enquires whether *HRDWR_can_send()* now says “yes, we can send” and if so, dequeues a further transmit request which may have been queued as described above. If so, then *HRDWR_send()* copies the data into the hardware buffers, or instructs the hardware to “send that” and remembers the new key, as above. These calls then all return to the “Network Delivery Thread” which then sleeps, awaiting the next asynchronous event.

12. All done . . .

Receive

1. Asynchronously, the hardware makes an interrupt to say “there is ready data in a receive buffer.” The ISR quietyens the interrupt source in the hardware and requests that the associated DSR be run.
2. The DSR calls (or *is*) the `eth_drv_dsr()` function in the generic driver.
3. `eth_drv_dsr()` in the generic driver awakens the “Network Delivery Thread” which calls the deliver function `HRDWR_deliver()` in the driver.
4. The deliver function realizes that there is data ready and calls the callback receive function `(sc->funs->eth_drv->recv)()` to tell it how many bytes to prepare for.
5. The callback receive function allocates memory within the stack (eg. MBUFs in BSD/Unix style stacks) and prepares a set of scatter-gather buffers that can accommodate the packet.
6. It then calls back into the hardware driver routine `HRDWR_rcv()`. `HRDWR_rcv()` must copy the data from the hardware’s buffers into the scatter-gather buffers provided, and return.
7. The network stack now has the data in-hand, and does with it what it will. This might include recursive calls to transmit a response packet. When this all is done, these calls return, and the “Network Delivery Thread” sleeps once more, awaiting the next asynchronous event.

XIX. Ethernet PHY Device Support

Chapter 51. Ethernet PHY Device Support

Ethernet PHY Device API

Modern ethernet subsystems are often separated into two pieces, the media access controller (sometimes known as a MAC) and the physical device or line interface (often referred to as a PHY). In this case, the MAC handles generating and parsing physical frames and the PHY handles how this data is actually moved to/from the wire. The MAC and PHY communicate via a special protocol, known as MII. This MII protocol can handle control over the PHY which allows for selection of such transmission criteria as line speed, duplex mode, etc.

In most cases, ethernet drivers only need to bother with the PHY during system initialization. Since the details of the PHY are separate from the MAC, there are different drivers for each. The drivers for the PHY are described by a set of exported functions which are commonly used by the MAC. The primary use of these functions currently is to initialize the PHY and determine the status of the line connection.

The connection between the MAC and the PHY differs from MAC to MAC, so the actual routines to manipulate this data channel are a property of the MAC instance. Furthermore, there are many PHY devices each with their own internal operations. A complete MAC/PHY driver setup will be comprised of the MAC MII access functions and the PHY internal driver.

A driver instance is contained within a `eth_phy_access_t`:

```
#define PHY_BIT_LEVEL_ACCESS_TYPE 0
#define PHY_REG_LEVEL_ACCESS_TYPE 1

typedef struct {
    int ops_type; // 0 => bit level, 1 => register level
    bool init_done;
    void (*init)(void);
    void (*reset)(void);
    union {
        struct {
            void (*set_data)(int);
            int (*get_data)(void);
            void (*set_clock)(int);
            void (*set_dir)(int);
        } bit_level_ops;
        struct {
            void (*put_reg)(int reg, int unit, unsigned short data);
            bool (*get_reg)(int reg, int unit, unsigned short *data);
        } reg_level_ops;
    } ops;
    int phy_addr;
    struct _eth_phy_dev_entry *dev; // Chip access functions
} eth_phy_access_t;

struct _eth_phy_dev_entry {
    char *name;
    unsigned long id;
    bool (*stat)(eth_phy_access_t *f, int *stat);
};
```

The `dev` element points to the PHY specific support functions. Currently, the only function which must be defined is `stat()`.

The MAC-MII-PHY interface is a narrow connection, with commands and status moving between the MAC and PHY using a bit-serial protocol. Some MAC devices contain the intelligence to run this protocol, exposing

a mechanism to access PHY registers one at a time. Other MAC devices may only provide access to the MII data lines (or even still, this may be considered completely separate from the MAC). In these cases, the PHY support layer must handle the serial protocol. The choice between the access methods is in the `ops_type` field. If it has the value `PHY_BIT_LEVEL_ACCESS_TYPE`, then the PHY device layer will run the protocol, using the access functions `set_data()`, `get_data()`, `set_clock()`, `set_dir()` are used to control the MII signals and run the protocol. If `ops_type` has the value `PHY_REG_LEVEL_ACCESS_TYPE`, then the routines `put_reg()`, and `get_reg()` are used to access the PHY registers.

Two additional functions may be defined. These are `init()`, and `reset()`. The purpose of these functions is for gross-level management of the MII interface. The `init()` function will be called once, at system initialization time. It should do whatever operations are necessary to prepare the MII channel. In the case of `PHY_BIT_LEVEL_ACCESS_TYPE` devices, `init()` should prepare the signals for use, i.e. set up the appropriate parallel port registers, etc. The `reset()` function may be called by a driver to cause the PHY device to be reset to a known state. Not all drivers will require this and this function may not even be possible, so it's use and behavior is somewhat target specific.

Currently, the only function required of device specific drivers is `stat()`. This routine should query appropriate registers in the PHY and return a status bitmap indicating the state of the physical connection. In the case where the PHY can auto-negotiate a line speed and condition, this information may be useful to the MAC to indicate what speed it should provide data, etc. The status bitmask contains these bits:

```
#define ETH_PHY_STAT_LINK    0x0001    // Link up/down
#define ETH_PHY_STAT_100MB  0x0002    // Connection is 100Mb/10Mb
#define ETH_PHY_STAT_FDX    0x0004    // Connection is full/half duplex
```

Note: the usage here is that if the bit is set, then the condition exists. For example, if the `ETH_PHY_STAT_LINK` is set, then a physical link has been established.

XX. SNMP

Chapter 52. SNMP for eCos

Version

This is a port of UCD-SNMP-4.1.2

Originally this document said: See <http://ucd-snmp.ucdavis.edu/> for details. And send them a postcard.

The project has since been renamed “net-snmp” and re-homed at <http://net-snmp.sourceforge.net/> (<http://net-snmp.sourceforge.net/>) where various new releases (of the original, not *eCos* ports) are available.

The original source base from which we worked to create the *eCos* port is available from various archive sites such as <ftp://ftp.freesnmp.com/mirrors/net-snmp/> (<ftp://ftp.freesnmp.com/mirrors/net-snmp/>) generally with this filename and details:

```
ucd-snmp-4.1.2.tar.gz. . . . . Nov 2 2000 1164k (ftp://ftp.freesnmp.com/mirrors/net-snmp/ucd-
```

SNMP packages in the eCos source repository

The SNMP/eCos package consists of two eCos packages; the SNMP library and the SNMP agent.

The sources are arranged this way partly for consistency with the original release from UCD, and so as to accommodate possible future use of the SNMP library without having an agent present. That could be used to build an eCos-based SNMP client application.

The library contains support code for talking SNMP over the net - the SNMP protocol itself - and a MIB file parser (ASN-1) which is not used in the agent case.

The agent contains the application specific handler files to get information about the system into the SNMP world, together with the SNMP agent thread (`snmpd` in UNIX terms).

MIBs supported

The standard set in MIB-II, together with the Ether-Like MIB, are supported by default. The MIB files used to compile the handlers in the agent and to “drive” the testing (**snmpwalk** *et al* under LINUX) are those acquired from that same UCD distribution.

These are the supported MIBs; all are below `mib2 == 1.3.6.1.2.1`:

```
system      { mib2 1 }
interfaces  { mib2 2 }
            [ address-translation "at" { mib2 3 } is deprecated ]
ip          { mib2 4 }
icmp        { mib2 5 }
tcp         { mib2 6 }
udp         { mib2 7 }
            [ exterior gateway protocol "egp" { mib2 8 } not supported ]
            [ cmot { mib2 9 } is "historic", just a placeholder ]
dot3        { mib2 10 7 } == { transmission 7 } "EtherLike MIB"
snmp        { mib2 11 }
```

On inclusion of SNMPv3 support packages, the following MIBs are added to the default set of MIBs enumerated above :

```
snmpEngine      { snmpFrameworkMIBObjects 1 }  SNMP-FRAMEWORK-MIB, as described in
                                                    RFC-2571 for support of SNMPv3
                                                    framework.

usmStats        {          usmMIBObjects 1 }  SNMP-USER-BASED-SM-MIB, as
usmUser         {          usmMIBObjects 2 }  specified in RFC-2574 for support
                                                    of user based security model in
                                                    SNMPv3 management domains.
```

Note: Not every MIB variable is necessarily supported - some don't really apply to eCos, some are simply not yet implemented, and some would be overly complex to implement to be worth it in an embedded system. Similarly writing to some variables may be permitted by the MIB definition, but may not produce any effect. For example trying to set an interface administratively up or down with IF-MIB::ifAdminStatus at present has no effect.

Changes to eCos sources

Small changes have been made in three areas:

1. Various hardware-specific ethernet drivers.
2. The generic ethernet device driver.
3. The OpenBSD TCP/IP networking package.

These changes were made in order to export information about the driver and the network that the SNMP agent must report. The changes were trivial in the case of the network stack, since it was already SNMP-friendly. The generic ethernet device driver was re-organized to have an extensive header file and to add a couple of APIs to extract statistics that the hardware-specific device drivers keep within themselves.

There may be a performance hit for recording that data; disabling a config option named something like `CYGDBG_DEVS_ETH_XXXX_XXXX_KEEP_STATISTICS` depending on the specific device driver will prevent that.

Not all platform ethernet device drivers export complete SNMP statistical information; if the exported information is missing, SNMP will report zero values for such data (in the dot3 MIB).

The interface chipset has an ID which is an OID; not all the latest greatest devices are listed in the available database, so new chipsets may need to be added to the client MIB, if not defined in those from UCD.

Starting the SNMP Agent

A routine to instantiate and start the SNMP agent thread in the default configuration is provided in `PACKAGES/net/snmp/agent/VERSION/src/snmptask.c`

It starts the `snmpd` thread at priority `CYGPKG_NET_THREAD_PRIORITY+1` by default, ie. one step less important than the TCP/IP stack service thread. It also statically creates and uses a very large stack of around 100 KiloBytes. To use that convenience function, this code fragment may be copied (in plain C).

```
#ifdef CYGPKG_SNMPAGENT
{
```

```
extern void cyg_net_snmp_init(void);
cyg_net_snmp_init();

}
#endif
```

In case you need to perform initialization, for example setting up SNMPv3 security features, when the snmp agent starts and every time it restarts, you can register a callback function by simply writing the global variable:

```
externC void (*snmpd_reinit_function)( void );
```

with a suitable function pointer.

The entry point to the SNMP agent is

```
externC void snmpd( void (*initfunc)( void ) );
```

so you can of course easily start it in a thread of your choice at another priority instead if required, after performing whatever other initialization your SNMP MIBs need. A larger than default stacksize is required. The `initfunc` parameter is the callback function mentioned above — a NULL parameter there is safe and obviously means no callback is registered.

Note that if you call `snmpd()` yourself and do *not* call `cyg_net_snmp_init()` then that routine, global variable, and the default large stack will not be used. This is the recommended way control such features from your application; create and start the thread yourself at the appropriate moment.

Other APIs from the `snmpd` module are available, specifically:

```
void SnmpdShutDown(int a);
```

which causes the `snmpd` to restart itself — including the callback to your `init` function — as soon as possible.

The parameter `a` is ignored. It is there because in `snmpd`'s “natural environment” this routine is a UNIX signal handler.

The helper functions in the network stack for managing DHCP leases will call `SnmpdShutDown()` when necessary, for example if network interfaces go down and/or come up again.

Configuring eCos

To use the SNMP agent, the SNMP library and agent packages must be included in your configuration. To incorporate the stack into your configuration select the SNMP library and SNMP agent packages in the eCos Configuration Tool, or at the command line type:

```
$ ecosconfig add snmplib snmpagent
```

After adding the networking, common ethernet device drivers, snmp library and snmp agent packages, there is no configuration required. However there are a number of configuration options that can be set such as some details for the System MIB, and disabling SNMPv3 support (see below).

Starting the SNMP agent is not integrated into network tests other than `snmping` below, nor is it started automatically in normal eCos startup - it is up to the application to start the agent when it is ready, at least after the network interfaces are both ‘up’.

Version usage (v1, v2 or v3)

The default build supports all three versions of the SNMP protocol, but without any dispatcher functionality (rfc 2571, section 3.1.1.2). This has the following implications :

1. There is no community authentication for v1 and v2c.
2. Security provided by v3 can be bypassed by using v1/v2c protocol.

To provide the dispatcher with rfc 2571 type functionality, it is required to set up security models and access profiles. This can be provided in the normal Unix style by writing the required configurations in `snmpd.conf` file. Application code may setup profiles in `snmpd.conf` and optionally set the environment variable `SNMPCONFPATH` to point to the file if it is not in the usual location. The whole concept works in the usual way as with the standard UCD-SNMP distribution.

Traps

The support of the `trapsink` command in the [snmpd.conf](#) file is not tested and there may be problems for it working as expected. Moreover, in systems that do not have filesystem support, there is no way to configure a trap-session in the conventional way.

For reasons mentioned above, applications need to initialize their own trap sessions and pass it the details of trap-sink. The following is a small sample for initializing a v1 trap session :

```
typedef struct trap {
    unsigned char ip [4];
    unsigned int  port;
    unsigned char community [256];
}

trap          trapsink;
unsigned char  sink [16];

...
...

if (trapsink.ip != 0) {
    sprintf (sink, "%d.%d.%d.%d",
             trapsink[0], trapsink[1], trapsink[2], trapsink[3]);
    if (create_trap_session (sink,
                             trapsink.port,
                             (char *)trapsink.community,
                             SNMP_VERSION_1,
                             SNMP_MSG_TRAP) == 0) {
        log_error ("Creation of trap session failed \n");
    }
}
```

snmpd.conf file

Using `snmpd.conf` requires the inclusion of one of the file-system packages (eg. `CYGPKG_RAMFS`) and `CYGPKG_FILEIO`. With these two packages included, the SNMP sub-system will read the `snmpd.conf` file from the location specified in `SNMPCONFPATH`, or the standard builtin locations, and use these profiles. Only the profiles specified in the `ACCESS-CONTROL` section of [snmpd.conf](#) file have been tested and shown to work. Other profiles which have been implemented in UCD-SNMP-4.1.2's `snmpd.conf` may not work because the sole purpose of adding support for the `snmpd.conf` file has been to set up `ACCESS-CONTROL` models.

At startup, the SNMP module tries to look for file `snmp.conf`. If this file is not available, the module successively looks for files `snmpd.conf`, `snmp.local.conf` and `snmpd.local.conf` at the locations pointed to by `SNMPCONFPATH` environment variable. In case `SNMPCONFPATH` is not defined, the search sequence is carried out in default directories. The default directories are `:/usr/share/snmp`, `/usr/local/share/snmp` and `$(HOME)/.snmp`. The configurations read from these files are used to control both, SNMP applications and the SNMP agent; in the usual UNIX fashion.

The inclusion of `snmpd.conf` support is enabled by default when suitable filesystems and `FILEIO` packages are active.

Test cases

Currently only one test program is provided which uses SNMP.

"snmpping" in the SNMP agent package runs the ping test from the TCPIP package, with the `snmpd` running also. This allows you to interrogate it using host tools of your choice. It supports MIBs as documented above, so eg. **snmpwalk** <hostname> **public dot3** under Linux/UNIX should have the desired effect.

For serious testing, you should increase the length of time the test runs by setting `CYGNUM_SNMPAGENT_TESTS_ITERATIONS` to something big (e.g., 999999). Build the test (**make -C net/snmp/agent/current tests**) and run it on the target.

Then start several jobs, some for pinging the board (to make the stats change) and some for interrogating the `snmpd`. Set `$IP` to whatever IP address the board has:

```
# in a root shell, for flood ping
while(1)
date
ping -f -c 3001 $IP
sleep 5
ping -c 32 -s 2345 $IP
end

# have more than one of these going at once
setenv MIBS all
while (1)
snmpwalk -OS $IP public
date
end
```

Leave to run for a couple of days or so to test stability.

The test program can also test `snmpd.conf` support. It tries to build a minimal `snmpd.conf` file on a RAM filesystem and passes it to the `snmp` sub-system. With this profile on target, the following `snmp[cmd]` (`cmd=walk, get, set`) should work :

```
snmp[cmd] -v1 $IP crux $OID
snmp[cmd] -v2 $IP crux $OID
snmp[cmd] -v3 $IP -u root -L noAuthNoPriv $OID
snmp[cmd] -v3 $IP -u root -L authNoPriv -A MD5 -a md5passwd $OID
```

The following commands would however fail since they violate the access model :

```
snmp[cmd] $IP public $OID
snmp[cmd] -v1 $IP public $OID
snmp[cmd] -v2c $IP public $OID
snmp[cmd] -v3 $IP -u no_user -L noAuthNoPriv $OID
```

```
snmp[cmd] -v3 $IP -u root -L authNoPriv -A MD5 -a badpasswd $OID
```

SNMP clients and package use

SNMP clients may use these packages, but this usage is currently untested: the reason why this port to eCos exists is to acquire the SNMP agent. The fact that the SNMP API (for clients) exists is a side-effect. See the standard man page `SNMP_API(3)` for details. There are further caveats below about client-side use of the SNMP library.

All of the SNMP header files are installed beneath `.../include/ucd-snmp` in the install tree. The SNMP code itself assumes that directory is on its include path, so we recommend that client code does the same. Further, like the TCP/IP stack, compiling SNMP code requires definition of `_KERNEL` and `__ECOS`, and additionally `IN_UCD_SNMP_SOURCE`.

Therefore, add all of these to your compile lines if you wish to include SNMP header files:

```
-D_KERNEL  
-D__ECOS  
-DIN_UCD_SNMP_SOURCE=1  
-I$(PREFIX)/include/ucd-snmp
```

Unimplemented features

Currently, the filesystem and persistent storage areas are left undone, to be implemented by the application.

The SNMP library package is intended to support client and agent code alike. It therefore contains lots of assumptions about the presence of persistent storage ie. a filesystem. Currently, by default, eCos has no such thing, so those areas have been simply commented out and made to return empty lists or say “no data here.”

Specifically the following files have omitted/unimplemented code :

```
PACKAGES/net/snmp/lib/VERSION/src/parse.c
```

contains code to enumerate MIB files discovered in the system MIB directories (“`/usr/share/snmp/mibs`”), and read them all in, building data structures that are used by client programs to interrogate an agent. This is not required in an agent, so the routine which enumerates the directories returns an empty list.

```
PACKAGES/net/snmp/lib/VERSION/src/read_config.c
```

 contains two systems:

The first tries to read the configuration file as described in the [snmpd.conf file](#) section and the second system contains code to record persistent data as files in a directory (typically `/var/ucd-snmp`) thus preserving the state permanently.

The first part is partially implemented to support multiple profiles and enables dispatcher functionality as discussed in [the Section called Version usage \(v1, v2 or v3\)](#). The second part is not supported at all in the default implementation. As required, a cleaner interface to permit application code to manage persistent data will be developed in consultation with customers.

MIB Compiler

In the directory `/snmp/agent/VERSION/utis/mib2c`, there are the following files:

```
README-eCos          notes about running with a nonstandard
```

	perl path.
README.mib2c	the README from UCD; full instructions on using mib2c
mib2c	the perl program
mib2c.conf	a configuration file altered to include the eCos/UCD
mib2c.conf-ORIG	copyright and better #include paths; and the ORIGinal.
mib2c.storage.conf	other config files, not modified.
mib2c.vartypes.conf	

mib2c is provided BUT it requires the SNMP perl package SNMP-3.1.0, and that in turn requires perl nsPerl5.005_03 (part of Red Hat Linux from 6.0, April 1999).

These are available from the CPAN (“the Comprehensive Perl Archive Network”) as usual; <http://www.cpan.org/> and links from there. Specifically:

- PERL itself: <http://people.netscape.com/kristian/nsPerl/>
- http://people.netscape.com/richm/nsPerl/nsPerl5.005_03-11-i686-linux.tar.gz
- SNMP.pl <http://www.cpan.org/modules/01modules.index.html>
- http://cpan.valueclick.com/modules/by-category/05_Networking_Devices_IPC/SNMP/
- <http://www.cpan.org/authors/id/G/GS/GSM/SNMP.tar.gz>

(note that the .tar.gz files are not browsable)

For documentation on the files produced, see the documentation available at <http://ucd-snmp.ucdavis.edu/> in general, and file `AGENT.txt` in particular.

It is likely that the output of mib2c will be further customized depending on eCos customer needs; it’s easy to do this by editing the mib2c.conf file to add or remove whatever you need with the resulting C sources.

The UCD autoconf-style configuration does not apply to eCos. So if you add a completely new MIB to the agent, and support it using mib2c so that the `my_new_mib.c` file contains a `init_my_new_mib()` routine to register the MIB handler, you will also need to edit a couple of control files; these claim to be auto-generated, but in the eCos release, they’re not, don’t worry.

```
PACKAGES/net/snmp/agent/VERSION/include/mib_module_includes.h
```

contains a number of lines like

```
#include "mibgroup/mibII/interfaces.h"
```

so add your new MIB thus:

```
#include "mibgroup/mibII/my_new_mib.h"
```

```
PACKAGES/net/snmp/agent/VERSION/include/mib_module_inits.h
```

contains a number of lines like

```
init_interfaces();
init_dot3();
```

and so on; add your new MIB as follows:

```
init_my_new_mib();
```

and this should work correctly.

snmpd.conf

SNMPD.CONF(5)

SNMPD.CONF(5)

NAME

share/snmp/snmpd.conf - configuration file for the ucd-snmp SNMP agent.

DESCRIPTION

snmpd.conf is the configuration file which defines how the ucd-snmp SNMP agent operates. These files may contain any of the directives found in the DIRECTIVES section below. This file is not required for the agent to operate and report mib entries.

PLEASE READ FIRST

First, make sure you have read the snmp_config(5) manual page that describes how the ucd-snmp configuration files operate, where they are located and how they all work together.

EXTENSIBLE-MIB

The ucd-snmp SNMP agent reports much of its information through queries to the 1.3.6.1.4.1.2021 section of the mib tree. Every mib in this section has the following table entries in it.

.1 -- index

This is the table's index numbers for each of the DIRECTIVES listed below.

.2 -- name

The name of the given table entry. This should be unique, but is not required to be.

.100 -- errorFlag

This is a flag returning either the integer value 1 or 0 if an error is detected for this table entry.

.101 -- errorMsg

This is a DISPLAY-STRING describing any error triggering the errorFlag above.

.102 -- errorFix

If this entry is SNMPset to the integer value of 1 AND the errorFlag defined above is indeed a 1, a program or script will get executed with the table entry name from above as the argument. The program to be executed is configured in the config.h file at compile time.

Directives

proc NAME

proc NAME MAX

proc NAME MAX MIN

Checks to see if the NAME'd processes are running

on the agent's machine. An error flag (1) and a description message are then passed to the 1.3.6.1.4.1.2021.2.100 and 1.3.6.1.4.1.2021.2.101 mib tables (respectively) if the NAME'd program is not found in the process table as reported by "/bin/ps -e".

If MAX and MIN are not specified, MAX is assumed to be infinity and MIN is assumed to be 1.

If MAX is specified but MIN is not specified, MIN is assumed to be 0.

`procfix NAME PROG ARGS`

This registers a command that knows how to fix errors with the given process NAME. When 1.3.6.1.4.1.2021.2.102 for a given NAMED program is set to the integer value of 1, this command will be called. It defaults to a compiled value set using the PROCFIXCMD definition in the config.h file.

`exec NAME PROG ARGS`

`exec MIBNUM NAME PROG ARGS`

If MIBNUM is not specified, the agent executes the named PROG with arguments of ARGS and returns the exit status and the first line of the STDOUT output of the PROG program to queries of the 1.3.6.1.4.1.2021.8.100 and 1.3.6.1.4.1.2021.8.101 mib tables (respectively). All STDOUT output beyond the first line is silently truncated.

If MIBNUM is specified, it acts as above but returns the exit status to MIBNUM.100.0 and the entire STDOUT output to the table MIBNUM.101 in a mib table. In this case, the MIBNUM.101 mib contains the entire STDOUT output, one mib table entry per line of output (ie, the first line is output as MIBNUM.101.1, the second at MIBNUM.101.2, etc...).

Note: The MIBNUM must be specified in dotted-integer notation and can not be specified as ".iso.org.dod.internet..." (should instead be

Note: The agent caches the exit status and STDOUT of the executed program for 30 seconds after the initial query. This is to increase speed and maintain consistency of information for consecutive table queries. The cache can be flushed by a `snmp-set` request of `integer(1)` to 1.3.6.1.4.1.2021.100.VER-CLEARCACHE.

`execfix NAME PROG ARGS`

This registers a command that knows how to fix errors with the given exec or sh NAME. When 1.3.6.1.4.1.2021.8.102 for a given NAMED entry is set to the integer value of 1, this command will be called. It defaults to a compiled value set using

the EXECFIXCMD definition in the config.h file.

disk PATH

disk PATH [MINSIZE | MINPERCENT%]

Checks the named disks mounted at PATH for available disk space. If the disk space is less than MINSIZE (kB) if specified or less than MINPERCENT (%) if a % sign is specified, or DEFDISKMINIMUMSPACE (kB) if not specified, the associated entry in the 1.3.6.1.4.1.2021.9.100 mib table will be set to (1) and a descriptive error message will be returned to queries of 1.3.6.1.4.1.2021.9.101.

load MAX1

load MAX1 MAX5

load MAX1 MAX5 MAX15

Checks the load average of the machine and returns an error flag (1), and a text-string error message to queries of 1.3.6.1.4.1.2021.10.100 and 1.3.6.1.4.1.2021.10.101 (respectively) when the 1-minute, 5-minute, or 15-minute averages exceed the associated maximum values. If any of the MAX1, MAX5, or MAX15 values are unspecified, they default to a value of DEFMAXLOADAVE.

file FILE [MAXSIZE]

Monitors file sizes and makes sure they don't grow beyond a certain size. MAXSIZE defaults to infinite if not specified, and only monitors the size without reporting errors about it.

Errors

Any errors in obtaining the above information are reported via the 1.3.6.1.4.1.2021.101.100 flag and the 1.3.6.1.4.1.2021.101.101 text-string description.

SMUX SUB-AGENTS

To enable and SMUX based sub-agent, such as gated, use the smuxpeer configuration entry

smuxpeer OID PASS

For gated a sensible entry might be

.1.3.6.1.4.1.4.1.3 secret

ACCESS CONTROL

snmpd supports the View-Based Access Control Model (vacm) as defined in RFC 2275. To this end, it recognizes the following keywords in the configuration file: com2sec, group, access, and view as well as some easier-to-use wrapper directives: rocommunity, rwcommunity, rouser, rwuser.

rocommunity COMMUNITY [SOURCE] [OID]

rwcommunity COMMUNITY [SOURCE] [OID]

These create read-only and read-write communities that can be used to access the agent. They are a quick method of using the following com2sec, group, access, and view directive lines. They are not as efficient either, as groups aren't created so the tables are possibly larger. In other words: don't use these if you have complex situations to set up.

The format of the SOURCE is token is described in the com2sec directive section below. The OID token restricts access for that community to everything below that given OID.

```
rouser USER [noauth|auth|priv] [OID]
```

```
rwuser USER [noauth|auth|priv] [OID]
```

Creates a SNMPv3 USM user in the VACM access configuration tables. Again, its more efficient (and powerful) to use the combined com2sec, group, access, and view directives instead.

The minimum level of authentication and privacy the user must use is specified by the first token (which defaults to "auth"). The OID parameter restricts access for that user to everything below the given OID.

```
com2sec NAME SOURCE COMMUNITY
```

This directive specifies the mapping from a source/community pair to a security name. SOURCE can be a hostname, a subnet, or the word "default". A subnet can be specified as IP/MASK or IP/BITS. The first source/community combination that matches the incoming packet is selected.

```
group NAME MODEL SECURITY
```

This directive defines the mapping from security-model/securityname to group. MODEL is one of v1, v2c, or usm.

```
access NAME CONTEXT MODEL LEVEL PREFIX READ WRITE NOTIFY
```

The access directive maps from group/security model/security level to a view. MODEL is one of any, v1, v2c, or usm. LEVEL is one of noauth, auth, or priv. PREFIX specifies how CONTEXT should be matched against the context of the incoming pdu, either exact or prefix. READ, WRITE and NOTIFY specifies the view to be used for the corresponding access. For v1 or v2c access, LEVEL will be noauth, and CONTEXT will be empty.

```
view NAME TYPE SUBTREE [MASK]
```

The defines the named view. TYPE is either included or excluded. MASK is a list of hex octets, separated by '.' or ':'. The MASK defaults to "ff" if not specified.

The reason for the mask is, that it allows you to control access to one row in a table, in a relatively simple way. As an example, as an ISP you might consider giving each customer access to his

or her own interface:

```
view cust1 included interfaces.ifTable.ifEntry.ifIndex.1 ff.a0
view cust2 included interfaces.ifTable.ifEntry.ifIndex.2 ff.a0

(interfaces.ifTable.ifEntry.ifIndex.1 == .1.3.6.1.2.1.2.2.1.1.1,
ff.a0 == 11111111.10100000. which nicely covers up and including
the row index, but lets the user vary the field of the row)
```

VACM Examples:

```
#      sec.name  source      community
com2sec local    localhost  private
com2sec mynet    10.10.10.0/24 public
com2sec public   default   public

#      sec.model  sec.name
group mygroup v1    mynet
group mygroup v2c   mynet
group mygroup usm   mynet
group local v1      local
group local v2c     local
group local usm     local
group public v1     public
group public v2c    public
group public usm    public

#      incl/excl subtree      mask
view all    included .1      80
view system included system   fe
view mib2   included .iso.org.dod.internet.mgmt.mib-2 fc

#      context sec.model sec.level prefix read  write notify
access mygroup ""      any      noauth  exact  mib2  none  none
access public  ""      any      noauth  exact  system none  none
access local   ""      any      noauth  exact  all   all   all
```

Default VACM model

The default configuration of the agent, as shipped, is functionally equivalent to the following entries:

```
com2sec public default public
group public v1 public
group public v2c public
group public usm public
view all included .1
access public "" any noauth exact all none none
```

SNMPv3 CONFIGURATION

engineID STRING

The `snmpd` agent needs to be configured with an `engineID` to be able to respond to SNMPv3 messages. With this configuration file line, the `engineID` will be configured from `STRING`. The default value of the `engineID` is configured with the first IP address found for the hostname of the machine.

```
createUser username (MD5|SHA) authpassphrase [DES] [priv-
passphrase]
```

This directive should be placed into the `"/var/ucd-snmp"/snmpd.conf` file instead of the other normal locations. The reason is that the information is read from the file and then the line is removed

(eliminating the storage of the master password for that user) and replaced with the key that is derived from it. This key is a localized key, so that if it is stolen it can not be used to access other agents. If the password is stolen, however, it can be.

MD5 and SHA are the authentication types to use, but you must have built the package with openssl installed in order to use SHA. The only privacy protocol currently supported is DES. If the privacy passphrase is not specified, it is assumed to be the same as the authentication passphrase. Note that the users created will be useless unless they are also added to the VACM access control tables described above.

Warning: the minimum pass phrase length is 8 characters.

SNMPv3 users can be created at runtime using the `snmpusm` command.

SETTING SYSTEM INFORMATION

`syslocation` STRING

`syscontact` STRING

Sets the system location and the system contact for the agent. This information is reported by the 'system' table in the mibII tree.

`authtrapenable` NUMBER

Setting `authtrapenable` to 1 enables generation of authentication failure traps. The default value is 2 (disable).

`trapcommunity` STRING

This defines the default community string to be used when sending traps. Note that this command must be used prior to any of the following three commands that are intended use this community string.

`trapsink` HOST [COMMUNITY [PORT]]

`trap2sink` HOST [COMMUNITY [PORT]]

`informsink` HOST [COMMUNITY [PORT]]

These commands define the hosts to receive traps (and/or inform notifications). The daemon sends a Cold Start trap when it starts up. If enabled, it also sends traps on authentication failures. Multiple `trapsink`, `trap2sink` and `informsink` lines may be specified to specify multiple destinations. Use `trap2sink` to send SNMPv2 traps and `informsink` to send inform notifications. If COMMUNITY is not specified, the string from a preceding `trapcommunity` directive will be used. If PORT is not specified, the well known SNMP trap port (162) will be

used.

PASS-THROUGH CONTROL

pass MIBOID EXEC

Passes entire control of MIBOID to the EXEC program. The EXEC program is called in one of the following three ways:

EXEC -g MIBOID

EXEC -n MIBOID

These call lines match to SNMP get and get-next requests. It is expected that the EXEC program will take the arguments passed to it and return the appropriate response through its stdout.

The first line of stdout should be the mib OID of the returning value. The second line should be the TYPE of value returned, where TYPE is one of the text strings: string, integer, unsigned, objectid, timeticks, ipaddress, counter, or gauge. The third line of stdout should be the VALUE corresponding with the returned TYPE.

For instance, if a script was to return the value integer value "42" when a request for .1.3.6.1.4.100 was requested, the script should return the following 3 lines:

```
.1.3.6.1.4.100
integer
42
```

To indicate that the script is unable to comply with the request due to an end-of-mib condition or an invalid request, simply exit and return no output to stdout at all. A snmp error will be generated corresponding to the SNMP NO-SUCH-NAME response.

EXEC -s MIBOID TYPE VALUE

For SNMP set requests, the above call method is used. The TYPE passed to the EXEC program is one of the text strings: integer, counter, gauge, timeticks, ipaddress, objid, or string, indicating the type of value passed in the next argument.

Return nothing to stdout, and the set will be assumed to have been successful. Otherwise, return one of the following error strings to signal an error: not-writable, or wrong-type and the appropriate error response will be generated instead.

Note: By default, the only community allowed to write (ie snmpset) to your script will be the "private"

community, or community #2 if defined differently by the "community" token discussed above. Which communities are allowed write access are controlled by the RWRITE definition in the `snmplib/snmp_impl.h` source file.

EXAMPLE

See the `EXAMPLE.CONF` file in the top level source directory for a more detailed example of how the above information is used in real examples.

RE-READING `snmpd.conf` and `snmpd.local.conf`

The `ucd-snmp` agent can be forced to re-read its configuration files. It can be told to do so by one of two ways:

1. An `snmpset` of `integer(1)` to `1.3.6.1.4.1.2021.100.VERUPDATECONFIG`.
2. A "kill -HUP" signal sent to the `snmpd` agent process.

FILES

`share/snmp/snmpd.conf`

SEE ALSO

`snmp_config(5)`, `snmpd(1)`, `EXAMPLE.conf`, `read_config(3)`.

27 Jan 2000

SNMPD.CONF(5)

XXI. Embedded HTTP Server

Chapter 53. Embedded HTTP Server

Introduction

The *eCos* HTTPD package provides a simple HTTP server for use with applications in eCos. This server is specifically aimed at the remote control and monitoring requirements of embedded applications. For this reason the emphasis is on dynamically generated content, simple forms handling and a basic CGI interface. It is *not* intended to be a general purpose server for delivering arbitrary web content. For these purposes a port of the GoAhead web server is available from www.goahead.com (<http://www.goahead.com>).

This server is also capable of serving content using IPv6 when the eCos configuration contains IPv6.

Server Organization

The server consists of one or more threads running in parallel to any application threads and which serve web pages to clients. Apart from defining content, the application does not need to do anything to start the HTTP server.

The HTTP server is, by default, started by a static constructor. This simply creates an initial thread and sets it running. Since this is called before the scheduler is started, nothing will happen until the application calls `cyg_scheduler_start()`. The server thread can also be started explicitly by the application, see the `CYGNUM_HTTPD_SERVER_AUTO_START` option for details.

When the thread gets to run it first optionally delays for some period of time. This is to allow the application to perform any initialization free of any interference from the HTTP server. When the thread does finally run it creates a socket, binds it to the HTTP server port, and puts it into listen mode. It will then create any additional HTTPD server threads that have been configured before becoming a server thread itself.

Each HTTPD server thread simply waits for a connection to be made to the server port. When the connection is made it reads the HTTP request and extracts the filename being accessed. If the request also contains form data, this is also preserved. The filename is then looked up in a table.

Each table entry contains a filename pattern string, a pointer to a handler function, and a user defined argument for the function. Table entries are defined using the same link-time table building mechanism used to generate device tables. This is all handled by the `CYG_HTTPD_TABLE_ENTRY()` macro which has the following format:

```
#include <cyg/httpd/httpd.h>

CYG_HTTPD_TABLE_ENTRY( __name, __pattern, __handler, __arg )
```

The `__name` argument is a variable name for the table entry since C does not allow us to define anonymous data structures. This name should be chosen so that it is unique and does not pollute the name space. The `__pattern` argument is the match pattern. The `__handler` argument is a pointer to the handler function and `__arg` the user defined value.

The link-time table building means that several different pieces of code can define server table entries, and so long as the patterns do not clash they can be totally oblivious of each other. However, note also that this mechanism does not guarantee the order in which entries appear, this depends on the order of object files in the link, which could vary from one build to the next. So any tricky pattern matching that relies on this may not always work.

A request filename matches an entry in the table if either it exactly matches the pattern string, or if the pattern ends in an asterisk, and it matches everything up to that point. So for example the pattern

"/monitor/threads.html" will only match that exact filename, but the pattern "/monitor/thread-*" will match "/monitor/thread-0040.html", "/monitor/thread-0100.html" and any other filename starting with "/monitor/thread-".

When a pattern is matched, the handler function is called. It has the following prototype:

```
cyg_bool cyg_httpd_handler(FILE *client,
                           char *filename,
                           char *formdata,
                           void *arg);
```

The *client* argument is the TCP connection to the client: anything output through this stream will be returned to the browser. The *filename* argument is the filename from the HTTP request and the *formdata* argument is any form response data, or NULL if none was sent. The *arg* argument is the user defined value from the table entry.

The handler is entirely responsible for generating the response to the client, both HTTP header and content. If the handler decides that it does not want to generate a response it can return `false`, in which case the table scan is resumed for another match. If no match is found, or no handler returns true, then a default response page is generated indicating that the requested page cannot be found.

Finally, the server thread closes the connection to the client and loops back to accept a new connection.

Server Configuration

The HTTP server has a number of configuration options:

CYGNUM_HTTPD_SERVER_PORT

This option defines the TCP port that the server will listen on. It defaults to the standard HTTP port number 80. It may be changed to a different number if, for example, another HTTP server is using the main HTTP port.

CYGDAT_HTTPD_SERVER_ID

This is the string that is reported to the client in the "Server:" field of the HTTP header.

CYGNUM_HTTPD_THREAD_COUNT

The HTTP server can be configured to use more than one thread to service HTTP requests. If you expect to serve complex pages with many images or other components that are fetched separately, or if any pages may take a long time to send, then it may be useful to increase the number of server threads. For most uses, however, the connection queuing in the TCP/IP stack and the speed with which each page is generated, means that a single thread is usually adequate.

CYGNUM_HTTPD_THREAD_PRIORITY

The HTTP server threads can be run at any priority. The exact priority depends on the importance of the server relative to the rest of the system. The default is to put them in the middle of the priority range to provide reasonable response without impacting genuine high priority threads.

CYGNUM_HTTPD_THREAD_STACK_SIZE

This is the amount of stack to be allocated for each of the HTTPD threads. The actual stack size allocated will be this value plus the values of `CYGNUM_HAL_STACK_SIZE_MINIMUM` and `CYGNUM_HTTPD_SERVER_BUFFER_SIZE`.

CYGNUM_HTTPD_SERVER_BUFFER_SIZE

This defines the size of the buffer used to receive the first line of each HTTP request. If you expect to use particularly long URLs or have very complex forms, this should be increased.

CYGNUM_HTTPD_SERVER_AUTO_START

This option causes the HTTP Daemon to be started automatically during system initialization. If this option is not set then the application must start the daemon explicitly by calling `cyg_httpd_startup()`. This option is set by default.

CYGNUM_HTTPD_SERVER_DELAY

This defines the number of system clock ticks that the HTTP server will wait before initializing itself and spawning any extra server threads. This is to give the application a chance to initialize properly without any interference from the HTTPD.

Support Functions and Macros

The emphasis of this server is on dynamically generated content, rather than fetching it from a filesystem. To do this the handler functions make calls to `fprintf()` and `fputs()`. Such handler functions would end up a mass of print calls, with the actual structure of the HTML page hidden in the format strings and arguments, making maintenance and debugging very difficult. Such an approach would also result in the definition of many, often only slightly different, format strings, leading to unnecessary bloat.

In an effort to expose the structure of the HTML in the structure of the C code, and to maximize the sharing of string constants, the `cyg/httpd/httpd.h` header file defines a set of helper functions and macros. Most of these are wrappers for predefined print calls on the *client* stream passed to the handler function. For examples of their use, see the System Monitor example.

Note: All arguments to macros are pointers to strings, unless otherwise stated. In general, wherever a function or macro has an *attr* or *__attr* parameter, then the contents of this string will be inserted into the tag being defined as HTML attributes. If it is a NULL or empty string it will be ignored.

HTTP Support

```
void cyg_http_start( FILE *client, char *content_type, int content_length );
void cyg_http_finish( FILE *client );
#define html_begin(__client)
#define html_end( __client )
```

The function `cyg_http_start()` generates a simple HTTP response header containing the value of `CYGDAT_HTTPD_SERVER_ID` in the "Server" field, and the values of `content_type` and `content_length` in the "Content-type" and "Content-length" field respectively. The function `cyg_http_finish()` just adds an extra newline to the end of the output and then flushes it to force the data out to the client.

The macro `html_begin()` generates an HTTP header with a "text/html" content type followed by an opening "<html>" tag. `html_end()` generates a closing "</html>" tag and calls `cyg_http_finish()`.

General HTML Support

```
void cyg_html_tag_begin( FILE *client, char *tag, char *attr );
void cyg_html_tag_end( FILE *client, char *tag );
#define html_tag_begin( __client, __tag, __attr )
#define html_tag_end( __client, __tag )
#define html_head( __client, __title, __meta )
#define html_body_begin( __client, __attr )
#define html_body_end( __client )
#define html_heading( __client, __level, __heading )
#define html_para_begin( __client, __attr )
#define html_url( __client, __text, __link )
#define html_image( __client, __source, __alt, __attr )
```

The function `cyg_html_tag_begin()` generates an opening tag with the given name. The function `cyg_html_tag_end()` generates a closing tag with the given name. The macros `html_tag_begin()` and `html_tag_end` are just wrappers for these functions.

The macro `html_head()` generates an HTML header section with `__title` as the title. The `__meta` argument defines any meta tags that will be inserted into the header. `html_body_begin()` and `html_body_end` generate HTML body begin and end tags.

`html_heading()` generates a complete HTML header where `__level` is a numerical level, between 1 and 6, and `__heading` is the heading text. `html_para_begin()` generates a paragraph break.

`html_url()` inserts a URL where `__text` is the displayed text and `__link` is the URL of the linked page. `html_image()` inserts an image tag where `__source` is the URL of the image to be included and `__alt` is the alternative text for when the image is not displayed.

Table Support

```
#define html_table_begin( __client, __attr )
#define html_table_end( __client )
#define html_table_header( __client, __content, __attr )
#define html_table_row_begin( __client, __attr )
#define html_table_row_end( __client )
#define html_table_data_begin( __client, __attr )
#define html_table_data_end( __client )
```

`html_table_begin()` starts a table and `html_table_end()` end it. `html_table_header()` generates a simple table column header containing the string `__content`.

`html_table_row_begin()` and `html_table_row_end()` begin and end a table row, and similarly `html_table_data_begin()` and `html_table_data_end()` begin and end a table entry.

Forms Support

```
#define html_form_begin( __client, __url, __attr )
#define html_form_end( __client )
#define html_form_input( __client, __type, __name, __value, __attr )
#define html_form_input_radio( __client, __name, __value, __checked )
#define html_form_input_checkbox( __client, __name, __value, __checked )
#define html_form_input_hidden( __client, __name, __value )
#define html_form_select_begin( __client, __name, __attr )
#define html_form_option( __client, __value, __label, __selected )
#define html_form_select_end( __client )
void cyg_formdata_parse( char *data, char *list[], int size );
char *cyg_formlist_find( char *list[], char *name );
```

`html_form_begin()` begins a form, the `__url` argument is the value for the action attribute. `html_form_end()` ends the form.

`html_form_input()` defines a general form input element with the given type, name and value. `html_form_input_radio` creates a radio button with the given name and value; the `__checked` argument is a boolean expression that is used to determine whether the checked attribute is added to the tag. Similarly `html_form_input_checkbox()` defines a checkbox element. `html_form_input_hidden()` defines a hidden form element with the given name and value.

`html_form_select_begin()` begins a multiple choice menu with the given name. `html_form_select_end()` end it. `html_form_option()` defines a menu entry with the given value and label; the `__selected` argument is a boolean expression controlling whether the selected attribute is added to the tag.

`cyg_formdata_parse()` converts a form response string into an NULL-terminated array of "name=value" entries. The `data` argument is the string as passed to the handler function; note that this string is not copied and will be updated in place to form the list entries. `list` is a pointer to an array of character pointers, and is `size` elements long. `cyg_formlist_find()` searches a list generated by `cyg_formdata_parse()` and returns a pointer to the value part of the string whose name part matches `name`; if there is no match it will return NULL.

Predefined Handlers

```
cyg_bool cyg_httpd_send_html( FILE *client, char *filename, char *request, void *arg );
```

```
typedef struct
{
    char          *content_type;
    cyg_uint32    content_length;
    cyg_uint8     *data;
} cyg_httpd_data;
#define CYG_HTTPD_DATA( __name, __type, __length, __data )
```

```
cyg_bool cyg_httpd_send_data( FILE *client, char *filename, char *request, void *arg );
```

The HTTP server defines a couple of predefined handlers to make it easier to deliver simple, static content.

`cyg_httpd_send_html()` takes a NULL-terminated string as the argument and sends it to the client with an HTTP header indicating that it is HTML. The following is an example of its use:

```
char cyg_html_message[] = "<head><title>Welcome</title></head>\n"
                          "<body><h2>Welcome to my Web Page</h2></body>\n"
```

```
CYG_HTTPD_TABLE_ENTRY( cyg_html_message_entry,
```

```
    "/message.html",  
    cyg_httpd_send_html,  
    cyg_html_message );
```

`cyg_httpd_send_data()` Sends arbitrary data to the client. The argument is a pointer to a `cyg_httpd_data` structure that defines the content type and length of the data, and a pointer to the data itself. The `CYG_HTTPD_DATA()` macro automates the definition of the structure. Here is a typical example of its use:

```
static cyg_uint8 ecos_logo_gif[] = {  
    ...  
};  
  
CYG_HTTPD_DATA( cyg_monitor_ecos_logo_data,  
    "image/gif",  
    sizeof(ecos_logo_gif),  
    ecos_logo_gif );  
  
CYG_HTTPD_TABLE_ENTRY( cyg_monitor_ecos_logo,  
    "/monitor/ecos.gif",  
    cyg_httpd_send_data,  
    &cyg_monitor_ecos_logo_data );
```

System Monitor

Included in the HTTPD package is a simple System Monitor that is intended to act as a test and an example of how to produce servers. It is also hoped that it might be of some use in and of itself.

The System Monitor is intended to work in the background of any application. Adding the network stack and the HTTPD package to any configuration will enable the monitor by default. It may be disabled by disabling the `CYGPKG_HTTPD_MONITOR` option.

The monitor is intended to be simple and self-explanatory in use. It consists of four main pages. The thread monitor page presents a table of all current threads showing such things as id, state, priority, name and stack dimensions. Clicking on the thread ID will link to a thread edit page where the thread's state and priority may be manipulated. The interrupt monitor just shows a table of the current interrupts and indicates which are active. The memory monitor shows a 256 byte page of memory, with controls to change the base address and display element size. Note: Accessing invalid memory locations can cause memory exceptions and the program to crash. The network monitor page shows information extracted from the active network interfaces and protocols. Finally, if kernel instrumentation is enabled, the instrumentation page provides some controls over the instrumentation mechanism, and displays the instrumentation buffer.

XXII. FTP Client for eCos TCP/IP Stack

The ftpclient package provides an FTP (File Transfer Protocol) client for use with the TCP/IP stack in eCos. It supports both IPv4 and IPv6 and will use the DNS client, when its is part of the eCos configuration.

Chapter 54. FTP Client Features

FTP Client API

This package implements an FTP client. The API is in include file `install/include/ftpclient.h` and it can be used thus:

```
#include <network.h>
#include <ftpclient.h>
```

It looks like this:

ftp_get

```
int ftp_get(char * hostname,
            char * username,
            char * passwd,
            char * filename,
            char * buf,
            unsigned buf_size,
            ftp_printf_t ftp_printf);
```

Use the FTP protocol to retrieve a file from a server. Only binary mode is supported. The filename can include a directory name. Only use unix style `'/'` file separators, not `'\'`. The file is placed into *buf*. *buf* has maximum size *buf_size*. If the file is bigger than this, the transfer fails and `FTP_TOOBIG` is returned. Other error codes listed in the header can also be returned. If the transfer is successful the number of bytes received is returned.

ftp_put

```
int ftp_put(char * hostname,
            char * username,
            char * passwd,
            char * filename,
            char * buf,
            unsigned buf_size,
            ftp_printf_t ftp_printf);
```

Use the FTP protocol to send a file to a server. Only binary mode is supported. The filename can include a directory name. Only use unix style `'/'` file separators, not `'\'`. The contents of *buf* are placed into the file on the server. If an error occurs one of the codes listed will be returned. If the transfer is successful zero is returned.

ftpclient_printf

```
void ftpclient_printf(unsigned error, const char *fmt, ...);
```

`ftp_get()` and `ftp_put` take a pointer to a function to use for printing out diagnostic and error messages. This is a sample implementation which can be used if you don't want to implement the function yourself.

error will be true when the message to print is an error message. Otherwise the message is diagnostic, eg. the commands sent and received from the server.

XXIII. Simple Network Time Protocol Client

The SNTP package provides implementation of a client for RFC 2030, the Simple Network Time Protocol (SNTP). The client listens for broadcasts or IPv6 multicasts from an NTP server and uses the information received to set the system's time of day clock. This will be either the POSIX `CLOCK_REALTIME` clock or the wallclock device, or both, depending on the configuration. It can also be configured to send SNTP time requests to specific NTP servers using SNTP's unicast mode.

Chapter 55. The SNTP Client

Starting the SNTP client

The sntp client is implemented as a thread which listens for NTP broadcasts and IPv6 multicasts, and optionally sends SNTP unicast requests to specific NTP servers. This thread may be automatically started by the system if it receives a list of (S)NTP servers from the DHCP server and unicast mode is enabled. Otherwise it must be started by the user application. The header file `cyg/sntp/sntp.h` declares the function to be called. The thread is then started by calling the function:

```
void cyg_sntp_start(void);
```

It is safe to call this function multiple times. Once started, the thread will run forever.

What it does

The SNTP client listens for NTP IPv4 broadcasts from any NTP servers, or IPv6 multicasts using the address `fe0x:0X::101`, where X can be 2 (Link Local), 5 (Site-Local) or 0xe (Global). Such packets contain a timestamp indicating the current time. The packet also contains information about where the server is in the hierarchy of time servers. A server at the root of the time server tree normally has an atomic clock. Such a server is said to be at stratum 0. A time server which is synchronised to a stratum 0 server is said to be at stratum 1 etc. The client will accept any NTP packets from servers using version 3 or 4 of the protocol. When receiving packets from multiple servers, it will use the packets from the server with the lowest stratum. However, if there are no packets from this server for 10 minutes and another server is sending packets, the client will change servers.

If SNTP unicast mode is enabled via the `CYGPKG_NET_SNTP_UNICAST` option, the SNTP client can additionally be configured with a list of specific NTP servers to query. The general algorithm is as follows: if the system clock has not yet been set via an NTP time update, then the client will send out NTP requests every 30 seconds to all configured NTP servers. Once an NTP time update has been received, the client will send out additional NTP requests every 30 minutes in order to update the system clock. These requests are resent every 30 seconds until a response is received.

The system clock in eCos is accurate to 1 second. The SNTP client will change the system clock when the time difference with the received timestamp is greater than 2 seconds. The change is made as a step.

Configuring the unicast list of NTP servers

If SNTP unicast mode is enabled via the `CYGPKG_NET_SNTP_UNICAST` option, the SNTP client can be configured with a list of NTP servers to contact for time updates.

By default, this list is configured with NTP server information received from DHCP. The number of NTP servers that are extracted from DHCP can be configured with the `CYGOPT_NET_SNTP_UNICAST_MAXDHCP` option. This option can also be used to disable DHCP usage entirely.

The list of NTP servers can be manually configured with the following API function. Note that manual configuration will override any servers that were automatically configured by DHCP. But later reconfigurations by DHCP will override manual configurations. Hence it is not recommended to manually configure servers when `CYGOPT_NET_SNTP_UNICAST` is enabled.

```
#include <cyg/sntp/sntp.h>

void cyg_sntp_set_servers(struct sockaddr *server_list, cyg_uint32 num_servers);
```

This function takes an array of `sockaddr` structures specifying the IP address and UDP port of each NTP server to query. Currently, both IPv4 and IPv6 `sockaddr` structures are supported. The `num_servers` argument specifies how many `sockaddr`'s are contained in the array. The `server_list` array must be maintained by the caller. Once the array is registered with this function, it must not be modified by the caller until it is replaced or unregistered by another call to this function.

Calling this function with a `server_list` of `NULL` and a `num_servers` value of 0 unregisters any previously configured `server_list` array.

Finally, note that if this function is called with a non-empty server list, it will implicitly start the SNTP client if it has not already been started (i.e. it will call `cyg_sntp_start()`).

Warning: timestamp wrap around

The timestamp in the NTP packet is a 32bit integer which represents the number of seconds after 00:00 01/01/1970. This 32bit number will wrap around at 06:28:16 Feb 7 2036. At this point in time, the eCos time will jump back to around 00:00:00 Jan 1 1970 when the next NTP packet is received.

YOU HAVE BEEN WARNED!

The SNTP test program

The SNTP package contains a simple test program. Testing an SNTP client is not easy, so the test program should be considered as more a proof of concept. It shows that an NTP packet has been received, and is accurate to within a few days.

The test program starts the network interfaces using the standard call. It then starts the SNTP thread. A loop is then entered printing the current system time every second for two minutes. When the client receives an NTP packet the time will jump from 1970 to hopefully the present day. Once the two minutes have expired, two simple tests are made. If the time is still less than 5 minutes since 00:00:00 01/01/1970 the test fails. This indicates no NTP messages have been received. Check that the server is actually sending packet, using the correct port (123), correct IPv6 multicast address, and at a sufficiently frequent rate that the target has a chance to receive a message within the 2 minute interval. If all this is correct, assume the target is broken.

The second test is that the current system time is compared with the build time as reported by the CPP macro `__DATE__`. If the build date is in the future relative to the system time, the test fails. If the build date is more than 90 days in the past relative to the system time the test also fails. If such failures are seen, use wallclock time to verify the time printed during the test. If this seems correct check the build date for the test. This is printed at startup. If all else fails check that the computer used to build the test has the correct time.

If SNTP unicast mode is enabled, the above tests are run twice. The first time, the SNTP client is configured with NTP server addresses from DHCP. The second time, unicast mode is disabled and only multicasts are listened for. Note that the unicast test is partially bogus in the sense that any multicast packet received will also make the unicast test pass. To reduce the chance of this happening the test will wait for a shorter time for replies. This is not ideal, but it is the best that can be done with an automated test.

XXIV. Another Tiny HTTP Server for eCos

This package provides an extensible, small footprint, full featured HTTP server for eCos. Many of these features can be disabled via the configuration tool, thus reducing the footprint of the server. The server has been written for the FreeBSD network stack.

Chapter 56. The ATHTTP Server

Features

This ATHTTP implementation provides the following features:

- GET, POST and HEAD Methods
- File system Access
- Callbacks to C functions
- MIME type support
- CGI mechanism through the OBJLOADER package or through a simple tcl interpreter
- Basic and Digest (MD5) Authentication
- Directory Listing
- Extendable Internal Resources

Ecos tables are used extensively through the server to provide a high degree of customization.

Starting the server

In order to start the web server, the user needs to call the function:

```
cyg_httpd_start();
```

in the application code. The server initialization code spawns a new thread which calls **init_all_network_interfaces()** to initialize the TCP/IP stack and then starts the daemon. The function is safe to call multiple times.

MIME types

The server has an internal table with all the recognized mime types. Each time a file or an internal resource is sent out by the server, its extension is searched in this table and if a match is found, the associated MIME type is then sent out in the header. The server already provides entries for the following standard file extensions: 'html', 'htm', 'gif', 'jpg', 'css', 'js', 'png' and the user is responsible for adding any further entry. The syntax for adding an entry is the following:

```
CYG_HTTPD_MIME_TABLE_ENTRY(entry_label, extension_string, mime_tipe_sting);
```

```
entry_label      : an identifier unique to this entry
extension_string : a string containing the extension for this entry
type_string      : the mime string. The strings for many more mime types
                  is included in a file in the "doc" directory.
```

The following is an example of how to add the Adobe Portable Document Format **pdf** MIME type to the table:

```
CYG_HTTPD_MIME_TABLE_ENTRY(hal_pdf_entry, "pdf", "application/pdf");
```

MIME Types for Chunked Frames

For chunked frames, which are generally used inside C language callbacks, there is no file name to match an extension to, and thus the extension to be used must be passed in the `cyg_httpd_start_chunked()` call. The server will then scan the MIME table to find a MIME type to match the extension. For example, to start a chunked transfer of an **html** file, the following call is used:

```
cyg_httpd_start_chunked("html");
```

In any event, it is the responsibility of the user to make sure that a match to all used extensions is found in the table search. Failing this, the default MIME type specified in the `CYGDAT_NET_ATHTTPD_DEFAULT_MIME_TYPE` string is returned.

C language callback functions

The server allows the association of particular URLs to C language callback functions. eCos tables are used to define the association between a URL and its corresponding callback. The syntax of the macro to add callback entries to the table is:

```
CYG_HTTPD_HANDLER_TABLE_ENTRY(entry_label, url_string, callback);
```

entry_label	: an identifier unique to this entry.
url_string	: a string with the extension url that will be appended to the default directory.
callback	: a function with a prototype: <code>cyg_int32 callback_function(CYG_HTTPD_STATE*);</code> Return value is ignored - just return 0.

CYG_HTTPD_STATE* is a pointer to a structure that contains, among others, a buffer (outbuffer) that can be used to send data out. The definitions of the structure is in `http.h`.

The following is an example of how to add a callback to a function `myForm()` whenever the URL `/myform.cgi` is requested:

```
CYG_HTTPD_HANDLER_TABLE_ENTRY(hal_cb_entry, "/myform.cgi", myForm);
```

and somewhere in the source tree there is a function:

```
cyg_int32 myForm(CYG_HTTPD_STATE* p)
{
    cyg_httpd_start_chunked("html");
    strcpy(p->outbuffer, "eCos Web Server");
    cyg_httpd_write_chunked(p->outbuffer, strlen(p->outbuffer))
    cyg_httpd_end_chunked();
}
```


This function also shows the correct method of using the chunked frames API inside a c language callback and also shows the use of outbuffer to collect data to send out.

Chunked frames are useful when the size of the frame is not known upfront. In this case it possible to send a response in chunks of various sizes, and terminate it with a null chunk (See RFC 2616 for details). To use chunked frames, the **cyg_httpd_start_chunked()** function is used. The prototype is the following:

```
ssize_t cyg_httpd_start_chunked(char *);
```

The only parameter is the **extension** to use in the search for the MIME type. For most files this will be "html" or "htm" and it will be searched in the MIME table for an appropriate MIME type that will be sent along in the header. The function returns the number of bytes sent out.

The chunked frame must be terminated by a call to **cyg_httpd_end_chunked()**:

```
void cyg_httpd_end_chunked()(void);
```

In between these two calls, the user can call the function **cyg_httpd_write_chunked()** to send out data any number of times. It is important that **cyg_httpd_write_chunked()** be the only function used to send data out for chunked frames. This guarantees that proper formatting of the response is respected. The prototype for the function is:

```
ssize_t cyg_httpd_write_chunked(char* p, int len);
```

The 'char*' points to the data to send out, the 'int' is the length of the data to send.

In the case in which the size of the data is known upfront, the callback can instead create the header with a call to **cyg_httpd_create_std_header()** with the following prototype:

```
void cyg_httpd_create_std_header(char *ext, int len);
```

```
extension    : the extension used in the search of the MIME type
len          : length of the data to send out
```

and use **cyg_httpd_write()** to send data out to the client. The prototype of **cyg_httpd_write()** is the same as **cyg_httpd_write_chunked()**

CGI

The web server allows writing of pseudo-CGI programs. This is helpful in order to modify the functionality of the server without having to recompile it and reflash it.

One way to implement CGI is, of course, the C language callback mechanism described above: This assumes, of course, that all the callbacks are written by compile time and cannot be modified later on. Another way to perform the same functionality is the use of a library in the form of an object file. These object files reside in the file system and are loaded, executed and unloaded on demand.

Yet a third way is the use of a scripting language. Since full fledged implementation of the most popular scripting languages such as Python or Perl are too large for most embedded systems, a slim down implementation of tcl was chosen for this server. Most of the tcl functionality is still there, and makes writing cgi a lot easier.

In order to limit the footprint of the operating system support for both the objloader and the tcl script for dealing with cgi files can be independently selected out. Tcl support in particular increases the memory requirements considerably.

CGI via objloader

In order to use the cgi mechanism the CYGPKG_OBJLOADER must be included when building the operating system. This will enable the proper option in the configuration tool and if selected, the necessary code will be compiled in the eCos kernel. The user will then have to compile the necessary libraries and place them in the file system under a directory defined by CYGDAT_NET_ATHTTPD_SERVEROPT_CGIDIR. When a request is made, the web server checks if the root directory of the requested URL is inside the CYGDAT_NET_ATHTTPD_SERVEROPT_CGIDIR directory. If so, the server assumes that the user requested a cgi file and looks into the directory to see if a library by the same name is present, and if so load it and tries to execute a function inside the library with the following prototype:

```
void exec_cgi(CYG_HTTPD_STATE *)
```

The pointer **CYG_HTTPD_STATE*** gives access to the socket data: The user will use this pointer to access the 'outbuffer' and use it to copy data to send data out.

When using the OBJLOADER package within the HTTP server a number of functions are automatically added to the externals table of the OBJLOADER package. These functions are likely to be used inside the library and the relocater need to have a pointer to them. In order to add more functions, see the OBJLOADER documentation. The complete list of the functions automatically added is:

- cyg_httpd_start_chunked()
- cyg_httpd_write_chunked()
- cyg_httpd_end_chunked()
- cyg_httpd_write()
- cyg_httpd_find_form_variable()
- cyg_httpd_find_ires()
- cyg_httpd_send_ires()
- diag_printf()
- cyg_httpd_format_header()
- cyg_httpd_find_mime_string()

Every time the web client issues a GET or POST request for a file with an extension of '.o' in the /cgi-bin directory (or whatever path the user chooses to hold the libraries) then the library by that name is loaded, run and when the execution is over, it is dumped from memory. The library must be compiled separately, using the same toolchain used to compile the server and then added to the file system.

In order to reduce the footprint of the server, CGI through OBJLOADER can be compiled out by unchecking CYGOPT_NET_ATHTTPD_USE_CGIBIN_OBJLOADER in the configuration tool.

CGI via the simple tcl interpreter

A small tcl interpreter has been added to the web server, and it can be used to write simple cgi scripts. The interpreter is admittedly very minimal, and it is only useful for very simple applications, but it is an excellent starting point for further development.

In order for the scripting language to be useful, it has to access the form variables passed on during the GET or POST request. Because of this, all form variables registered with the CYG_HTTPD_FVAR_TABLE_ENTRY() macro are accessible via tcl. For example, if we have registered a form variable called foo, and during the GET request we are defining foo as being "1":

```
GET /myForm.cgi?foo=1
```

then tcl will be able to access the variable foo as \$foo. The data in the body of a POST request is also accessible through the use of the variable \$post_data. This is useful if the data is not in "multipart/form-data" and tcl has to perform any type of processing on the data itself.

In order to send back a response to the client a few functions have been added to the interpreter. These functions are:

start_chunked

```
start_chunked "extension";
```

"extension" is a string used to search the table of the mime types. For example, to send back to the client an HTML file, we can use: start_chunked "html";

write_chunked

```
write_chunked content;
```

content is a string to send back to the client.

end_chunked

```
end_chunked;
```

No parameters. Send back an end of frame to the client.

tcl hello world example

The following example demonstrates how to send a log file in the file /ram/log to a web client. It replaces newline characters with
 so that it is formatted on the browser correctly.

```
start_chunked "html";

set fp [aio.open "/ram/log" r];
$fp seek 0 end;
set fsize [$fp tell];
$fp seek 0 start;
set data "abcxxx";
set data [$fp read $fsize];
$fp close;
set data [string map {\n <br>} $data];

set datax "";
append datax "<html><body>" $data "</body></html>";

write_chunked $datax;
end_chunked;
```

The above file should exist on a filesystem on the embedded target within its `cgi-bin` directory, for example as `/cgi-bin/hello.tcl`. Thereafter it may be accessed at the URL `http://TARGET_NAME/cgi-bin/hello.tcl`.

Authentication

The server supports both Basic (base64) and Digest (MD5) authentication, although they have not been tested with all clients. In this implementation, the contents of certain directories of the file system can be protected, such that the user will be required to issue a username/password to access the content of the directory.

To protect a directory with a basic authentication, there is a specific macro:

```
CYG_HTTPD_AUTH_TABLE_ENTRY(entry, path, domain, un, pw, mode)
```

<code>entry</code>	: an identifier unique to this entry.
<code>path</code>	: the path to the directory whose content must be authenticated before it is sent out
<code>domain</code>	: a domain identifier for this directory.
<code>un</code>	: username for authentication
<code>pw</code>	: password for authentication
<code>mode</code>	: <code>CYG_HTTPD_AUTH_BASIC</code> for base64 encoding or <code>CYG_HTTPD_AUTH_DIGEST</code> for MD5 encoding

for example, to require basic authentication of the content of directory `/ecos/` with a username of `"foo"` and password `"bar"`, the following is used:

```
CYG_HTTPD_AUTH_TABLE_ENTRY(hal_domain1_entry, \
                           "/ecos/", "ecos_domain", \
                           "foo", "bar", \
                           CYG_HTTPD_AUTH_BASIC);
```

Any request for a file in the directory `/ecos/` will now trigger a credential check. These credentials, once provided, are automatically sent by the client for every request within the particular domain.

It must be noticed that the path name set in the macro is relative to the HTML document directory, `CYG_DAT_NET_HTTPD_SERVEROPT_HTMLDIR` and it is the first part of the path provided by the client request (including the leading slash).

In order to reduce the footprint of the server, authentication is not enabled by default, and so the option `CYGOPT_NET_ATHTTPD_USE_AUTH` must be used to enable support for basic and digest authentication.

The MD5 digest authentication support is implemented using the RSA Data Security, Inc. MD5 Message-Digest Algorithm. Derivative works with MD5 digest authentication included must be identified as "derived from the RSA Data Security, Inc. MD5 Message-Digest Algorithm" in all material mentioning or referencing the derived work. See the file `md5.c` within this package for license details.

Directory Listing

If the user issues a `"GET"` request with a URL terminating in a slash, the server will try to locate one of the following index files in the directory, choosing one in the following order:

- `index.html`

- index.htm
- default.html
- home.html

If any of these files is found, its contents are sent back to the client. If no such file is found the server uses the user-provided index file name (if any is specified with the `CYGDAT_NET_ATHTTPD_ALTERNATE_HOME` setting. Failing all this a directory listing is sent.

Trailing slash redirection for directory names is supported.

In order to reduce the footprint of the server, directory listing can be disabled by unchecking `CYGOPT_NET_ATHTTPD_USE_DIRLIST`. The savings are substantial since directory listing also makes use of a few internal resources (gif files) which are also compiled out.

Form Variables

The server will automatically try to parse form variables when a form is submitted in the following cases:

- In a GET request, when the URL is followed by a question mark sign
- In a POST request, when the the 'Content-Type' header line is set to 'application/x-www-form-urlencoded'

The variable names to look for during the parsing are held in an eCos table. In order to take advantage of this feature, the user first adds the variable names to the table, which also requires providing a buffer where the parsed value will eventually be stored. The values will then be available in the buffers during the processing of the request, presumably in the body of a c language callback or CGI script.

For example, if the user wants two form variables, "foo" and "bar", to be parsed automatically, those variable names must be added to the table with the following macro:

```
CYG_HTTPD_FVAR_TABLE_ENTRY(entry, name, buffp, buflen)
```

```
entry          : an identifier unique to this entry.
name           : name of the form variable
buffp          : a pointer to a buffer of characters where to store the value
                  of the form variable.
buflen         : The length of the buffer. Must include a trailing string
                  terminator.
```

or, in the specific instance mentioned above:

```
#define HTML_VAR_LEN    20
char var_foo[HTML_VAR_LEN];
char var_bar[HTML_VAR_LEN];
CYG_HTTPD_FVAR_TABLE_ENTRY(hal_form_entry_foo, "foo", var_foo, HTML_VAR_LEN);
CYG_HTTPD_FVAR_TABLE_ENTRY(hal_form_entry_bar, "bar", var_bar, HTML_VAR_LEN);
```

and after the GET or POST submissions, the list will contain the value for "foo" and "bar" (if they were found in the form data.) It is the responsibility of the user to make sure that the buffer is large enough to hold all the data parsed (including the string terminator). The parser will write only up to the length of the buffer minus one (the last being the terminator) and discard any additional data.

The values parsed are likely going to be used in c language callback, or in CGI files. In a c language callback the user can directly access the pointers of individual variables for further processing, keeping in mind that the parsing always result in a string of characters to be produced, and any conversion (e.g. from strings to integer) must be performed within the callback. In a TCL script the user can just access a variable by its

name. For example, in the case of the variables 'foo' and 'bar' shown above, it is possible to do something like 'write_chunked "You wrote \$foo"'. The data that was sent in the body of a POST request is accessible in through a variable called 'post_data'. In CGI functions implemented using the objloader the pointers to the variables cannot be accessed directly, since the library will likely not know their location in memory. The proper way to access them is by using the `cyg_httpd_find_form_variable()` function from within the library:

```
char* cyg_httpd_find_form_variable(char* name)

name           : name of the form variable to look up

returns a pointer to the buffer, or 0 if the variable was not found.
```

When using the OBJLOADER package within the web server, an entry for the `cyg_httpd_find_form_variable()` function is automatically added to the externals table the OBJLOADER for relocation. See the OBJLOADER paragraph of the ATHTTP user's guide for the full list of the exported functions.

In order to avoid stale data, all the buffers in the table are cleared before running the parser and thus any variable in the list that was not assigned a new value during the request will be an empty string.

Internal Resources

When the server does not use a file system the user must be responsible to provide a C language callback function for each URL that will be requested by the client. This means locating the data and sending it out using either `cyg_httpd_write()` or `cyg_httpd_write_chunked()`.

In order to simplify this process the server allows registering any number of URLs as internal resources, by providing the URL name, the pointer to the resource data and its size. When a URL is requested the server will look it up among all internal resources, and if found, it will send out the resource.

Internal resource can also be used along with a file system. In this case the file system is searched first, and if a file is found, it is sent. If a file is not found, the internal resources are searched and if a match is found it is sent.

The drawback of this approach is, of course, that all these resources are going to add to the size of the operating system image, and thus it should be used only when memory is not a major constraint of the design.

As always, to provide this type of customization, ecos tables are used. The format for adding a new resource to the internal table is the following:

```
CYG_HTTPD_IRES_TABLE_ENTRY(entry, name, buffp, len)

entry           : an identifier unique to this entry.
name            : name of the URL including leading '/'
buffp           : a pointer to a buffer of characters where to store the value
                  of the form variable.
len             : size of the array
```

As an example, if the user wants to provide his own web page by hardcoding it in the application code, here is how he would do it:

```
#define MY_OWN_HOME_PAGE "eCos RTOS"
CYG_HTTPD_IRES_TABLE_ENTRY(cyg_httpd_ires_home, \
                           "/index.html", \
                           MY_OWN_HOME_PAGE, \
                           9);
```

The extension of the file name determines the MIME type to be used for internal resources.

When using directory listing you are implicitly making use of internal resources. The small icons that appear to the left of file names and directories are internal resources. Unchecking `CYGOPT_NET_HTTP_USE_DIRLIST` will prevent the addition of these files.

In order to use internal resources, a generic file must first be turned into a c language array, which is then compiled in the application code. To create this array you can use the tcl script that comes with the ecos distribution at `packages/fs/rom/current/support/file2.tcl`.

XXV. CRC Algorithms

The CRC package provides implementation of CRC algorithms. This includes the POSIX CRC calculation which produces the same result as the cksum command on Linux, another 32 bit CRC by Gary S. Brown and a 16bit CRC. The CRC used for Ethernet FCS is also implemented.

Chapter 57. CRC Functions

CRC API

The package implements a number of CRC functions as described below. The API to these functions is in the include file `cyg/crc/crc.h`.

cyg_posix_crc32

This function implements a 32 bit CRC which is compliant to the POSIX 1008.2 Standard. This is the same as the Linux `cksum` program.

```
cyg_uint32 cyg_posix_crc32(unsigned char * s, int len);
```

The CRC calculation is run over the data pointed to by *s*, of length *len*. The CRC is returned as an unsigned long.

cyg_crc32

These functions implement a 32 bit CRC by Gary S. Brown. They use the polynomial $X^{32}+X^{26}+X^{23}+X^{22}+X^{16}+X^{12}+X^{11}+X^{10}+X^8+X^7+X^5+X^4+X^2+X^1+X^0$.

```
cyg_uint32 cyg_crc32(unsigned char * s, int len);
cyg_uint32 cyg_crc32_accumulate(cyg_uint32 crc, unsigned char * s, int len);
```

The CRC calculation is run over the data pointed to by *s*, of length *len*. The CRC is returned as an unsigned long.

The CRC can be calculated over data separated into multiple buffers by using the function `cyg_crc32_accumulate()`. The parameter *crc* should be the result from the previous CRC calculation.

cyg_ether_crc32

These functions implement the 32 bit CRC used by the Ethernet FCS word.

```
cyg_uint32 cyg_ether_crc32(unsigned char * s, int len);
cyg_uint32 cyg_ether_crc32_accumulate(cyg_uint32 crc, unsigned char * s, int len);
```

The CRC calculation is run over the data pointed to by *s*, of length *len*. The CRC is returned as an unsigned long.

The CRC can be calculated over data separated into multiple buffers by using the function `cyg_ether_crc32_accumulate()`. The parameter *crc* should be the result from the previous CRC calculation.

cyg_crc16

This function implements a 16 bit CRC. It uses the polynomial $x^{16}+x^{12}+x^5+1$.

Chapter 57. CRC Functions

```
cyg_uint16 cyg_crc16(unsigned char * s, int len);
```

The CRC calculation is run over the data pointed to by *s*, of length *len*. The CRC is returned as an unsigned short.

XXVI. CPU load measurements

The cpuload package provides a way to estimate the cpuload. It gives an estimated percentage load for the last 100 milliseconds, 1 second and 10 seconds.

Chapter 58. CPU Load Measurements

CPU Load API

The package allows the CPU load to be estimated. The measurement code must first be calibrated to the target it is running on. Once this has been performed the measurement process can be started. This is a continuous process, so always providing the most up to data measurements. The process can be stopped at any time if required. Once the process is active, the results can be retrieved.

Note that if the target/processor performs any power saving actions, such as reducing the clock speed, or halting until the next interrupt etc, these will interfere with the CPU load measurement. Under these conditions the measurement results are undefined. The synthetic target is one such system. See the implementation details at the foot of this page for further information.

SMP systems are not supported, only uniprocessor system.

The API for load measuring functions can be found in the file `cyg/cpload/cpload.h`.

cyg_cpload_calibrate

This function is used to calibrate the cpu load measurement code. It makes a measurement to determine the CPU properties while idle.

```
void cyg_cpload_calibrate(cyg_uint32 *calibration);
```

The function returns the calibration value at the location pointed to by *calibration*.

This function is quite unusual. For it to work correctly a few conditions must be met. The function makes use of the two highest thread priorities. No other threads must be using these priorities while the function is being used. The kernel scheduler must be started and not disabled. The function takes 100ms to complete during which time no other threads will be run.

cyg_cpload_create

This function starts the CPU load measurements.

```
void cyg_cpload_create(cyg_cpload_t *cpload,  
                      cyg_uint32 calibrate,  
                      cyg_handle_t *handle);
```

The measurement process is started and a handle to it is returned in **handle*. This handle is used to access the results and the stop the measurement process.

cyg_cpload_delete

This function stops the measurement process.

```
void cyg_cpload_delete(cyg_handle_t handle);
```

handle should be the value returned by the create function.

cyg_cpuload_get

This function returns the latest measurements.

```
void cyg_cpuload_get(cyg_handle_t handle,
    cyg_uint32 *average_point1s,
    cyg_uint32 *average_1s,
    cyg_uint32 *average_10s);
```

handle should be the value returned by the create function. The load measurements for the last 100ms, 1s and 10s are returned in **average_point1s*, **average_1s* and **average_10s* respectively.

Implementation details

This section gives a few details of how the measurements are made. This should help to understand what the results mean.

When there are no other threads runnable, eCos will execute the idle thread. This thread is always runnable and uses the lowest thread priority. The idle thread does little. It is an endless loop which increments the variable, *idle_thread_loops* and executes the macro *HAL_IDLE_THREAD_ACTION*. The cpu load measurement code makes use of the variable. It periodically examines the value of the variable and sees how much it has changed. The idler the system, the more it will have incremented. From this it is simple to determine the load of the system.

The function *cyg_cpuload_calibrate* executes the idle thread for 100ms to determine how much *idle_thread_loops* is incremented on a system idle for 100ms. *cyg_cpuload_create* starts an alarm which every 100ms calls an alarm function. This function looks at the difference in *idle_thread_loops* since the last invocation of the alarm function and so calculated how idle or busy the system has been. The structure *cyg_cpuload* is updated during the alarm functions with the new results. The 100ms result is simply the result from the last measurement period. A simple filter is used to average the load over a period of time, namely 1s and 10s. Due to rounding errors, the 1s and 10s value will probably never reach 100% on a fully loaded system, but 99% is often seen.

As stated above, clever power management code will interfere with these measurements. The basic assumption is that the idle thread will be executed un-hindered and under the same conditions as when the calibration function was executed. If the CPU clock rate is reduced, the idle thread counter will be incremented less and so the CPU load measurements will give values too high. If the CPU is halted entirely, 100% cpu load will be measured.

XXVII. gprof Profiling Support

Profiling

Name

CYGPKG_PROFILE_GPROF — eCos Support for the gprof profiling tool

Description

The GNU gprof tool provides profiling support. After a test run it can be used to find where the application spent most of its time, and that information can then be used to guide optimization effort. Typical gprof output will look something like this:

Each sample counts as 0.003003 seconds.

% time	cumulative seconds	self seconds	calls	self us/call	total us/call	name
14.15	1.45	1.45	120000	12.05	12.05	Proc_7
11.55	2.63	1.18	120000	9.84	9.84	Func_1
8.04	3.45	0.82				main
7.60	4.22	0.78	40000	19.41	86.75	Proc_1
6.89	4.93	0.70	40000	17.60	28.99	Proc_6
6.77	5.62	0.69	40000	17.31	27.14	Func_2
6.62	6.30	0.68	40000	16.92	16.92	Proc_8
5.94	6.90	0.61				strcmp
5.58	7.47	0.57	40000	14.26	26.31	Proc_3
5.01	7.99	0.51	40000	12.79	12.79	Proc_4
4.46	8.44	0.46	40000	11.39	11.39	Func_3
3.68	8.82	0.38	40000	9.40	9.40	Proc_5
3.32	9.16	0.34	40000	8.48	8.48	Proc_2
...						

This output is known as the flat profile. The data is obtained by having a hardware timer generate regular interrupts. The interrupt handler stores the program counter of the interrupted code. gprof performs a statistical analysis of the resulting data and works out where the time was spent.

gprof can also provide information about the call graph, for example:

index	% time	self	children	called	name
...					
		0.78	2.69	40000/40000	main [1]
[2]	34.0	0.78	2.69	40000	Proc_1 [2]
		0.70	0.46	40000/40000	Proc_6 [5]
		0.57	0.48	40000/40000	Proc_3 [7]
		0.48	0.00	40000/120000	Proc_7 [3]

This shows that function `Proc_1` was called only from `main`, and `Proc_1` in turn called three other functions. Callgraph information is obtained only if the application code is compiled with the `-pg` option. This causes the compiler to insert extra code into each compiled function, specifically a call to `mcount`, and the implementation of `mcount` stores away the data for subsequent processing by gprof.

Caution

There are a number of reasons why the output will not be 100% accurate. Collecting the flat profile typically involves timer interrupts so any code that runs with interrupts disabled will not appear. The current host-side gprof implementation maps program counter values onto symbols using a bin mechanism. When a bin spans the end of one function and the start of the next gprof may report the wrong function. This is especially likely on architectures with single-byte instructions such as an x86. When examining gprof output it may prove useful to look at a linker map or program disassembly.

The eCos profiling package requires some additional support from the HAL packages, and this may not be available on all platforms:

1. There must be an implementation of the profiling timer. Typically this is provided by the variant or platform HAL using one of the hardware timers. If there is no implementation then the configuration tools will report an unresolved conflict related to `CYGINT_PROFILE_HAL_TIMER` and profiling is not possible. Some implementations overload the system clock, which means that profiling is only possible in configurations containing the eCos kernel and `CYGVAR_KERNEL_COUNTERS_CLOCK`.
2. There should be a hardware-specific implementation of `mcount`, which in turn will call the generic functionality provided by this package. It is still possible to do some profiling without `mcount` but the resulting data will be less useful. To check whether or not `mcount` is available, look at the current value of the CDL interface `CYGINT_PROFILE_HAL_MCOUNT` in the graphical configuration tool or in an `ecos.ecc` save file.

This document only describes the eCos profiling support. Full details of gprof functionality and output formats can be found in the gprof documentation. However it should be noted that that documentation describes some functionality which cannot be implemented using current versions of the gcc compiler: the section on annotated source listings is not relevant, and neither are associated command line options like `-A` and `-y`.

Building Applications for Profiling

To perform application profiling the gprof package `CYGPKG_PROFILE_GPROF` must first be added to the eCos configuration. On the command line this can be achieved using:

```
$ ecosconfig add profile_gprof
$ ecosconfig tree
$ make
```

Alternatively the same steps can be performed using the graphical configuration tool.

If the HAL packages implement `mcount` for the target platform then usually application code should be compiled with `-pg`. Optionally eCos itself can also be compiled with this option by modifying the configuration option `CYGBLD_GLOBAL_CFLAGS`. Compiling with `-pg` is optional but gives more complete profiling data.

Note: The profiling package itself must not be compiled with `-pg` because that could lead to infinite recursion when doing `mcount` processing. This is handled automatically by the package's CDL.

Profiling does not happen automatically. Instead it must be started explicitly by the application, using a call to `profile_on`. A typical example would be:

```
#include <pkgconf/system.h>
#ifdef CYGPKG_PROFILE_GPROF
```

```
# include <cyg/profile/profile.h>
#endif
...
int
main(int argc, char** argv)
{
    ...
#ifdef CYGPKG_PROFILE_GPROF
    {
        extern char _stext[], _etext[];
        profile_on(_stext, _etext, 16, 3500);
    }
#endif
    ...
}
```

The `profile_on` takes four arguments:

```
start address
end address
```

These specify the range of addresses that will be profiled. Usually profiling should cover the entire application. On most targets the linker script will export symbols `_stext` and `_etext` corresponding to the beginning and end of code, so these can be used as the addresses. It is possible to perform profiling on a subset of the code if that code is located contiguously in memory.

```
bucket size
```

`profile_on` divides the range of addresses into a number of buckets of this size. It then allocates a single array of 16-bit counters with one entry for each bucket. When the profiling timer interrupts the interrupt handler will examine the program counter of the interrupted code and, assuming it is within the range of valid addresses, find the containing bucket and increment the appropriate counter.

The size of the array counters is determined by the range of addresses being profiled and by the bucket size. For a bucket size of 16, one counter is needed for every 16 bytes of code. For an application with say 512K of code that means dynamically allocating a 64K array. If the target hardware is low on memory then this may be unacceptable, and the requirements can be reduced by increasing the bucket size. However this will affect the accuracy of the results and `gprof` is more likely to report the wrong function. It also increases the risk of a counter overflow.

For the sake of run-time efficiency the bucket size must be a power of 2, and it will be adjusted if necessary.

```
time interval
```

The final argument specifies the interval between profile timer interrupts, in units of microseconds. Increasing the interrupt frequency gives more accurate profiling results, but at the cost of higher run-time overheads and a greater risk of a counter overflow. The HAL package may modify this interval because of hardware restrictions, and the generated profile data will contain the actual interval that was used. Usually it is a good idea to use an interval that is not a simple fraction of the system clock, typically 10000 microseconds. Otherwise there is a risk that the profiling timer will disproportionally sample code that runs only in response to the system clock.

`profile_on` can be invoked multiple times, and on subsequent invocations, it will delete profiling data and allocate a fresh profiling range.

Profiling can be turned off using the function `profile_off`:

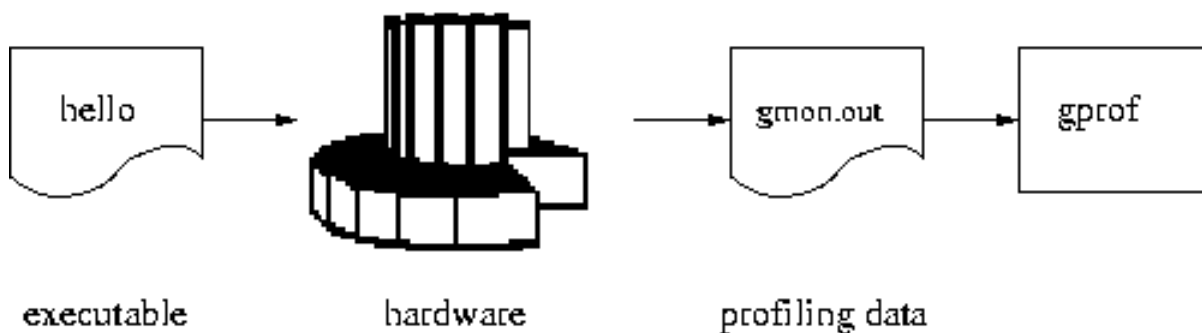
```
void profile_off(void);
```

This will also reset any existing profile data.

If the eCos configuration includes a TCP/IP stack and if a tftp daemon will be used to [extract](#) the data from the target then the call to `profile_on` should happen after the network is up. `profile_on` will attempt to start a tftp daemon thread, and this will fail if networking has not yet been enabled.

```
int
main(int argc, char** argv)
{
    ...
    init_all_network_interfaces();
    ...
#ifdef CYGPKG_PROFILE_GPROF
    {
        extern char _stext[], _etext[];
        profile_on(_stext, _etext, 16, 3000);
    }
#endif
    ...
}
```

The application can then be linked and run as usual.



When `gprof` is used for native development rather than for embedded targets the profiling data will automatically be written out to a file `gmon.out` when the program exits. This is not possible on an embedded target because the code has no direct access to the host's file system. Instead the `gmon.out` file has to be [extracted](#) from the target as described below. `gprof` can then be invoked normally:

```
$ gprof dhrystone
Flat profile:
```

Each sample counts as 0.003003 seconds.

%	cumulative	self	self	total		
time	seconds	seconds	calls	us/call	us/call	name
14.15	1.45	1.45	120000	12.05	12.05	Proc_7
11.55	2.63	1.18	120000	9.84	9.84	Func_1
8.04	3.45	0.82				main
...						

If `gmon.out` does not contain call graph data, either because `mcount` is not supported or because this functionality was explicitly disabled, then the `-no-graph` must be used.

```
$ gprof --no-graph dhrystone
```

Flat profile:

Each sample counts as 0.003003 seconds.

% time	cumulative seconds	self seconds	calls	self us/call	total us/call	name
14.15	1.45	1.45				Proc_7
11.55	2.63	1.18				Func_1
8.04	3.45	0.82				main
...						

Extracting the Data

By default gprof expects to find the profiling data in a file `gmon.out` in the current directory. This package provides two ways of extracting data: a gdb macro or tftp transfers. Using tftp is faster but requires a TCP/IP stack on the target. It also consumes some additional target-side resources, including an extra tftp daemon thread and its stack. The gdb macro can be used even when the eCos configuration does not include a TCP/IP stack. However it is much slower, typically taking tens of seconds to retrieve all the data for a non-trivial application.

The gdb macro is called **gprof_dump**, and can be found in the file `gprof.gdb` in the `host` subdirectory of this package. A typical way of using this macro is:

```
(gdb) source <repo>/services/profile/gprof/<version>/host/gprof.gdb
(gdb) gprof_dump
```

This macro can be used any time after the call to `profile_on`. It will store the profiling data accumulated so far to the file `gmon.out` in the current directory, and then reset all counts. gprof uses only a 16 bit counter for every bucket of code. These counters can easily saturate if the profiling run goes on for a long time, or if the application code spends nearly all its time in just a few tight inner loops. The counters will not actually wrap around back to zero, instead they will stick at 0xFFFF, but this will still affect the accuracy of the gprof output. Hence it is desirable to reset the counters once the profiling data has been extracted.

The file `gprof.gdb` contains two other macros which may prove useful. **gprof_fetch** extracts the profiling data and generates the file `gmon.out`, but does not reset the counters. **gprof_reset** only resets the counters, without extracting the data or overwriting `gmon.out`.

If the configuration includes a TCP/IP stack then the profiling data can be extracted using tftp instead. There are two relevant configuration options. `CYPKG_PROFILE_TFTP` controls whether or not tftp is supported. It is enabled by default if the configuration includes a TCP/IP stack, but can be disabled to save target-side resources. `CYGNUM_PROFILE_TFTP_PORT` controls the UDP port which will be used. This port cannot be shared with other tftp daemons. If neither application code nor any other package (for example the gcov test coverage package) provides a tftp service then the default port can be used. Otherwise it will be necessary to assign unique ports to each daemon.

If enabled the tftp daemon will be started automatically by `profile_on`. This should only happen once the network is up and running, typically after the call to `init_all_network_interfaces`.

The data can then be retrieved using a standard tftp client. There are a number of such clients available with very different interfaces, but a typical session might look something like this:

```
$ tftp
tftp> connect 10.1.1.134
tftp> binary
tftp> get gmon.out
Received 64712 bytes in 0.9 seconds
```

```
tftp> quit
```

The address 10.1.1.134 should be replaced with the target's IP address. Extracting the profiling data by tftp will automatically reset the counters.

Configuration Options

This package contains a number of configuration options. Two of these, `CYGPKG_PROFILE_TFTP` and `CYGNUM_PROFILE_TFTP_PORT`, related to support for [tftp transfers](#) and have already been described.

Support for collecting the call graph data via `mcount` is optional and can be controlled via `CYGPKG_PROFILE_CALLGRAPH`. This option will only be active if the HAL provides the underlying `mcount` support and implements `CYGINT_PROFILE_HAL_MCOUNT`. The call graph data allows `gprof` to produce more useful output, but at the cost of extra run-time and memory overheads. If this option is disabled then the `-pg` compiler flag should not be used.

If `CYGPKG_PROFILE_CALLGRAPH` is enabled then there are two further options which can be used to control memory requirements. Collecting the data requires two blocks of memory, a simple hash table and an array of arc records. The `mcount` code uses the program counter address to index into the hash table, giving the first element of a singly linked list. The array of arc records contains the various linked lists for each hash slot. The required number of arc records depends on the number of function calls in the application. For example if a function `Proc_7` is called from three different places in the application then three arc records will be needed.

`CYGNUM_PROFILE_CALLGRAPH_HASH_SHIFT` controls the size of the hash table. The default value of 8 means that the program counter is shifted right by eight places to give a hash table index. Hence each hash table slot corresponds to 256 bytes of code, and for an application with say 512K of code `profile_on` will dynamically allocate an 8K hash table. Increasing the shift size reduces the memory requirement, but means that each hash table slot will correspond to more code and hence `mcount` will need to traverse a longer linked list of arc records.

`CYGNUM_PROFILE_CALLGRAPH_ARC_PERCENTAGE` controls how much memory `profile_on` will allocate for the arc records. This uses a simple heuristic, a percentage of the overall code size. By default the amount of arc record space allocated will be 5% of the code size, so for a 512K executable that requires approximately 26K. This default should suffice for most applications. In exceptional cases it may be insufficient and a diagnostic will be generated when the profiling data is extracted.

Implementing the HAL Support

The profiling package requires HAL support: A function `hal_enable_profile_timer` and an implementation of `mcount`. The profile timer is required. Typically it will be implemented by the variant or platform HAL using a spare hardware timer, and that HAL package will also implement the CDL interface `CYGINT_PROFILE_HAL_TIMER`. Support for `mcount` is optional but very desirable. Typically it will be implemented by the architectural HAL, which will also implement the CDL interface `CYGINT_PROFILE_HAL_MCOUNT`.

```
#include <pkgconf/system.h>
#ifdef CYGPKG_PROFILE_GPROF
# include <cyg/profile/profile.h>
#endif

int
hal_enable_profile_timer(int resolution)
{
```



```

...
return actual_resolution;
}

```

This function takes a single argument, a time interval in microseconds. It should arrange for a timer interrupt to go off after every interval. The timer VSR or ISR should then determine the program counter of the interrupted code and register this with the profiling package:

```

...
__profile_hit(interrupted_pc);
...

```

The exact details of how this is achieved, especially obtaining the interrupted PC, are left to the HAL implementor. The HAL is allowed to modify the requested time interval because of hardware constraints, and should return the interval that is actually used.

`mcount` can be more difficult. The calls to `mcount` are generated internally by the compiler and the details depend on the target architecture. In fact `mcount` may not use the standard calling conventions at all. Typically implementing `mcount` requires looking at the code that is actually generated, and possibly at the sources of the appropriate compiler back end.

The HAL `mcount` function should call into the profiling package using standard calling conventions:

```

...
__profile_mcount((CYG_ADDRWORD) caller_pc, (CYG_ADDRWORD) callee_pc);
...

```

If `mcount` was invoked because `main` called `Proc_1` then the caller pc should be an address inside `main`, typically corresponding to the return location, and the callee pc should be an address inside `Proc_1`, usually near the start of the function.

For some targets the compiler does additional work, for example automatically allocating a per-function word of memory to eliminate the need for the hash table. This is too target-specific and hence cannot easily be used by the generic profiling package.

XXVIII. eCos USB Slave Support

Introduction

Name

Introduction — eCos support for USB slave devices

Introduction

The eCos USB slave support allows developers to produce USB peripherals. It consists of a number of different eCos packages:

1. Device drivers for specific implementations of USB slave hardware, for example the on-chip USB Device Controller provided by the Intel SA1110 processor. A typical USB peripheral will only provide one USB slave port and therefore only one such device driver package will be needed. Usually the device driver package will be loaded automatically when you create an eCos configuration for target hardware that has a USB slave device. If you select a target which does have a USB slave device but no USB device driver is loaded, this implies that no such device driver is currently available.
2. The common USB slave package. This serves two purposes. It defines the API that specific device drivers should implement. It also provides various utilities that will be needed by most USB device drivers and applications, such as handlers for standard control messages. Usually this package will be loaded automatically at the same time as the USB device driver.
3. The common USB package. This merely provides some information common to both the host and slave sides of USB, such as details of the control protocol. It is also used to place the other USB-related packages appropriately in the overall configuration hierarchy. Usually this package will be loaded at the same time as the USB device driver.
4. Class-specific USB support packages. These make it easier to develop specific classes of USB peripheral, such as a USB-ethernet device. If no suitable package is available for a given class of peripheral then the USB device driver can instead be accessed directly from application code. Such packages will never be loaded automatically since the configuration system has no way of knowing what class of USB peripheral is being developed. Instead developers have to add the appropriate package or packages explicitly.

These packages only provide support for developing USB peripherals, not USB hosts.

USB Concepts

Information about USB can be obtained from a number of sources including the USB Implementers Forum web site (<http://www.usb.org/>). Only a brief summary is provided here.

A USB network is asymmetrical: it consists of a single host, one or more slave devices, and possibly some number of intermediate hubs. The host side is significantly more complicated than the slave side. Essentially, all operations are initiated by the host. For example, if the host needs to receive some data from a particular USB peripheral then it will send an IN token to that peripheral; the latter should respond with either a NAK or with appropriate data. Similarly, when the host wants to transmit data to a peripheral it will send an OUT token followed by the data; the peripheral will return a NAK if it is currently unable to receive more data or if there was corruption, otherwise it will return an ACK. All transfers are check-summed and there is a clearly-defined error recovery process. USB peripherals can only interact with the host, not with each other.

USB supports four different types of communication: control messages, interrupt transfers, isochronous transfers, and bulk transfers. Control messages are further subdivided into four categories: standard, class, vendor and a reserved category. All USB peripherals must respond to certain standard control messages, and usually

this will be handled by the common USB slave package (for complicated peripherals, application support will be needed). Class and vendor control messages may be handled by an class-specific USB support package, for example the USB-ethernet package will handle control messages such as getting the MAC address or enabling/disabling promiscuous mode. Alternatively, some or all of these messages will have to be handled by application code.

Interrupt transfers are used for devices which need to be polled regularly. For example, a USB keyboard might be polled once every millisecond. The host will not poll the device more frequently than this, so interrupt transfers are best suited to peripherals that involve a relatively small amount of data. Isochronous transfers are intended for multimedia-related peripherals where typically a large amount of video or audio data needs to be exchanged continuously. Given appropriate host support a USB peripheral can reserve some of the available bandwidth. Isochronous transfers are not reliable; if a particular packet is corrupted then it will just be discarded and software is expected to recover from this. Bulk transfers are used for everything else: after taking care of any pending control, isochronous and interrupt transfers the host will use whatever bandwidth remains for bulk transfers. Bulk transfers are reliable.

Transfers are organized into USB packets, with the details depending on the transfer type. Control messages always involve an initial 8-byte packet from host to peripheral, optionally followed by some additional packets; in theory these additional packets can be up to 64 bytes, but hardware may limit it to 8 bytes. Interrupt transfers involve a single packet of up to 64 bytes. Isochronous transfers involve a single packet of up to 1024 bytes. Bulk transfers involve multiple packets. There will be some number, possibly zero, of 64-byte packets. The transfer is terminated by a single packet of less than 64 bytes. If the transfer involves an exact multiple of 64 bytes then the final packet will be 0 bytes, consisting of just a header and checksum which typically will be generated by the hardware. There is no pre-defined limit on the size of a bulk transfer. Instead higher-level protocols are expected to handle this, so for a USB-ethernet peripheral the protocol could impose a limit of 1514 bytes of data plus maybe some additional protocol overhead.

Transfers from the host to a peripheral are addressed not just to that peripheral but to a specific endpoint within that peripheral. Similarly, the host requests incoming data from a specific endpoint rather than from the peripheral as a whole. For example, a combined keyboard/touchpad device could provide the keyboard events on endpoint 1 and the mouse events on endpoint 2. A given USB peripheral can have up to 16 endpoints for incoming data and another 16 for outgoing data. However, given the comparatively high speed of USB I/O this endpoint addressing is typically implemented in hardware rather than software, and the hardware will only implement a small number of endpoints. Endpoint 0 is generally used only for control messages.

In practice, many of these details are irrelevant to application code or to class packages. Instead, such higher-level code usually just performs blocking `read` and `write`, or non-blocking USB-specific calls, to transfer data between host and target via a specific endpoint. Control messages are more complicated but are usually handled by existing code.

When a USB peripheral is plugged into the host there is an initial enumeration and configuration process. The peripheral provides information such as its class of device (audio, video, etc.), a vendor id, which endpoints should be used for what kind of data, and so on. The host OS uses this information to identify a suitable host device driver. This could be a generic driver for a class of peripherals, or it could be a vendor-specific driver. Assuming a suitable driver is installed the host will then activate the USB peripheral and perform additional application-specific initialisation. For example for a USB-ethernet device this would involve obtaining an ethernet MAC address. Most USB peripherals will be fairly simple, but it is possible to build multifunction peripherals with multiple configurations, interfaces, and alternate interface settings.

It is not possible for any of the eCos packages to generate all the enumeration data automatically. Some of the required information such as the vendor id cannot be supplied by generic packages; only by the application developer. Class support code such as the USB-ethernet package could in theory supply some of the information automatically, but there are also hardware dependencies such as which endpoints get used for incoming and outgoing ethernet frames. Instead it is the responsibility of the application developer to provide all the enumeration data and perform some additional initialisation. In addition, the common USB slave package can

handle all the standard control messages for a simple USB peripheral, but for something like a multifunction peripheral additional application support is needed.

Note: The initial implementation of the eCos USB slave packages involved hardware that only supported control and bulk transfers, not isochronous or interrupt. There may be future changes to the USB code and API to allow for isochronous and interrupt transfers, especially the former. Other changes may be required to support different USB devices. At present there is no support for USB remote wakeups, since again it is not supported by the hardware.

eCos USB I/O Facilities

For protocols other than control messages, eCos provides two ways of performing USB I/O. The first involves device table or devtab entries such as `/dev/usb1r`, with one entry per endpoint per USB device. It is possible to `open` these devices and use conventional blocking I/O functions such as `read` and `write` to exchange data between host and peripheral.

There is also a lower-level USB-specific API, consisting of functions such as `usbs_start_rx_buffer`. A USB device driver will supply a data structure for each endpoint, for example a `usbs_rx_endpoint` structure for every receive endpoint. The first argument to `usbs_start_rx_buffer` should be a pointer to such a data structure. The USB-specific API is non-blocking: the initial call merely starts the transfer; some time later, once the transfer has completed or has been aborted, the device driver will invoke a completion function.

Control messages are different. With four different categories of control messages including application and vendor specific ones, the conventional `open/read/write` model of I/O cannot easily be applied. Instead, a USB device driver will supply a `usbs_control_endpoint` data structure which can be manipulated appropriately. In practice the standard control messages will usually be handled by the common USB slave package, and other control messages will be handled by class-specific code such as the USB-ethernet package. Typically, application code remains responsible for supplying the `enumeration data` and for actually `starting` up the USB device.

Enabling the USB code

If the target hardware contains a USB slave device then the appropriate USB device driver and the common packages will typically be loaded into the configuration automatically when that target is selected (assuming a suitable device driver exists). However, the driver will not necessarily be active. For example a processor might have an on-chip USB device, but not all applications using that processor will want to use USB functionality. Hence by default the USB device is disabled, ensuring that applications do not suffer any memory or other penalties for functionality that is not required.

If the application developer explicitly adds a class support package such as the USB-ethernet one then this implies that the USB device is actually needed, and the device will be enabled automatically. However, if no suitable class package is available and the USB device will instead be accessed by application code, it is necessary to enable the USB device manually. Usually the easiest way to do this is to enable the configuration option `CYGGLO_IO_USB_SLAVE_APPLICATION`, and the USB device driver and related packages will adjust accordingly. Alternatively, the device driver may provide some configuration options to provide more fine-grained control.

USB Enumeration Data

Name

Enumeration Data — The USB enumeration data structures

Synopsis

```
#include <cyg/io/usb/usb.h>
#include <cyg/io/usb/usbs.h>

typedef struct usb_device_descriptor {
    ...
} usb_device_descriptor __attribute__((packed));

typedef struct usb_configuration_descriptor {
    ...
} usb_configuration_descriptor __attribute__((packed));

typedef struct usb_interface_descriptor {
    ...
} usb_interface_descriptor __attribute__((packed));

typedef struct usb_endpoint_descriptor {
    ...
} usb_endpoint_descriptor;

typedef struct usbs_enumeration_data {
    usb_device_descriptor      device;
    int                        total_number_interfaces;
    int                        total_number_endpoints;
    int                        total_number_strings;
    const usb_configuration_descriptor* configurations;
    const usb_interface_descriptor* interfaces;
    const usb_endpoint_descriptor* endpoints;
    const unsigned char**      strings;
} usbs_enumeration_data;
```

USB Enumeration Data

When a USB host detects that a peripheral has been plugged in or powered up, one of the first steps is to ask the peripheral to describe itself by supplying enumeration data. Some of this data depends on the class of peripheral. Other fields are vendor-specific. There is also a dependency on the hardware, specifically which endpoints are available should be used. In general it is not possible for generic code to provide this information, so it is the responsibility of application code to provide a suitable `usbs_enumeration_data` data structure and install it in the endpoint 0 data structure during initialization. This must happen before the USB device is enabled by a call to `usbs_start`, for example:

```
const usbs_enumeration_data usb_enum_data = {
    ...
};

int
main(int argc, char** argv)
```

```

{
    usbs_sallx0_ep0.enumeration_data = &usb_enum_data;
    ...
    usbs_start(&usbs_sallx0_ep0);
    ...
}

```

For most applications the enumeration data will be static, although the `usbs_enumeration_data` structure can be filled in at run-time if necessary. Full details of the enumeration data can be found in the Universal Serial Bus specification obtainable from the USB Implementers Forum web site (<http://www.usb.org/>), although the meaning of most fields is fairly obvious. The various data structures and utility macros are defined in the header files `cyg/io/usb/usb.h` and `cyg/io/usb/usbs.h`. Note that the example code below makes use of the gcc labelled element extension.

usb_device_descriptor

The main information about a USB peripheral comes from a single `usb_device_descriptor` structure, which is embedded in the `usbs_enumeration_data` structure. A typical example might look like this:

```

const usbs_enumeration_data usb_enum_data = {
    {
        length:                USB_DEVICE_DESCRIPTOR_LENGTH,
        type:                   USB_DEVICE_DESCRIPTOR_TYPE,
        usb_spec_lo:            USB_DEVICE_DESCRIPTOR_USB11_LO,
        usb_spec_hi:            USB_DEVICE_DESCRIPTOR_USB11_HI,
        device_class:            USB_DEVICE_DESCRIPTOR_CLASS_VENDOR,
        device_subclass:         USB_DEVICE_DESCRIPTOR_SUBCLASS_VENDOR,
        device_protocol:         USB_DEVICE_DESCRIPTOR_PROTOCOL_VENDOR,
        max_packet_size:         8,
        vendor_lo:               0x42,
        vendor_hi:               0x42,
        product_lo:              0x42,
        product_hi:              0x42,
        device_lo:               0x00,
        device_hi:               0x01,
        manufacturer_str:        1,
        product_str:              2,
        serial_number_str:        0,
        number_configurations:    1
    },
    ...
};

```

The length and type fields are specified by the USB standard. The `usb_spec_lo` and `usb_spec_hi` fields identify the particular revision of the standard that the peripheral implements, for example revision 1.1.

The device class, subclass, and protocol fields are used by generic host-side USB software to determine which host-side device driver should be loaded to interact with the peripheral. A number of standard classes are defined, for example mass-storage devices and human-interface devices. If a peripheral implements one of the standard classes then a standard existing host-side device driver may exist, eliminating the need to write a custom driver. The value `0xFF` (VENDOR) is reserved for peripherals that implement a vendor-specific protocol rather than a standard one. Such peripherals will require a custom host-side device driver. The value `0x00` (INTERFACE) is reserved and indicates that the protocol used by the peripheral is defined at the interface level rather than for the peripheral as a whole.

The `max_package_size` field specifies the maximum length of a control message. There is a lower bound of eight bytes, and typical hardware will not support anything larger because control messages are usually small and not performance-critical.

The `vendor_lo` and `vendor_hi` fields specify a vendor id, which must be obtained from the USB Implementor's Forum. The numbers used in the code fragment above are examples only and must not be used in real USB peripherals. The product identifier is determined by the vendor, and different USB peripherals should use different identifiers. The device identifier field should indicate a release number in binary-coded decimal.

The above fields are all numerical in nature. A USB peripheral can also provide a number of strings as described [below](#), for example the name of the vendor can be provided. The various `_str` fields act as indices into an array of strings, with index 0 indicating that no string is available.

A typical USB peripheral involves just a single configuration. However more complicated peripherals can support multiple configurations. Only one configuration will be active at any one time, and the host will switch between them as appropriate. If a peripheral does involve multiple configurations then typically it will be the responsibility of application code to [handle](#) the standard set-configuration control message.

usb_configuration_descriptor

A USB peripheral involves at least one and possibly several different configurations. The `usbs_enumeration_data` structure requires a pointer to an array, possibly of length 1, of `usb_configuration_descriptor` structures. Usually a single structure suffices:

```
const usb_configuration_descriptor usb_configuration = {
    length:           USB_CONFIGURATION_DESCRIPTOR_LENGTH,
    type:             USB_CONFIGURATION_DESCRIPTOR_TYPE,
    total_length_lo:  USB_CONFIGURATION_DESCRIPTOR_TOTAL_LENGTH_LO(1, 2),
    total_length_hi:  USB_CONFIGURATION_DESCRIPTOR_TOTAL_LENGTH_HI(1, 2),
    number_interfaces: 1,
    configuration_id:  1,
    configuration_str:  0,
    attributes:        USB_CONFIGURATION_DESCRIPTOR_ATTR_REQUIRED |
                       USB_CONFIGURATION_DESCRIPTOR_ATTR_SELF_POWERED,
    max_power:         50
};

const usbs_enumeration_data usb_enum_data = {
    ...
    configurations:    &usb_configuration,
    ...
};
```

The values for the `length` and `type` fields are determined by the standard. The `total_length` field depends on the number of interfaces and endpoints used by this configuration, and convenience macros are provided to calculate this: the first argument to the macros specify the number of interfaces, the second the number of endpoints. The `number_interfaces` field is self-explanatory. If the peripheral involves multiple configurations then each one must have a unique id, and this will be used in the set-configuration control message. The id 0 is reserved, and a set-configuration control message that uses this id indicates that the peripheral should be inactive. Configurations can have a string description if required. The `attributes` field must have the `REQUIRED` bit set; the `SELF_POWERED` bit informs the host that the peripheral has its own power supply and will not draw any power over the bus, leaving more bus power available to other peripherals; the `REMOTE_WAKEUP` bit is used if the peripheral can interrupt the host when the latter is in power-saving mode. For peripherals that are not self-powered, the `max_power` field specifies the power requirements in units of 2mA.

usb_interface_descriptor

A USB configuration involves one or more interfaces, typically corresponding to different streams of data. For example, one interface might involve video data while another interface is for audio. Multiple interfaces in a single configuration will be active at the same time.

```
const usb_interface_descriptor usb_interface = {
    length:          USB_INTERFACE_DESCRIPTOR_LENGTH,
    type:            USB_INTERFACE_DESCRIPTOR_TYPE,
    interface_id:    0,
    alternate_setting: 0,
    number_endpoints: 2,
    interface_class:  USB_INTERFACE_DESCRIPTOR_CLASS_VENDOR,
    interface_subclass: USB_INTERFACE_DESCRIPTOR_SUBCLASS_VENDOR,
    interface_protocol: USB_INTERFACE_DESCRIPTOR_PROTOCOL_VENDOR,
    interface_str:    0
};

const usbs_enumeration_data usb_enum_data = {
    ...
    total_number_interfaces: 1,
    interfaces:              &usb_interface,
    ...
};
```

Again, the *length* and *type* fields are specified by the standard. Each interface within a configuration requires its own id. However, a given interface may have several alternate settings, in other words entries in the interfaces array with the same id but different *alternate_setting* fields. For example, there might be one setting which requires a bandwidth of 100K/s and another setting that only needs 50K/s. The host can use the standard set-interface control message to choose the most appropriate setting. The handling of this request is the responsibility of higher-level code, so the application may have to [install](#) its own handler.

The number of endpoints used by an interface is specified in the *number_endpoints* field. Exact details of which endpoints are used is held in a separate array of endpoint descriptors. The class, subclass and protocol fields are used by host-side code to determine which host-side device driver should handle this specific interface. Usually this is determined on a per-peripheral basis in the *usb_device_descriptor* structure, but that can defer the details to individual interfaces. A per-interface string is allowed as well.

For USB peripherals involving multiple configurations, the array of *usb_interface_descriptor* structures should first contain all the interfaces for the first configuration, then all the interfaces for the second configuration, and so on.

usb_endpoint_descriptor

The host also needs information about which endpoint should be used for what. This involves an array of endpoint descriptors:

```
const usb_endpoint_descriptor usb_endpoints[] = {
    {
        length:          USB_ENDPOINT_DESCRIPTOR_LENGTH,
        type:            USB_ENDPOINT_DESCRIPTOR_TYPE,
        endpoint:        USB_ENDPOINT_DESCRIPTOR_ENDPOINT_OUT | 1,
        attributes:      USB_ENDPOINT_DESCRIPTOR_ATTR_BULK,
        max_packet_lo:   64,
        max_packet_hi:   0,
        interval:        0
    },
};
```

```

    {
        length:          USB_ENDPOINT_DESCRIPTOR_LENGTH,
        type:            USB_ENDPOINT_DESCRIPTOR_TYPE,
        endpoint:        USB_ENDPOINT_DESCRIPTOR_ENDPOINT_IN | 2,
        attributes:      USB_ENDPOINT_DESCRIPTOR_ATTR_BULK,
        max_packet_lo:   64,
        max_packet_hi:   0,
        interval:        0
    }
};

const usbs_enumeration_data usb_enum_data = {
    ...
    total_number_endpoints:    2,
    endpoints:                 usb_endpoints,
    ...
};

```

As usual the values for the *length* and *type* fields are specified by the standard. The *endpoint* field gives both the endpoint number and the direction, so in the above example endpoint 1 is used for OUT (host to peripheral) transfers and endpoint 2 is used for IN (peripheral to host) transfers. The *attributes* field indicates the USB protocol that should be used on this endpoint: CONTROL, ISOCRONOUS, BULK or INTERRUPT. The *max_packet* field specifies the maximum size of a single USB packet. For bulk transfers this will typically be 64 bytes. For isochronous transfers this can be up to 1023 bytes. For interrupt transfers it can be up to 64 bytes, although usually a smaller value will be used. The *interval* field is ignored for control and bulk transfers. For isochronous transfers it should be set to 1. For interrupt transfers it can be a value between 1 and 255, and indicates the number of milliseconds between successive polling operations.

For USB peripherals involving multiple configurations or interfaces the array of endpoint descriptors should be organized sequentially: first the endpoints corresponding to the first interface of the first configuration, then the second interface in that configuration, and so on; then all the endpoints for all the interfaces in the second configuration; etc.

Strings

The enumeration data can contain a number of strings with additional information. Unicode encoding is used for the strings, and it is possible for a peripheral to supply a given string in multiple languages using the appropriate characters. The first two bytes of each string give a length and type field. The first string is special; after the two bytes header it consists of an array of 2-byte language id codes, indicating the supported languages. The language code 0x0409 corresponds to English (United States).

```

const unsigned char* usb_strings[] = {
    "\004\003\011\004",
    "\020\003R\000e\000d\000 \000H\000a\000t\000"
};

const usbs_enumeration_data usb_enum_data = {
    ...
    total_number_strings:    2,
    strings:                 usb_strings,
    ...
};

```

The default handler for standard control messages assumes that the peripheral only uses a single language. If this is not the case then higher-level code will have to handle the standard get-descriptor control messages when a string descriptor is requested.

usbs_enumeration_data

The `usbs_enumeration_data` data structure collects together all the various descriptors that make up the enumeration data. It is the responsibility of application code to supply a suitable data structure and install it in the control endpoints's *enumeration_data* field before the USB device is started.

Starting up a USB Device

Name

usbs_start — Starting up a USB Device

Synopsis

```
#include <cyg/io/usb/usbs.h>
void usbs_start(usbs_control_endpoint* ep0);
```

Description

Initializing a USB device requires some support from higher-level code, typically the application, in the form of enumeration data. Hence it is not possible for the low-level USB driver to activate a USB device itself. Instead the higher-level code has to take care of this by invoking `usbs_start`. This function takes a pointer to a USB control endpoint data structure. USB device drivers should provide exactly one such data structure for every USB device, so the pointer uniquely identifies the device.

```
const usbs_enumeration_data usb_enum_data = {
    ...
};

int
main(int argc, char** argv)
{
    usbs_sallx0_ep0.enumeration_data = &usb_enum_data;
    ...
    usbs_start(&usbs_sallx0_ep0);
    ...
}
```

The exact behaviour of `usbs_start` depends on the USB hardware and the device driver. A typical implementation would change the USB data pins from tristated to active. If the peripheral is already plugged into a host then the latter should detect this change and start interacting with the peripheral, including requesting the enumeration data. Some of this may happen before `usbs_start` returns, but given that multiple interactions between USB host and peripheral are required it is likely that the function will return before the peripheral is fully configured. Control endpoints provide a [mechanism](#) for informing higher-level code of USB state changes. `usbs_start` will return even if the peripheral is not currently connected to a host: it will not block until the connection is established.

`usbs_start` should only be called once for a given USB device. There are no defined error conditions. Note that the function affects the entire USB device and not just the control endpoint: there is no need to start any data endpoints as well.

Devtab Entries

Name

Devtab Entries — Data endpoint data structure

Synopsis

```
/dev/usb0c  
/dev/usb1r  
/dev/usb2w
```

Devtab Entries

USB device drivers provide two ways of transferring data between host and peripheral. The first involves USB-specific functionality such as [usbs_start_rx_buffer](#). This provides non-blocking I/O: a transfer is started, and some time later the device driver will call a supplied completion function. The second uses the conventional I/O model: there are entries in the device table corresponding to the various endpoints. Standard calls such as `open` can then be used to get a suitable handle. Actual I/O happens via blocking `read` and `write` calls. In practice the blocking operations are simply implemented using the underlying non-blocking functionality.

Each endpoint will have its own devtab entry. The exact names are controlled by the device driver package, but typically the root will be `/dev/usb`. This is followed by one or more decimal digits giving the endpoint number, followed by `c` for a control endpoint, `r` for a receive endpoint (host to peripheral), and `w` for a transmit endpoint (peripheral to host). If the target hardware involves more than one USB device then different roots should be used, for example `/dev/usb0c` and `/dev/usb1_0c`. This may require explicit manipulation of device driver configuration options by the application developer.

At present the devtab entry for a control endpoint does not support any I/O operations.

write operations

`cyg_io_write` and similar functions in higher-level packages can be used to perform a transfer from peripheral to host. Successive write operations will not be coalesced. For example, when doing a 1000 byte write to an endpoint that uses the bulk transfer protocol this will involve 15 full-size 64-byte packets and a terminating 40-byte packet. USB device drivers are not expected to do any locking, and if higher-level code performs multiple concurrent write operations on a single endpoint then the resulting behaviour is undefined.

A USB `write` operation will never transfer less data than specified. It is the responsibility of higher-level code to ensure that the amount of data being transferred is acceptable to the host-side code. Usually this will be defined by a higher-level protocol. If an attempt is made to transfer more data than the host expects then the resulting behaviour is undefined.

There are two likely error conditions. `EPIPE` indicates that the connection between host and target has been broken. `EAGAIN` indicates that the endpoint has been stalled, either at the request of the host or by other activity inside the peripheral.

read operations

`cyg_io_read` and similar functions in higher-level packages can be used to perform a transfer from host to peripheral. This should be a complete transfer: higher-level protocols should define an upper bound on the

amount of data being transferred, and the `read` operation should involve at least this amount of data. The return value will indicate the actual transfer size, which may be less than requested.

Some device drivers may support partial reads, but USB device drivers are not expected to perform any buffering because that involves both memory and code overheads. One technique that may work for bulk transfers is to exploit the fact that such transfers happen in 64-byte packets. It is possible to `read` an initial 64 bytes, corresponding to the first packet in the transfer. These 64 bytes can then be examined to determine the total transfer size, and the remaining data can be transferred in another `read` operation. This technique is not guaranteed to work with all USB hardware. Also, if the delay between accepting the first packet and the remainder of the transfer is excessive then this could cause timeout problems for the host-side software. For these reasons the use of partial reads should be avoided.

There are two likely error conditions. `EPIPE` indicates that the connection between host and target has been broken. `EAGAIN` indicates that the endpoint has been stalled, either at the request of the host or by other activity inside the peripheral.

USB device drivers are not expected to do any locking. If higher-level code performs multiple concurrent read operations on a single endpoint then the resulting behaviour is undefined.

select operations

Typical USB device drivers will not provide any support for `select`. Consider bulk transfers from the host to the peripheral. At the USB device driver level there is no way of knowing in advance how large a transfer will be, so it is not feasible for the device driver to buffer the entire transfer. It may be possible to buffer part of the transfer, for example the first 64-byte packet, and copy this into application space at the start of a `read`, but this adds code and memory overheads. Worse, it means that there is an unknown but potentially long delay between a peripheral accepting the first packet of a transfer and the remaining packets, which could confuse or upset the host-side software.

With some USB hardware it may be possible for the device driver to detect OUT tokens from the host without actually accepting the data, and this would indicate that a `read` is likely to succeed. However, it would not be reliable since the host-side I/O operation could time out. A similar mechanism could be used to implement `select` for outgoing data, but again this would not be reliable.

Some device drivers may provide partial support for `select` anyway, possibly under the control of a configuration option. The device driver's documentation should be consulted for further information. It is also worth noting that the USB-specific non-blocking API can often be used as an alternative to `select`.

get_config and set_config operations

There are no `set_config` or `get_config` (also known as `ioctl`) operations defined for USB devices. Some device drivers may provide hardware-specific facilities this way.

Note: Currently the USB-specific functions related to [halted endpoints](#) cannot be accessed readily via devtab entries. This functionality should probably be made available via `set_config` and `get_config`. It may also prove useful to provide a `get_config` operation that maps from the devtab entries to the underlying endpoint data structures.

Presence

The devtab entries are optional. If the USB device is accessed primarily by class-specific code such as the USB-ethernet package and that package uses the USB-specific API directly, the devtab entries are redundant. Even if application code does need to access the USB device, the non-blocking API may be more convenient than the blocking I/O provided via the devtab entries. In these cases the devtab entries serve no useful purpose, but they still impose a memory overhead. It is possible to suppress the presence of these entries by disabling the configuration option `CYGGLO_IO_USB_SLAVE_PROVIDE_DEVTAB_ENTRIES`.

Receiving Data from the Host

Name

`usbs_start_rx_buffer` — Receiving Data from the Host

Synopsis

```
#include <cyg/io/usb/usbs.h>
void usbs_start_rx_buffer(usbs_rx_endpoint* ep, unsigned char* buffer, int length, void
(*) (void*,int) complete_fn, void * complete_data);
void usbs_start_rx(usbs_rx_endpoint* ep);
```

Description

`usbs_start_rx_buffer` is a USB-specific function to accept a transfer from host to peripheral. It can be used for bulk, interrupt or isochronous transfers, but not for control messages. Instead those involve manipulating the [usbs_control_endpoint](#) data structure directly. The function takes five arguments:

1. The first argument identifies the specific endpoint that should be used. Different USB devices will support different sets of endpoints and the device driver will provide appropriate data structures. The device driver's documentation should be consulted for details of which endpoints are available.
2. The *buffer* and *length* arguments control the actual transfer. USB device drivers are not expected to perform any buffering or to support partial transfers, so the length specified should correspond to the maximum transfer that is currently possible and the buffer should be at least this large. For isochronous transfers the USB specification imposes an upper bound of 1023 bytes, and a smaller limit may be set in the [enumeration data](#). Interrupt transfers are similarly straightforward with an upper bound of 64 bytes, or less as per the enumeration data. Bulk transfers are more complicated because they can involve multiple 64-byte packets plus a terminating packet of less than 64 bytes, so there is no predefined limit on the transfer size. Instead it is left to higher-level protocols to specify an appropriate upper bound.

One technique that may work for bulk transfers is to exploit the fact that such transfers happen in 64-byte packets: it may be possible to receive an initial 64 bytes, corresponding to the first packet in the transfer; these 64 bytes can then be examined to determine the total transfer size, and the remaining data can be transferred in another receive operation. This technique is not guaranteed to work with all USB hardware. Also, if the delay between accepting the first packet and the remainder of the transfer is excessive then this could cause timeout problems for the host-side software. For these reasons this technique should be avoided.

3. `usbs_start_rx_buffer` is non-blocking. It merely starts the receive operation, and does not wait for completion. At some later point the USB device driver will invoke the completion function parameter with two arguments: the completion data defined by the last parameter and a result field. A result ≥ 0 indicates a successful transfer of that many bytes, which may be less than the upper bound imposed by the *length* argument. A result < 0 indicates an error. The most likely errors are `-EPIPE` to indicate that the connection between the host and the target has been broken, and `-EAGAIN` for when the endpoint has been [halted](#). Specific USB device drivers may specify additional error conditions.

The normal sequence of events is that the USB device driver will update the appropriate hardware registers. At some point after that the host will attempt to send data by transmitting an OUT token followed by a data packet, and since a receive operation is now in progress the data will be accepted and ACK'd. If there were no receive operation then the peripheral would instead generate a NAK. The USB hardware will generate an interrupt once the whole packet has been received, and the USB device driver will service this interrupt and arrange for a DSR to be called. Isochronous and interrupt transfers involve just a single packet. However, bulk transfers may involve multiple packets so the device driver has to check whether the packet was a full 64 bytes or whether it was a terminating packet of less than this. When the device driver DSR detects a complete transfer it will inform higher-level code by invoking the supplied completion function.

This means that the completion function will normally be invoked by a DSR and not in thread context - although some USB device drivers may have a different implementation. Therefore the completion function is restricted in what it can do. In particular it must not make any calls that will or may block such as locking a mutex or allocating memory. The kernel documentation should be consulted for more details of DSR's and interrupt handling generally.

It is possible that the completion function will be invoked before `usbs_start_rx_buffer` returns. Such an event would be unusual because the transfer cannot happen until the next time the host tries to send data to this peripheral, but it may happen if for example another interrupt happens and a higher priority thread is scheduled to run. Also, if the endpoint is currently halted then the completion function will be invoked immediately with `-EAGAIN`: typically this will happen in the current thread rather than in a separate DSR. The completion function is allowed to start another transfer immediately by calling `usbs_start_rx_buffer` again.

USB device drivers are not expected to perform any locking. It is the responsibility of higher-level code to ensure that there is only one receive operation for a given endpoint in progress at any one time. If there are concurrent calls to `usbs_start_rx_buffer` then the resulting behaviour is undefined. For typical USB applications this does not present any problems, because only one piece of code will access a given endpoint at any particular time.

The following code fragment illustrates a very simple use of `usbs_start_rx_buffer` to implement a blocking receive, using a semaphore to synchronise between the foreground thread and the DSR. For a simple example like this no completion data is needed.

```
static int error_code = 0;
static cyg_sem_t completion_wait;

static void
completion_fn(void* data, int result)
{
    error_code = result;
    cyg_semaphore_post(&completion_wait);
}

int
blocking_receive(usbs_rx_endpoint* ep, unsigned char* buf, int len)
{
    error_code = 0;
    usbs_start_rx_buffer(ep, buf, len, &completion_fn, NULL);
    cyg_semaphore_wait(&completion_wait);
    return error_code;
}
```

There is also a utility function `usbs_start_rx`. This can be used by code that wants to manipulate [data endpoints](#) directly, specifically the `complete_fn`, `complete_data`, `buffer` and `buffer_size` fields. `usbs_start_tx` just invokes a function supplied by the device driver.

Sending Data to the Host

Name

`usbs_start_tx_buffer` — Sending Data to the Host

Synopsis

```
#include <cyg/io/usb/usbs.h>
void usbs_start_tx_buffer(usbs_tx_endpoint* ep, const unsigned char* buffer, int
length, void (*)(void*,int) complete_fn, void * complete_data);
void usbs_start_tx(usbs_tx_endpoint* ep);
```

Description

`usbs_start_tx_buffer` is a USB-specific function to transfer data from peripheral to host. It can be used for bulk, interrupt or isochronous transfers, but not for control messages; instead those involve manipulating the [usbs_control_endpoint](#) data structure directly. The function takes five arguments:

1. The first argument identifies the specific endpoint that should be used. Different USB devices will support different sets of endpoints and the device driver will provide appropriate data structures. The device driver's documentation should be consulted for details of which endpoints are available.
2. The *buffer* and *length* arguments control the actual transfer. USB device drivers are not allowed to modify the buffer during the transfer, so the data can reside in read-only memory. The transfer will be for all the data specified, and it is the responsibility of higher-level code to make sure that the host is expecting this amount of data. For isochronous transfers the USB specification imposes an upper bound of 1023 bytes, but a smaller limit may be set in the [enumeration data](#). Interrupt transfers have an upper bound of 64 bytes or less, as per the enumeration data. Bulk transfers are more complicated because they can involve multiple 64-byte packets plus a terminating packet of less than 64 bytes, so the basic USB specification does not impose an upper limit on the total transfer size. Instead it is left to higher-level protocols to specify an appropriate upper bound. If the peripheral attempts to send more data than the host is willing to accept then the resulting behaviour is undefined and may well depend on the specific host operating system being used.

For bulk transfers, the USB device driver or the underlying hardware will automatically split the transfer up into the appropriate number of full-size 64-byte packets plus a single terminating packet, which may be 0 bytes.

3. `usbs_start_tx_buffer` is non-blocking. It merely starts the transmit operation, and does not wait for completion. At some later point the USB device driver will invoke the completion function parameter with two arguments: the completion data defined by the last parameter, and a result field. This result will be either an error code < 0 , or the amount of data transferred which should correspond to the *length* argument. The most likely errors are `-EPIPE` to indicate that the connection between the host and the target has been broken, and `-EAGAIN` for when the endpoint has been [halted](#). Specific USB device drivers may define additional error conditions.

The normal sequence of events is that the USB device driver will update the appropriate hardware registers. At some point after that the host will attempt to fetch data by transmitting an IN token. Since a transmit operation is now in progress the peripheral can send a packet of data, and the host will generate an ACK. At this point the USB hardware will generate an interrupt, and the device driver will service this interrupt and arrange for a DSR to be called. Isochronous and interrupt transfers involve just a single packet. However, bulk transfers may involve multiple packets so the device driver has to check whether there is more data to send and set things up for the next packet. When the device driver DSR detects a complete transfer it will inform higher-level code by invoking the supplied completion function.

This means that the completion function will normally be invoked by a DSR and not in thread context - although some USB device drivers may have a different implementation. Therefore the completion function is restricted in what it can do, in particular it must not make any calls that will or may block such as locking a mutex or allocating memory. The kernel documentation should be consulted for more details of DSR's and interrupt handling generally.

It is possible that the completion function will be invoked before `usbs_start_tx_buffer` returns. Such an event would be unusual because the transfer cannot happen until the next time the host tries to fetch data from this peripheral, but it may happen if, for example, another interrupt happens and a higher priority thread is scheduled to run. Also, if the endpoint is currently halted then the completion function will be invoked immediately with `-EAGAIN`: typically this will happen in the current thread rather than in a separate DSR. The completion function is allowed to start another transfer immediately by calling `usbs_start_tx_buffer` again.

USB device drivers are not expected to perform any locking. It is the responsibility of higher-level code to ensure that there is only one transmit operation for a given endpoint in progress at any one time. If there are concurrent calls to `usbs_start_tx_buffer` then the resulting behaviour is undefined. For typical USB applications this does not present any problems because only piece of code will access a given endpoint at any particular time.

The following code fragment illustrates a very simple use of `usbs_start_tx_buffer` to implement a blocking transmit, using a semaphore to synchronise between the foreground thread and the DSR. For a simple example like this no completion data is needed.

```
static int error_code = 0;
static cyg_sem_t completion_wait;

static void
completion_fn(void* data, int result)
{
    error_code = result;
    cyg_semaphore_post(&completion_wait);
}

int
blocking_transmit(usbs_tx_endpoint* ep, const unsigned char* buf, int len)
{
    error_code = 0;
    usbs_start_tx_buffer(ep, buf, len, &completion_fn, NULL);
    cyg_semaphore_wait(&completion_wait);
    return error_code;
}
```

There is also a utility function `usbs_start`. This can be used by code that wants to manipulate [data endpoints](#) directly, specifically the `complete_fn`, `complete_data`, `buffer` and `buffer_size` fields. `usbs_start_tx` just calls a function supplied by the device driver.

Halted Endpoints

Name

Halted Endpoints — Support for Halting and Halted Endpoints

Synopsis

```
#include <cyg/io/usb/usbs.h>
cyg_bool usbs_rx_endpoint_halted(usbs_rx_endpoint* ep);
void usbs_set_rx_endpoint_halted(usbs_rx_endpoint* ep, cyg_bool new_state);
void usbs_start_rx_endpoint_wait(usbs_rx_endpoint* ep, void (*)(void*, int)
complete_fn, void * complete_data);
cyg_bool usbs_tx_endpoint_halted(usbs_tx_endpoint* ep);
void usbs_set_tx_endpoint_halted(usbs_tx_endpoint* ep, cyg_bool new_state);
void usbs_start_tx_endpoint_wait(usbs_tx_endpoint* ep, void (*)(void*, int)
complete_fn, void * complete_data);
```

Description

Normal USB traffic involves straightforward handshakes, with either an ACK to indicate that a packet was transferred without errors, or a NAK if an error occurred, or if a peripheral is currently unable to process another packet from the host, or has no packet to send to the host. There is a third form of handshake, a STALL, which indicates that the endpoint is currently *halted*.

When an endpoint is halted it means that the host-side code needs to take some sort of recovery action before communication over that endpoint can resume. The exact circumstances under which this can happen are not defined by the USB specification, but one example would be a protocol violation if say the peripheral attempted to transmit more data to the host than was permitted by the protocol in use. The host can use the standard control messages get-status, set-feature and clear-feature to examine and manipulate the halted status of a given endpoint. There are USB-specific functions which can be used inside the peripheral to achieve the same effect. Once an endpoint has been halted the host can then interact with the peripheral using class or vendor control messages to perform appropriate recovery, and then the halted condition can be cleared.

Halting an endpoint does not constitute a device state change, and there is no mechanism by which higher-level code can be informed immediately. However, any ongoing receive or transmit operations will be aborted with an -EAGAIN error, and any new receives or transmits will fail immediately with the same error.

There are six functions to support halted endpoints, one set for receive endpoints and another for transmit endpoints, with both sets behaving in essentially the same way. The first, `usbs_rx_endpoint_halted`, can be used to determine whether or not an endpoint is currently halted: it takes a single argument that identifies the endpoint of interest. The second function, `usbs_set_rx_endpoint_halted`, can be used to change the halted condition of an endpoint: it takes two arguments; one to identify the endpoint and another to specify the new state. The last function `usbs_start_rx_endpoint_wait` operates in much the same way as `usbs_start_rx_buffer`: when the endpoint is no longer halted the device driver will invoke the supplied completion function with a status of 0. The completion function has the same signature as that for a transfer operation. Often it will be possible to use a single completion function and have the foreground code invoke either `usbs_start_rx_buffer` or `usbs_start_rx_endpoint_wait` depending on the current state of the endpoint.

Control Endpoints

Name

Control Endpoints — Control endpoint data structure

Synopsis

```
#include <cyg/io/usb/usbs.h>

typedef struct usbs_control_endpoint {
    *hellip;
} usbs_control_endpoint;
```

usbs_control_endpoint Data Structure

The device driver for a USB slave device should supply one `usbs_control_endpoint` data structure per USB device. This corresponds to endpoint 0 which will be used for all control message interaction between the host and that device. The data structure is also used for internal management purposes, for example to keep track of the current state. In a typical USB peripheral there will only be one such data structure in the entire system, but if there are multiple USB slave ports, allowing the peripheral to be connected to multiple hosts, then there will be a separate data structure for each one. The name or names of the data structures are determined by the device drivers. For example, the SA11x0 USB device driver package provides `usbs_sa11x0_ep0`.

The operations on a control endpoint do not fit cleanly into a conventional open/read/write I/O model. For example, when the host sends a control message to the USB peripheral this may be one of four types: standard, class, vendor and reserved. Some or all of the standard control messages will be handled automatically by the common USB slave package or by the device driver itself. Other standard control messages and the other types of control messages may be handled by a class-specific package or by application code. Although it would be possible to have devtab entries such as `/dev/usbs_ep0/standard` and `/dev/usbs_ep0/class`, and then support read and write operations on these devtab entries, this would add significant overhead and code complexity. Instead, all of the fields in the control endpoint data structure are public and can be manipulated directly by higher level code if and when required.

Control endpoints involve a number of callback functions, with higher-level code installing suitable function pointers in the control endpoint data structure. For example, if the peripheral involves vendor-specific control messages then a suitable handler for these messages should be installed. Although the exact details depend on the device driver, typically these callback functions will be invoked at DSR level rather than thread level. Therefore, only certain eCos functions can be invoked; specifically, those functions that are guaranteed not to block. If a potentially blocking function such as a semaphore wait or a mutex lock operation is invoked from inside the callback then the resulting behaviour is undefined, and the system as a whole may fail. In addition, if one of the callback functions involves significant processing effort then this may adversely affect the system's real time characteristics. The eCos kernel documentation should be consulted for more details of DSR handling.

Initialization

The `usbs_control_endpoint` data structure contains the following fields related to initialization.

```
typedef struct usbs_control_endpoint {
    ...
```

```

    const usbs_enumeration_data* enumeration_data;
    void (*start_fn)(usbs_control_endpoint*);
    ...
};

```

It is the responsibility of higher-level code, usually the application, to define the USB enumeration data. This needs to be installed in the control endpoint data structure early on during system startup, before the USB device is actually started and any interaction with the host is possible. Details of the enumeration data are supplied in the section [USB Enumeration Data](#). Typically, the enumeration data is constant for a given peripheral, although it can be constructed dynamically if necessary. However, the enumeration data cannot change while the peripheral is connected to a host: the peripheral cannot easily claim to be a keyboard one second and a printer the next.

The `start_fn` member is normally accessed via the utility `usbs_start` rather than directly. It is provided by the device driver and should be invoked once the system is fully initialized and interaction with the host is possible. A typical implementation would change the USB data pins from tristated to active. If the peripheral is already plugged into a host then the latter should detect this change and start interacting with the peripheral, including requesting the enumeration data.

State

There are three `usbs_control_endpoint` fields related to the current state of a USB slave device, plus some state constants and an enumeration of the possible state changes:

```

typedef struct usbs_control_endpoint {
    ...
    int      state;
    void      (*state_change_fn)(struct usbs_control_endpoint*, void*,
                                usbs_state_change, int);
    void*     state_change_data;
    ...
};

#define USBS_STATE_DETACHED          0x01
#define USBS_STATE_ATTACHED         0x02
#define USBS_STATE_POWERED          0x03
#define USBS_STATE_DEFAULT          0x04
#define USBS_STATE_ADDRESSED        0x05
#define USBS_STATE_CONFIGURED       0x06
#define USBS_STATE_MASK             0x7F
#define USBS_STATE_SUSPENDED        (1 << 7)

typedef enum {
    USBS_STATE_CHANGE_DETACHED      = 1,
    USBS_STATE_CHANGE_ATTACHED      = 2,
    USBS_STATE_CHANGE_POWERED       = 3,
    USBS_STATE_CHANGE_RESET         = 4,
    USBS_STATE_CHANGE_ADDRESSED     = 5,
    USBS_STATE_CHANGE_CONFIGURED    = 6,
    USBS_STATE_CHANGE_DECONFIGURED  = 7,
    USBS_STATE_CHANGE_SUSPENDED     = 8,
    USBS_STATE_CHANGE_RESUMED       = 9
} usbs_state_change;

```

The USB standard defines a number of states for a given USB peripheral. The initial state is *detached*, where the peripheral is either not connected to a host at all or, from the host's perspective, the peripheral has not

started up yet because the relevant pins are tristated. The peripheral then moves via intermediate *attached* and *powered* states to its default or *reset* state, at which point the host and peripheral can actually start exchanging data. The first message is from host to peripheral and provides a unique 7-bit address within the local USB network, resulting in a state change to *addressed*. The host then requests enumeration data and performs other initialization. If everything succeeds the host sends a standard set-configuration control message, after which the peripheral is *configured* and expected to be up and running. Note that some USB device drivers may be unable to distinguish between the *detached*, *attached* and *powered* states but generally this is not important to higher-level code.

A USB host should generate at least one token every millisecond. If a peripheral fails to detect any USB traffic for a period of time then typically this indicates that the host has entered a power-saving mode, and the peripheral should do the same if possible. This corresponds to the *suspended* bit. The actual state is a combination of *suspended* and the previous state, for example *configured* and *suspended* rather than just *suspended*. When the peripheral subsequently detects USB traffic it would switch back to the *configured* state.

The USB device driver and the common USB slave package will maintain the current state in the control endpoint's *state* field. There should be no need for any other code to change this field, but it can be examined whenever appropriate. In addition whenever a state change occurs the generic code can invoke a state change callback function. By default, no such callback function will be installed. Some class-specific packages such as the USB-ethernet package will install a suitable function to keep track of whether or not the host-peripheral connection is up, that is whether or not ethernet packets can be exchanged. Application code can also update this field. If multiple parties want to be informed of state changes, for example both a class-specific package and application code, then typically the application code will install its state change handler after the class-specific package and is responsible for chaining into the package's handler.

The state change callback function is invoked with four arguments. The first identifies the control endpoint. The second is an arbitrary pointer: higher-level code can fill in the *state_change_data* field to set this. The third argument specifies the state change that has occurred, and the last argument supplies the previous state (the new state is readily available from the control endpoint structure).

eCos does not provide any utility functions for updating or examining the *state_change_fn* or *state_change_data* fields. Instead, it is expected that the fields in the *usbs_control_endpoint* data structure will be manipulated directly. Any utility functions would do just this, but at the cost of increased code and cpu overheads.

Standard Control Messages

```
typedef struct usbs_control_endpoint {
    ...
    unsigned char    control_buffer[8];
    usbs_control_return (*standard_control_fn)(struct usbs_control_endpoint*, void*);
    void*            standard_control_data;
    ...
} usbs_control_endpoint;

typedef enum {
    USBS_CONTROL_RETURN_HANDLED = 0,
    USBS_CONTROL_RETURN_UNKNOWN = 1,
    USBS_CONTROL_RETURN_STALL   = 2
} usbs_control_return;

extern usbs_control_return usbs_handle_standard_control(struct usbs_control_endpoint*);
```

When a USB peripheral is connected to the host it must always respond to control messages sent to endpoint 0. Control messages always consist of an initial eight-byte header, containing fields such as a request type. This may be followed by a further data transfer, either from host to peripheral or from peripheral to host. The way this is handled is described in the [Buffer Management](#) section below.

The USB device driver will always accept the initial eight-byte header, storing it in the *control_buffer* field. Then it determines the request type: standard, class, vendor, or reserved. The way in which the last three of these are processed is described in the section [Other Control Messages](#). Some standard control messages will be handled by the device driver itself; typically the *set-address* request and the *get-status*, *set-feature* and *clear-feature* requests when applied to endpoints.

If a standard control message cannot be handled by the device driver itself, the driver checks the *standard_control_fn* field in the control endpoint data structure. If higher-level code has installed a suitable callback function then this will be invoked with two arguments, the control endpoint data structure itself and the *standard_control_data* field. The latter allows the higher level code to associate arbitrary data with the control endpoint. The callback function can return one of three values: *HANDLED* to indicate that the request has been processed; *UNKNOWN* if the message should be handled by the default code; or *STALL* to indicate an error condition. If higher level code has not installed a callback function or if the callback function has returned *UNKNOWN* then the device driver will invoke a default handler, *usbs_handle_standard_control* provided by the common USB slave package.

The default handler can cope with all of the standard control messages for a simple USB peripheral. However, if the peripheral involves multiple configurations, multiple interfaces in a configuration, or alternate settings for an interface, then this cannot be handled by generic code. For example, a multimedia peripheral may support various alternate settings for a given data source with different bandwidth requirements, and the host can select a setting that takes into account the current load. Clearly higher-level code needs to be aware when the host changes the current setting, so that it can adjust the rate at which data is fed to or retrieved from the host. Therefore the higher-level code needs to install its own standard control callback and process appropriate messages, rather than leaving these to the default handler.

The default handler will take care of the *get-descriptor* request used to obtain the enumeration data. It has support for string descriptors but ignores language encoding issues. If language encoding is important for the peripheral then this will have to be handled by an application-specific standard control handler.

The header file `<cyg/io/usb/usb.h>` defines various constants related to control messages, for example the function codes corresponding to the standard request types. This header file is provided by the common USB package, not by the USB slave package, since the information is also relevant to USB hosts.

Other Control Messages

```
typedef struct usbs_control_endpoint {
    ...
    usbs_control_return (*class_control_fn)(struct usbs_control_endpoint*, void*);
    void*                class_control_data;
    usbs_control_return (*vendor_control_fn)(struct usbs_control_endpoint*, void*);
    void*                vendor_control_data;
    usbs_control_return (*reserved_control_fn)(struct usbs_control_endpoint*, void*);
    void*                reserved_control_data;
    ...
} usbs_control_endpoint;
```

Non-standard control messages always have to be processed by higher-level code. This could be class-specific packages. For example, the USB-ethernet package will handle requests for getting the MAC address and for enabling or disabling promiscuous mode. In all cases the device driver will store the initial request in the *control_buffer* field, check for an appropriate handler, and invoke it with details of the control endpoint and any handler-specific data that has been installed alongside the handler itself. The handler should return either *USBS_CONTROL_RETURN_HANDLED* to report success or *USBS_CONTROL_RETURN_STALL* to report failure. The device driver will report this to the host.

If there are multiple parties interested in a particular type of control messages, it is the responsibility of application code to install an appropriate handler and process the requests appropriately.

Buffer Management

```
typedef struct usbs_control_endpoint {
    ...
    unsigned char*    buffer;
    int               buffer_size;
    void              (*fill_buffer_fn)(struct usbs_control_endpoint*);
    void*             fill_data;
    int               fill_index;
    usbs_control_return (*complete_fn)(struct usbs_control_endpoint*, int);
    ...
} usbs_control_endpoint;
```

Many USB control messages involve transferring more data than just the initial eight-byte header. The header indicates the direction of the transfer, OUT for host to peripheral or IN for peripheral to host. It also specifies a length field, which is exact for an OUT transfer or an upper bound for an IN transfer. Control message handlers can manipulate six fields within the control endpoint data structure to ensure that the transfer happens correctly.

For an OUT transfer, the handler should examine the length field in the header and provide a single buffer for all the data. A class-specific protocol would typically impose an upper bound on the amount of data, allowing the buffer to be allocated statically. The handler should update the *buffer* and *complete_fn* fields. When all the data has been transferred the completion callback will be invoked, and its return value determines the response sent back to the host. The USB standard allows for a new control message to be sent before the current transfer has completed, effectively cancelling the current operation. When this happens the completion function will also be invoked. The second argument to the completion function specifies what has happened, with a value of 0 indicating success and an error code such as *-EPIPE* or *-EIO* indicating that the current transfer has been cancelled.

IN transfers are a little bit more complicated. The required information, for example the enumeration data, may not be in a single contiguous buffer. Instead a mechanism is provided by which the buffer can be refilled, thus allowing the transfer to move from one record to the next. Essentially, the transfer operates as follows:

1. When the host requests another chunk of data (typically eight bytes), the USB device driver will examine the *buffer_size* field. If non-zero then *buffer* contains at least one more byte of data, and then *buffer_size* is decremented.
2. When *buffer_size* has dropped to 0, the *fill_buffer_fn* field will be examined. If non-null it will be invoked to refill the buffer.
3. The *fill_data* and *fill_index* fields are not used by the device driver. Instead these fields are available to the refill function to keep track of the current state of the transfer.
4. When *buffer_size* is 0 and *fill_buffer_fn* is NULL, no more data is available and the transfer has completed.
5. Optionally a completion function can be installed. This will be invoked with 0 if the transfer completes successfully, or with an error code if the transfer is cancelled because of another control message.

If the requested data is contiguous then the only fields that need to be manipulated are *buffer* and *buffer_size*, and optionally *complete_fn*. If the requested data is not contiguous then the initial control message handler should update *fill_buffer_fn* and some or all of the other fields, as required. An example of this is the handling of the standard *get-descriptor* control message by *usbs_handle_standard_control*.

Polling Support

```
typedef struct usbs_control_endpoint {
```

Control Endpoints

```
void (*poll_fn)(struct usbs_control_endpoint*);
int interrupt_vector;
...
} usbs_control_endpoint;
```

In nearly all circumstances USB I/O should be interrupt-driven. However, there are special environments such as RedBoot where polled operation may be appropriate. If the device driver can operate in polled mode then it will provide a suitable function via the *poll_fn* field, and higher-level code can invoke this regularly. This polling function will take care of all endpoints associated with the device, not just the control endpoint. If the USB hardware involves a single interrupt vector then this will be identified in the data structure as well.

Data Endpoints

Name

Data Endpoints — Data endpoint data structures

Synopsis

```
#include <cyg/io/usb/usbs.h>

typedef struct usbs_rx_endpoint {
    void (*start_rx_fn)(struct usbs_rx_endpoint*);
    void (*set_halted_fn)(struct usbs_rx_endpoint*, cyg_bool);
    void (*complete_fn)(void*, int);
    void* complete_data;
    unsigned char* buffer;
    int buffer_size;
    cyg_bool halted;
} usbs_rx_endpoint;

typedef struct usbs_tx_endpoint {
    void (*start_tx_fn)(struct usbs_tx_endpoint*);
    void (*set_halted_fn)(struct usbs_tx_endpoint*, cyg_bool);
    void (*complete_fn)(void*, int);
    void* complete_data;
    const unsigned char* buffer;
    int buffer_size;
    cyg_bool halted;
} usbs_tx_endpoint;
```

Receive and Transmit Data Structures

In addition to a single `usbs_control_endpoint` data structure per USB slave device, the USB device driver should also provide receive and transmit data structures corresponding to the other endpoints. The names of these are determined by the device driver. For example, the SA1110 USB device driver package provides `usbs_sa11x0_ep1` for receives and `usbs_sa11x0_ep2` for transmits.

Unlike control endpoints, the common USB slave package does provide a number of utility routines to manipulate data endpoints. For example `usbs_start_rx_buffer` can be used to receive data from the host into a buffer. In addition the USB device driver can provide devtab entries such as `/dev/usbs1r` and `/dev/usbs2w`, so higher-level code can open these devices and then perform blocking `read` and `write` operations.

However, the operation of data endpoints and the various endpoint-related functions is relatively straightforward. First consider a `usbs_rx_endpoint` structure. The device driver will provide the members `start_rx_fn` and `set_halted_fn`, and it will maintain the `halted` field. To receive data, higher-level code sets the `buffer`, `buffer_size`, `complete_fn` and optionally the `complete_data` fields. Next the `start_rx_fn` member should be called. When the transfer has finished the device driver will invoke the completion function, using `complete_data` as the first argument and a size field for the second argument. A negative size indicates an error of some sort: `-EGAIN` indicates that the endpoint has been halted, usually at the request of the host; `-EPIPE` indicates that the connection between the host and the peripheral has been broken. Certain device drivers may generate other error codes.

If higher-level code needs to halt or unhalt an endpoint then it can invoke the *set_halted_fn* member. When an endpoint is halted, invoking *start_rx_fn* with *buffer_size* set to 0 indicates that higher-level code wants to block until the endpoint is no longer halted; at that point the completion function will be invoked.

USB device drivers are allowed to assume that higher-level protocols ensure that host and peripheral agree on the amount of data that will be transferred, or at least on an upper bound. Therefore there is no need for the device driver to maintain its own buffers, and copy operations are avoided. If the host sends more data than expected then the resulting behaviour is undefined.

Transmit endpoints work in essentially the same way as receive endpoints. Higher-level code should set the *buffer* and *buffer_size* fields to point at the data to be transferred, then call *start_tx_fn*, and the device driver will invoke the completion function when the transfer has completed.

USB device drivers are not expected to perform any locking. If at any time there are two concurrent receive operations for a given endpoint, or two concurrent transmit operations, then the resulting behaviour is undefined. It is the responsibility of higher-level code to perform any synchronisation that may be necessary. In practice, conflicts are unlikely because typically a given endpoint will only be accessed sequentially by just one part of the overall system.

Writing a USB Device Driver

Name

Writing a USB Device Driver — USB Device Driver Porting Guide

Introduction

Often the best way to write a USB device driver will be to start with an existing one and modify it as necessary. The information given here is intended primarily as an outline rather than as a complete guide.

Note: At the time of writing only one USB device driver has been implemented. Hence it is possible, perhaps probable, that some portability issues have not yet been addressed. One issue involves the different types of transfer, for example the initial target hardware had no support for isochronous or interrupt transfers, so additional functionality may be needed to switch between transfer types. Another issue would be hardware where a given endpoint number, say endpoint 1, could be used for either receiving or transmitting data, but not both because a single fifo is used. Issues like these will have to be resolved as and when additional USB device drivers are written.

The Control Endpoint

A USB device driver should provide a single `usbs_control_endpoint` data structure for every USB device. Typical peripherals will have only one USB port so there will be just one such data structure in the entire system, but theoretically it is possible to have multiple USB devices. These may all involve the same chip, in which case a single device driver should support multiple device instances, or they may involve different chips. The name or names of these data structures are determined by the device driver, but appropriate care should be taken to avoid name clashes.

A USB device cannot be used unless the control endpoint data structure exists. However, the presence of USB hardware in the target processor or board does not guarantee that the application will necessarily want to use that hardware. To avoid unwanted code or data overheads, the device driver can provide a configuration option to determine whether or not the endpoint 0 data structure is actually provided. A default value of `CYGINT_IO_USB_SLAVE_CLIENTS` ensures that the USB driver will be enabled automatically if higher-level code does require USB support, while leaving ultimate control to the user.

The USB device driver is responsible for filling in the `start_fn`, `poll_fn` and `interrupt_vector` fields. Usually this can be achieved by static initialization. The driver is also largely responsible for maintaining the `state` field. The `control_buffer` array should be used to hold the first packet of a control message. The `buffer` and other fields related to data transfers will be managed [jointly](#) by higher-level code and the device driver. The remaining fields are generally filled in by higher-level code, although the driver should initialize them to NULL values.

Hardware permitting, the USB device should be inactive until the `start_fn` is invoked, for example by tristating the appropriate pins. This prevents the host from interacting with the peripheral before all other parts of the system have initialized. It is expected that the `start_fn` will only be invoked once, shortly after power-up.

Where possible the device driver should detect state changes, such as when the connection between host and peripheral is established, and [report](#) these to higher-level code via the `state_change_fn` callback, if any. The state change to and from configured state cannot easily be handled by the device driver itself, instead higher-level code such as the common USB slave package will take care of this.

Once the connection between host and peripheral has been established, the peripheral must be ready to accept control messages at all times, and must respond to these within certain time constraints. For example, the standard set-address control message must be handled within 50ms. The USB specification provides more information on these constraints. The device driver is responsible for receiving the initial packet of a control message. This packet will always be eight bytes and should be stored in the `control_buffer` field. Certain standard control messages should be detected and handled by the device driver itself. The most important is set-address, but usually the get-status, set-feature and clear-feature requests when applied to halted endpoints should also be handled by the driver. Other standard control messages should first be passed on to the `standard_control_fn` callback (if any), and finally to the default handler `usbs_handle_standard_control` provided by the common USB slave package. Class, vendor and reserved control messages should always be dispatched to the appropriate callback and there is no default handler for these.

Some control messages will involve further data transfer, not just the initial packet. The device driver must handle this in accordance with the USB specification and the [buffer management strategy](#). The driver is also responsible for keeping track of whether or not the control operation has succeeded and generating an ACK or STALL handshake.

The polling support is optional and may not be feasible on all hardware. It is only used in certain specialised environments such as RedBoot. A typical implementation of the polling function would just check whether or not an interrupt would have occurred and, if so, call the same code that the interrupt handler would.

Data Endpoints

In addition to the control endpoint data structure, a USB device driver should also provide appropriate [data endpoint](#) data structures. Obviously this is only relevant if the USB support generally is desired, that is if the control endpoint is provided. In addition, higher-level code may not require all the endpoints, so it may be useful to provide configuration options that control the presence of each endpoint. For example, the intended application might only involve a single transmit endpoint and of course control messages, so supporting receive endpoints might waste memory.

Conceptually, data endpoints are much simpler than the control endpoint. The device driver has to supply two functions, one for data transfers and another to control the halted condition. These implement the functionality for `usbs_start_rx_buffer`, `usbs_start_tx_buffer`, `usbs_set_rx_endpoint_halted` and `usbs_set_tx_endpoint_halted`. The device driver is also responsible for maintaining the `halted` status.

For data transfers, higher-level code will have filled in the `buffer`, `buffer_size`, `complete_fn` and `complete_data` fields. The transfer function should arrange for the transfer to start, allowing the host to send or receive packets. Typically this will result in an interrupt at the end of the transfer or after each packet. Once the entire transfer has been completed, the driver's interrupt handling code should invoke the completion function. This can happen either in DSR context or thread context, depending on the driver's implementation. There are a number of special cases to consider. If the endpoint is halted when the transfer is started then the completion function can be invoked immediately with `-EAGAIN`. If the transfer cannot be completed because the connection is broken then the completion function should be invoked with `-EPIPE`. If the endpoint is stalled during the transfer, either because of a standard control message or because higher-level code calls the appropriate `set_halted_fn`, then again the completion function should be invoked with `-EAGAIN`. Finally, the `<usbs_start_rx_endpoint_wait` and `usbs_start_tx_endpoint_wait` functions involve calling the device driver's data transfer function with a buffer size of 0 bytes.

Note: Giving a buffer size of 0 bytes a special meaning is problematical because it prevents transfers of that size. Such transfers are allowed by the USB protocol, consisting of just headers and acknowledgements and an empty data phase, although rarely useful. A future modification of the device driver specification will

address this issue, although care has to be taken that the functionality remains accessible through devtab entries as well as via low-level accesses.

Devtab Entries

For some applications or higher-level packages it may be more convenient to use traditional open/read/write I/O calls rather than the non-blocking USB I/O calls. To support this the device driver can provide a devtab entry for each endpoint, for example:

```
#ifdef CYGVAR_DEVS_USB_SALLX0_EP1_DEVTAB_ENTRY

static CHAR_DEVIO_TABLE(usbs_sallx0_ep1_devtab_functions,
                        &cyg_devio_cwrite,
                        &usbs_devtab_cread,
                        &cyg_devio_bwrite,
                        &cyg_devio_bread,
                        &cyg_devio_select,
                        &cyg_devio_get_config,
                        &cyg_devio_set_config);

static CHAR_DEVTAB_ENTRY(usbs_sallx0_ep1_devtab_entry,
                        CYGDAT_DEVS_USB_SALLX0_DEVTAB_BASENAME "1r",
                        0,
                        &usbs_sallx0_ep1_devtab_functions,
                        &usbs_sallx0_devtab_dummy_init,
                        0,
                        (void*) &usbs_sallx0_ep1);

#endif
```

Again care must be taken to avoid name clashes. This can be achieved by having a configuration option to control the base name, with a default value of e.g. `/dev/usbs`, and appending an endpoint-specific string. This gives the application developer sufficient control to eliminate any name clashes. The common USB slave package provides functions `usbs_devtab_cwrite` and `usbs_devtab_cread`, which can be used in the function tables for transmit and receive endpoints respectively. The private field `priv` of the devtab entry should be a pointer to the underlying endpoint data structure.

Because devtab entries are never accessed directly, only indirectly, they would usually be eliminated by the linker. To avoid this the devtab entries should normally be defined in a separate source file which ends up the special library `libextras.a` rather than in the default library `libtarget.a`.

Not all applications or higher-level packages will want to use the devtab entries and the blocking I/O facilities. It may be appropriate for the device driver to provide additional configuration options that control whether or not any or all of the devtab entries should be provided, to avoid unnecessary memory overheads.

Interrupt Handling

A typical USB device driver will need to service interrupts for all of the endpoints and possibly for additional USB events such as entering or leaving suspended mode. Usually these interrupts need not be serviced directly by the ISR. Instead, they can be left to a DSR. If the peripheral is not able to accept or send another packet just yet, the hardware will generate a NAK and the host will just retry a little bit later. If high throughput is required then it may be desirable to handle the bulk transfer protocol largely at ISR level, that is take care of each packet in the ISR and only activate the DSR once the whole transfer has completed.

Control messages may involve invoking arbitrary callback functions in higher-level code. This should normally happen at DSR level. Doing it at ISR level could seriously affect the system's interrupt latency and impose unacceptable constraints on what operations can be performed by those callbacks. If the device driver requires a thread anyway then it may be appropriate to use this thread for invoking the callbacks, but usually it is not worthwhile to add a new thread to the system just for this; higher-level code is expected to write callbacks that function sensibly at DSR level. Much the same applies to the completion functions associated with data transfers. These should also be invoked at DSR or thread level.

Support for USB Testing

Optionally a USB device driver can provide support for the [USB test software](#). This requires defining a number of additional data structures, allowing the generic test code to work out just what the hardware is capable of and hence what testing can be performed.

The key data structure is `usbs_testing_endpoint`, defined in `cyg/io/usb/usbs.h`. In addition some commonly required constants are provided by the common USB package in `cyg/io/usb/usb.h`. One `usbs_testing_endpoint` structure should be defined for each supported endpoint. The following fields need to be filled in:

endpoint_type

This specifies the type of endpoint and should be one of `USB_ENDPOINT_DESCRIPTOR_ATTR_CONTROL`, `BULK`, `ISOCRONOUS` or `INTERRUPT`.

endpoint_number

This identifies the number that should be used by the host to address this endpoint. For a control endpoint it should be 0. For other types of endpoints it should be between 1 and 15.

endpoint_direction

For control endpoints this field is irrelevant. For other types of endpoint it should be either `USB_ENDPOINT_DESCRIPTOR_ENDPOINT_IN` or `USB_ENDPOINT_DESCRIPTOR_ENDPOINT_OUT`. If a given endpoint number can be used for traffic in both directions then there should be two entries in the array, one for each direction.

endpoint

This should be a pointer to the appropriate `usbs_control_endpoint`, `usbs_rx_endpoint` or `usbs_tx_endpoint` structure, allowing the generic testing code to perform low-level I/O.

devtab_entry

If the endpoint also has an entry in the system's device table then this field should give the corresponding string, for example `"/dev/usbs1r"`. This allows the generic testing code to access the device via higher-level calls like `open` and `read`.

min_size

This indicates the smallest transfer size that the hardware can support on this endpoint. Typically this will be one.

Note: Strictly speaking a minimum size of one is not quite right since it is valid for a USB transfer to involve zero bytes, in other words a transfer that involves just headers and acknowledgements and an empty data phase, and that should be tested as well. However current device drivers interpret a transfer size of 0 as special, so that would have to be resolved first.

max_size

Similarly, this specifies the largest transfer size. For control endpoints the USB protocol uses only two bytes to hold the transfer length, so there is an upper bound of 65535 bytes. In practice it is very unlikely that any control transfers would ever need to be this large, and in fact such transfers would take a long time and probably violate timing constraints. For other types of endpoint any of the protocol, the hardware, or the device driver may impose size limits. For example a given device driver might be unable to cope with transfers larger than 65535 bytes. If it should be possible to transfer arbitrary amounts of data then a value of -1 indicates no upper limit, and transfer sizes will be limited by available memory and by the capabilities of the host machine.

max_in_padding

This field is needed on some hardware where it is impossible to send packets of a certain size. For example the hardware may be incapable of sending an empty bulk packet to terminate a transfer that is an exact multiple of the 64-byte bulk packet size. Instead the driver has to do some padding and send an extra byte, and the host has to be prepared to receive this extra byte. Such a driver should specify a value of 1 for the padding field. For most drivers this field should be set to 0.

A better solution would be for the device driver to supply a fragment of Tcl code that would adjust the receive buffer size only when necessary, rather than for every transfer. Forcing receive padding on all transfers when only certain transfers will actually be padded reduces the accuracy of certain tests.

alignment

On some hardware data transfers may need to be aligned to certain boundaries, for example a word boundary or a cacheline boundary. Although in theory device drivers could hide such alignment restrictions from higher-level code by having their own buffers and performing appropriate copying, that would be expensive in terms of both memory and cpu cycles. Instead the generic testing code will align any buffers passed to the device driver to the specified boundary. For example, if the driver requires that buffers be aligned to a word boundary then it should specify an alignment value of 4.

The device driver should provide an array of these structures `usbs_testing_endpoints[]`. The USB testing code examines this array and uses the information to perform appropriate tests. Because different USB devices support different numbers of endpoints the number of entries in the array is not known in advance, so instead the testing code looks for a special terminator `USBS_TESTING_ENDPOINTS_TERMINATOR`. An example array, showing just the control endpoint and the terminator, might look like this:

```
usbs_testing_endpoint usbs_testing_endpoints[] = {
    {
        endpoint_type      : USB_ENDPOINT_DESCRIPTOR_ATTR_CONTROL,
        endpoint_number     : 0,
        endpoint_direction : USB_ENDPOINT_DESCRIPTOR_ENDPOINT_IN,
        endpoint            : (void*) &ep0.common,
        devtab_entry        : (const char*) 0,
        min_size            : 1,
        max_size            : 0xFFFF,
        max_in_padding      : 0,
        alignment           : 0
    },
    ...,
    USBS_TESTING_ENDPOINTS_TERMINATOR
}
```

```
};
```

Note: The use of a single array `usbs_testing_endpoints` limits USB testing to platforms with a single USB device: if there were multiple devices, each defining their own instance of this array, then there would be a collision at link time. In practice this should not be a major problem since typical USB peripherals only interact with a single host machine via a single slave port. In addition, even if a peripheral did have multiple slave ports the current USB testing code would not support this since it would not know which port to use.

Testing

Name

Testing — Testing of USB Device Drivers

Introduction

The support for USB testing provided by the eCos USB common slave package is somewhat different in nature from the kind of testing used in many other packages. One obvious problem is that USB tests cannot be run on just a bare target platform: instead the target platform must be connected to a suitable USB host machine, and that host machine must be running appropriate software for the test code to interact with. This is very different from say a kernel test which typically will have no external dependencies. Another important difference between USB testing and say a C library `strcmp` test is sensitivity to timing and to hardware boundary conditions: although a simple test case that just performs a small number of USB transfers is better than no testing at all, it should also be possible to run tests for hours or days on end, under a variety of loads. In order to provide the required functionality the basic architecture of the USB testing support is as follows:

1. There is a single target-side program `usbtarg`. By default when this is run on a target platform it will appear to do nothing. In fact it is waiting to be contacted by another program `usbhost` which will tell it what test or tests to run. `usbtarg` provides mechanisms for running a wide range of tests.
2. `usbtarg` is a generic program, but USB testing depends to some extent on the functionality provided by the hardware. For example there is no point in testing bulk transmits to endpoint 12 if the target hardware does not support an endpoint 12. Therefore each USB device driver should supply information about what the hardware is actually capable of, in the form of an array of `usbs_testing_endpoint` data structures.
3. There is a single host-side program `usbhost`, which acts as a counterpart to `usbtarg`. Again `usbhost` has no built-in knowledge of the test or tests that are supposed to run, it only provides mechanisms for running a wide range of tests. On start-up `usbhost` will search the USB bus for hardware running the target-side program, specifically a USB device that identifies itself as the product "Red Hat eCos USB test".
4. `usbhost` contains a Tcl interpreter, and will execute any Tcl scripts specified on the command line together with appropriate arguments. The Tcl interpreter has been extended with various commands such as `usbtest::bulktest`, so the script can perform the desired test or tests.
5. Adding a new test simply involves writing a short Tcl script that invokes the appropriate USB-specific commands. Running multiple tests involves passing appropriate arguments to `usbhost`, or alternatively writing a single script that just invokes other scripts.

The current implementation of `usbhost` depends heavily on functionality provided by the Linux kernel and in particular the `usbdevfs` support. It uses `/proc/bus/usb/devices` to find out what devices are attached to the bus, and will then access the device by opening `/proc/bus/usb/xxx/yyy` and performing `ioctl` operations. This allows USB testing to take place without having to write a new host-side device driver, but getting the code working on host machines not running Linux would obviously be problematical.

Building and Running the Target-side Code

The target-side component of the USB testing software consists of a single program `usbtarg` which contains support for a range of different tests, under the control of host-side software. This program is not built by default alongside other eCos test cases since it will only operate in certain environments, specifically when the target board's connector is plugged into a Linux host, and when the appropriate host-side software has been

installed on that host. Instead the user must enable a configuration option `CYGBLD_IO_USB_SLAVE_USBTST` to add the program to the list of tests for the current configuration.

Starting the `usbtarget` program does not require anything unusual, so it can be run in a normal `gdb` session just like any eCos application. After initialization the program will wait for activity from the host. Depending on the hardware, the Linux host will detect that a new USB peripheral is present on the bus either when the `usbtarget` initialization is complete or when the cable between target and host is connected. The host will perform the normal USB enumeration sequence and discover that the peripheral does not match any known vendor or product id and that there is no device driver for "Red Hat eCos USB test", so it will ignore the peripheral. When the `usbhost` program is run on the host it will connect to the target-side software, and testing can now commence.

Building and Running the Host-side Code

Note: In theory the host-side software should be built when the package is installed in the component repository, and removed when a package is uninstalled. The current eCos administration tool does not provide this functionality.

The host-side software should be built via the usual sequence of "configure/make/make install". It can only be built on a Linux host and the **configure** script contains an explicit test for this. Because the eCos component repository should generally be treated as a read-only resource the configure script will also prevent you from trying to build inside the source tree. Instead a separate build tree is required. Hence a typical sequence for building the host-side software would be as follows:

```
$ mkdir usbhost_build
$ cd usbhost_build
$ <repo>packages/io/usb/slave/current/host/configure ❶ ❷ <args> ❸
$ make
<output from make>
$ su ❹
$ make install
<output from make install>
$
```

- ❶ The location of the eCos component repository should be substituted for `<repo>`.
- ❷ If the package has been obtained via CVS or anonymous CVS then the package version will be `current`, as per the example. If instead the package has been obtained as part of a full eCos release or as a separate `.epk` file then the appropriate package version should be used instead of `current`.
- ❸ The **configure** script takes the usual arguments such as `--prefix=` to specify where the executables and support files should be installed. The only other parameter that some users may wish to specify is the location of a suitable Tcl installation. By default `usbhost` will use the existing Tcl installation in `/usr`, as provided by your Linux distribution. An alternative Tcl installation can be specified using the parameter `--with-tcl=`, or alternatively using some combination of `--with-tcl-include`, `--with-tcl-lib` and `--with-tcl-version`.
- ❹ One of the host-side executables that gets built, `usbchmod`, needs to be installed with `suid` root privileges. Although the Linux kernel makes it possible for applications to perform low-level USB operations such as transmitting bulk packets, by default access to this functionality is restricted to programs with superuser privileges. It is undesirable to run a complex program such as `usbhost` with such privileges, especially since the program contains a general-purpose Tcl interpreter. Therefore when `usbhost` starts up and discovers that it does not have sufficient access to the appropriate entries in `/proc/bus/usb`, it spawns an instance of

usbchmod to modify the permissions on these entries. usbchmod will only do this for a USB device "Red Hat eCos USB test", so installing this program `sudo` should not introduce any security problems.

During **make install** the following actions will take place:

1. `usbhost` will be installed in `/usr/local/bin`, or some other `bin` directory if the default location is changed at configure-time using a `--prefix=` or similar option. It will be installed as the executable `usbhost_<version>`, for example `usbhost_current`, thus allowing several releases of the USB slave package to co-exist. For convenience a symbolic link from `usbhost` to this executable will be created, so users can just run **usbhost** to access the most recently-installed version.
2. `usbchmod` will be installed in `/usr/local/libexec/ecos/io_usb_slave_<version>`. This program should only be run by `usbhost`, not invoked directly, so it is not placed in the `bin` directory. Again the presence of the package version in the directory name allows multiple releases of the package to co-exist.
3. A Tcl script `usbhost.tcl` will get installed in the same directory as `usbchmod`. This Tcl script is loaded automatically by the `usbhost` executable.
4. A number of additional Tcl scripts, for example `list.tcl` will get installed alongside `usbhost.tcl`. These correspond to various test cases provided as standard. If a given test case is specified on the command line and cannot be found relative to the current directory then `usbhost` will search the install directory for these test cases.

Note: Strictly speaking installing the `usbhost.tcl` and other Tcl scripts below the `libexec` directory deviates from standard practice: they are architecture-independent data files so should be installed below the `share` subdirectory. In practice the files are sufficiently small that there is no point in sharing them, and keeping them below `libexec` simplifies the host-side software somewhat.

The **usbhost** should be run only when there is a suitable target attached to the USB bus and running the `usbtarget` program. It will search `/proc/bus/usb/devices` for an entry corresponding to this program, invoke `usbchmod` if necessary to change the access rights, and then interact with `usbtarget` over the USB bus. **usbhost** should be invoked as follows:

```
$ usbhost [-v|--version] [-h|--help] [-V|--verbose] <test> [<test parameters>]
```

1. The `-v` or `--version` option will display version information for `usbhost` including the version of the USB slave package that was used to build the executable.
2. The `-h` or `--help` option will display usage information.
3. The `-V` or `--verbose` option can be used to obtain more information at run-time, for example some output for every USB transfer. This option can be repeated multiple times to increase the amount of output.
4. The first argument that does not begin with a hyphen specifies a test that should be run, in the form of a Tcl script. For example an argument of `list.tcl` will cause `usbhost` to look for a script with that name, adding a `.tcl` suffix if necessary, and run that script. `usbhost` will look in the current directory first, then in the install tree for standard test scripts provided by the USB slave package.
5. Some test scripts may want their own parameters, for example a duration in seconds. These can be passed on the command line after the name of the test, for example **usbhost mytest 60**.

Writing a Test

Each test is defined by a Tcl script, running inside an interpreter provided by `usbhost`. In addition to the normal Tcl functionality this interpreter provides a number of variables and functions related to USB testing. For example there is a variable `bulk_in_endpoints` that lists all the endpoints on the target that can perform bulk IN operations, and a related array `bulk_in` which contains information such as the minimum and maximum packets sizes. There is a function `bulktest` which can be used to perform bulk tests on a particular endpoint. A simple test script aimed at specific hardware could ignore the information variables since it would know exactly what USB hardware is available on the target, whereas a general-purpose script would use the information to adapt to the hardware capabilities.

To avoid namespace pollution all USB-related Tcl variables and functions live in the `usbtest::` namespace. Therefore accessing requires either explicitly including the namespace any references, for example `$usbtest::bulk_in_endpoints`, or by using Tcl's namespace `import` facility.

A very simple test script might look like this:

```
usbtest::bulktest 1 out 4000
usbtest::bulktest 2 in 4000
if { [usbtest::start 60] } {
    puts "Test successful"
} else
    puts "Test failed"
    foreach result $usbtest::results {
        puts $result
    }
}
```

This would perform a test run involving 4000 bulk transfers from the host to the target's endpoint 1, and concurrently 4000 bulk transfers from endpoint 2. Default settings for packet sizes, contents, and delays would be used. The actual test would not start running until `usbtest` is invoked, and it is expected that the test would complete within 60 seconds. If any failures occur then they are reported.

Available Hardware

Each target-side USB device driver provides information about the actual capabilities of the hardware, for example which endpoints are available. Strictly speaking it provides information about what is actually supported by the device driver, which may be a subset of what the hardware is capable of. For example, the hardware may support isochronous transfers on a particular endpoint but if there is no software support for this in the driver then this endpoint will not be listed. When `usbhost` first contacts the `usbtarget` program running on the target platform, it obtains this information and makes it available to test scripts via Tcl variables:

`bulk_in_endpoints`

This is a simple list of the endpoints which can support bulk IN transfers. For example if the target-side hardware supports these transfers on endpoints 3 and 5 then the value would be `"3 5"`. Typical test scripts would iterate over the list using something like:

```
if { 0 != [llength $usbtest::bulk_in_endpoints] } {
    puts "Bulk IN endpoints: $usbtest::bulk_in_endpoints"
    foreach endpoint $usbtest::bulk_in_endpoints {
        ...
    }
}
```

`bulk_in()`

This array holds additional information about each bulk IN endpoint. The array is indexed by two fields, the endpoint number and one of `min_size`, `max_size`, `max_in_padding` and `devtab`:

`min_size`

This field specifies a lower bound on the size of bulk transfers, and will typically will have a value of 1.

Note: The typical minimum transfer size of a single byte is not strictly speaking correct, since under some circumstances it can make sense to have a transfer size of zero bytes. However current target-side device drivers interpret a request to transfer zero bytes as a way for higher-level code to determine whether or not an endpoint is stalled, so it is not actually possible to perform zero-byte transfers. This issue will be addressed at some future point.

`max_size`

This field specifies an upper bound on the size of bulk transfers. Some target-side drivers may be limited to transfers of say 0xFFFF bytes because of hardware limitations. In practice the transfer size is likely to be limited primarily to limit memory consumption of the test code on the target hardware, and to ensure that tests complete reasonably quickly. At the time of writing transfers are limited to 4K.

`max_in_padding`

On some hardware it may be necessary for the target-side device driver to send more data than is actually intended. For example the SA11x0 USB hardware cannot perform bulk transfers that are an exact multiple of 64 bytes, instead it must pad such transfers with an extra byte and the host must be ready to accept and discard this byte. The `max_in_padding` field indicates the amount of padding that is required. The low-level code inside `usbhost` will use this field automatically, and there is no need for test scripts to adjust packet sizes for padding. The field is provided for informational purposes only.

`devtab`

This is a string indicating whether or not the target-side USB device driver supports access to this endpoint via entries in the device table, in other words through conventional calls like `open` and `write`. Some device drivers may only support low-level USB access because typically that is what gets used by USB class-specific packages such as USB-ethernet. An empty string indicates that no `devtab` entry is available, otherwise it will be something like `"/dev/usbs2w"`.

Typical test scripts would access this data using something like:

```
foreach endpoint $usbtest::bulk_in_endpoints {
    puts "Endpoint $endpoint: "
    puts "    minimum transfer size $usbtest::bulk_in($endpoint,min_size)"
    puts "    maximum transfer size $usbtest::bulk_in($endpoint,max_size)"
    if { 0 == $usbtest::bulk_in($endpoint,max_in_padding) } {
        puts "        no IN padding required"
    } else {
        puts "        $usbtest::bulk_in($endpoint,max_in_padding) bytes of IN padding required"
    }
    if { "" == $usbtest::bulk_in($endpoint,devtab) } {
        puts "        no devtab entry provided"
    } else {
```

```

        puts "    corresponding devtab entry is $usbttest::bulk_in($endpoint,devtab)"
    }
}

```

`bulk_out_endpoint`

This is a simple list of the endpoints which can support bulk OUT transfers. It is analogous to `bulk_in_endpoints`.

`bulk_out()`

This array holds additional information about each bulk OUT endpoint. It can be accessed in the same way as `bulk_in()`, except that there is no `max_in_padding` field because that field only makes sense for IN transfers.

`control()`

This array holds information about the control endpoint. It contains two fields, `min_size` and `max_size`. Note that there is no variable `control_endpoints` because a USB target always supports a single control endpoint 0. Similarly the `control` array does not use an endpoint number as the first index because that would be redundant.

`isochronous_in_endpoints` and `isochronous_in()`

These variables provide the same information as `bulk_in_endpoints` and `bulk_in`, but for endpoints that support isochronous IN transfers.

`isochronous_out_endpoints` and `isochronous_out()`

These variables provide the same information as `bulk_out_endpoints` and `bulk_out`, but for endpoints that support isochronous OUT transfers.

`interrupt_in_endpoints` and `interrupt_in()`

These variables provide the same information as `bulk_in_endpoints` and `bulk_in`, but for endpoints that support interrupt IN transfers.

`interrupt_out_endpoints` and `interrupt_out()`

These variables provide the same information as `bulk_out_endpoints` and `bulk_out`, but for endpoints that support interrupt OUT transfers.

Testing Bulk Transfers

The main function for initiating a bulk test is `usbttest::bulktest`. This takes three compulsory arguments, and can be given a number of additional arguments to control the exact behaviour. The compulsory arguments are:

`endpoint`

This specifies the endpoint to use. It should correspond to one of the entries in `usbttest::bulk_in_endpoints` or `usbttest::bulk_out_endpoints`, depending on the transfer direction.

direction

This should be either `in` or `out`.

number of transfers

This specifies the number of transfers that should take place. The testing software does not currently support the concept of performing transfers for a given period of time because synchronising this on both the host and a wide range of targets is difficult. However it is relatively easy to work out the approximate time a number of bulk transfers should take place, based on a typical bandwidth of 1MB/second and assuming say a 1ms overhead per transfer. Alternatively a test script could perform a small initial run to determine what performance can actually be expected from a given target, and then use this information to run a much longer test.

Additional arguments can be used to control the exact transfer. For example a `txdelay+` argument can be used to slowly increase the delay between transfers. All such arguments involve a value which can be passed either as part of the argument itself, for example `txdelay+=5`, or as a subsequent argument, `txdelay+ 5`. The possible arguments fall into a number of categories: data, I/O mechanism, transmit size, receive size, transmit delay, and receive delay.

Data

An obvious parameter to control is the actual data that gets sent. This can be controlled by the argument `data` which can take one of five values: `none`, `bytefill`, `intfill`, `byteseq` and `wordseq`. The default value is `none`.

`none`

The transmit code will not attempt to fill the buffer in any way, and the receive code will not check it. The actual data that gets transferred will be whatever happened to be in the buffer before the transfer started.

`bytefill`

The entire buffer will be filled with a single byte, as per `memset`.

`intfill`

The buffer will be treated as an array of 32-bit integers, and will be filled with the same integer repeated the appropriate number of times. If the buffer size is not a multiple of four bytes then the last few bytes will be set to 0.

`byteseq`

The buffer will be filled with a sequence of bytes, generated by a linear congruential generator. If the first byte in the buffer is filled with the value `x`, the next byte will be $(m \cdot x) + i$. For example a sequence of slowly incrementing bytes can be achieved by setting both the multiplier and the increment to 1. Alternatively a pseudo-random number sequence can be achieved using values 1103515245 and 12345, as per the standard C library `rand` function. For convenience these two constants are available as Tcl variables `usbtest::MULTIPLIER` and `usbtest::INCREMENT`.

`wordseq`

This acts like `byteseq`, except that the buffer is treated as an array of 32-bit integers rather than as an array of bytes. If the buffer is not a multiple of four bytes then the last few bytes will be filled with zeroes.

The above requires three additional parameters `data1`, `data*` and `data+`. `data1` specifies the value to be used for byte or word fills, or the first number when calculating a sequence. The default value is 0. `data*` and `data+` specify the multiplier and increment for a sequence, and have default values of 1 and 0 respectively.

For example, to perform a bulk transfer of a pseudo-random sequence of integers starting with 42 the following code could be used:

```
bulktest 2 IN 1000 data=wordseq data1=42 \
    data* $usbttest::MULTIPLIER data+ $usbttest::INCREMENT
```

The above parameters define what data gets transferred for the first transfer, but a test can involve multiple transfers. The data format will be the same for all transfers, but it is possible to adjust the current value, the multiplier, and the increment between each transfer. This is achieved with parameters *data1**, *data1+*, *data***, *data*+*, *data+**, and *data++*, with default values of 1 for each multiplier and 0 for each increment. For example, if the multiplier for the first transfer is set to 2 using *data**, and arguments *data** 2* and *data** -1* are also supplied, then the multiplier for subsequent transfers will be 3, 5, 9, ...

Note: Currently it is not possible for a test script to send specific data, for example a specific sequence of bytes captured by a protocol analyser that caused a problem. If the transfer was from host to target then the target would have to know the exact sequence of bytes to expect, which means transferring data over the USB bus when that data is known to have caused problems in the past. Similarly for target to host transfers the target would have to know what bytes to send. A possible future extension of the USB testing support would allow for bounce operations, where a given message is first sent to the target and then sent back to the host, with only the host checking that the data was returned correctly.

I/O Mechanism

On the target side USB transfers can happen using either low-level USB calls such as *usbs_start_rx_buffer*, or by higher-level calls which go through the device table. By default the target-side code will use the low-level calls. If it is desired to test the higher-level calls instead, for example because those are what the application uses, then that can be achieved with an argument *mechanism=devtab*.

Transmit Size

The next set of arguments can be used to control the size of the transmitted buffer: *txsize1*, *txsize>=*, *txsize<= txsize**, *txsize/*, and *txsize+*.

txsize1 determines the size of the first transfer, and has a default value of 32 bytes. The size of the next transfer is calculated by first multiplying by the *txsize** value, then dividing by the *txsize/* value, and finally adding the *txsize+* value. The defaults for these are 1, 1, and 0 respectively, which means that the transfer size will remain unchanged. If for example the transfer size should increase by approximately 50 per cent each time then suitable values might be *txsize* 3*, *txsize/ 2*, and *txsize+ 1*.

The *txsize>=* and *txsize<=* arguments can be used to impose lower and upper bounds on the transfer. By default the *min_size* and *max_size* values appropriate for the endpoint will be used. If at any time the current size falls outside the bounds then it will be normalized.

Receive Size

The receive size, in other words the number of bytes that either host or target will expect to receive as opposed to the number of bytes that actually get sent, can be adjusted using a similar set of arguments: *rxsize1*, *rxsize>=*, *rxsize<=*, *rxsize**, *rxsize/* and *rxsize+*. The current receive size will be adjusted between transfers just like the transmit size. However when communicating over USB it is not a good idea to attempt to receive less data than will actually be sent: typically neither the hardware nor the software will be able to do anything useful with the excess, so there will be problems. Therefore if at any time the calculated

receive size is less than the transmit size, the actual receive will be for the exact number of bytes that will get transmitted. However this will not affect the calculations for the next receive size.

The default values for `rxsize1`, `rxsize*`, `rxsize/` and `rxsize+` are 0, 1, 1 and 0 respectively. This means that the calculated receive size will always be less than the transmit size, so the receive operation will be for the exact number of bytes transmitted. For some USB protocols this would not accurately reflect the traffic that will happen. For example with USB-ethernet transfer sizes will vary between 16 and 1516 bytes, so the receiver will always expect up to 1516 bytes. This can be achieved using `rxsize1 1516`, leaving the other parameters at their default values.

For target hardware which involves non-zero `max_in_padding`, on the host side the padding will be added automatically to the receive size if necessary.

Transmit and Receive Delays

Typically during the testing there will be some minor delays between transfers on both host and target. Some of these delays will be caused by timeslicing, for example another process running on the host, or a concurrent test thread running inside the target. Other delays will be caused by the USB bus itself, for example activity from another device on the bus. However it is desirable that test cases be allowed to inject additional and somewhat more controlled delays into the system, for example to make sure that the target behaves correctly even if the target is not yet ready to receive data from the host.

The transmit delay is controlled by six parameters: `txdelay1`, `txdelay*`, `txdelay/`, `txdelay+`, `txdelay>=` and `txdelay<=`. The default values for these are 0, 1, 1, 0, 0 and 1000000000 respectively, so that by default transmits will happen as quickly as possible. Delays are measured in nanoseconds, so a value of 1000000 would correspond to a delay of 0.001 seconds or one millisecond. By default delays have an upper bound of one second. Between transfers the transmit delay is updated in much the same way as the transfer sizes.

The receive delay is controlled by a similar set of six parameters: `rxdelay1`, `rxdelay*`, `rxdelay/`, `rxdelay+`, `rxdelay>=` and `rxdelay<=`. The default values for these are the same as for transmit delays.

The transmit delay is used on the side which sends data over the USB bus, so for a bulk IN transfer it is the target that sends data and hence sleeps for the specified transmit delay, while the host receives data sleeps for the receive delay. For an OUT transfer the positions are reversed.

It should be noted that although the delays are measured in nanoseconds, the actual delays will be much less precise and are likely to be of the order of milliseconds. The exact details will depend on the kernel clock speed.

Other Types of Transfer

Support for testing other types of USB traffic such as isochronous transfers is not yet implemented.

Starting a Test and Collecting Results

A USB test script should prepare one or more transfers using appropriate functions such as `usbtest::bulktest`. Once all the individual tests have been prepared they can be started by a call to `usbtest::start`. This takes a single argument, a maximum duration measured in seconds. If all transfers have not been completed in the specified time then any remaining transfers will be aborted.

`usbtest::start` will return 1 if all the tests have succeeded, or 0 if any of them have failed. More detailed reports will be stored in the Tcl variable `usbtests::results`, which will be a list of string messages.

Existing Test Scripts

A number of test scripts are provided as standard. These are located in the `host` subdirectory of the common USB slave package, and will be installed as part of the process of building the host-side software. When a script is specified on the command line `usbhost` will first search for it in the current directory, then in the install tree. Standard test scripts include the following:

`list.tcl`

This script simply displays information about the capabilities of the target platform, as provided by the target-side USB device driver. It can help with tracking down problems, but its primary purpose is to let users check that everything is working correctly: if running **`usbhost list.tcl`** outputs sensible information then the user knows that the target side is running correctly and that communication between host and target is possible.

`verbose.tcl`

The target-side code can provide information about what is happening while tests are prepared and run. This facility should not normally be used since the extra I/O involved will significantly affect the behaviour of the system, but in some circumstances it may prove useful. Since an eCos application cannot easily be given command-line arguments the target-side verbosity level cannot be controlled using `-V` or `--verbose` options. Instead it can be controlled from inside `gdb` by changing the integer variable `verbose`. Alternatively it can be manipulated by running the test script `verbose.tcl`. This script takes a single argument, the desired verbosity level, which should be a small integer. For example, to disable target-side run-time logging the command **`usbhost verbose 0`** can be used.

`bulk-boundaries.tcl`

This script performs simple bulk IN and OUT transfers of different sizes around interesting boundaries. This test is useful to ensure the driver correctly handles the case where a transfer is just smaller than, the same size as, and just bigger than the hardware buffer in the endpoint hardware. This script takes no parameters. It determines what endpoints the device has by asking it.

Possible Problems

If all transfers succeed within the specified time then both host and target remain in synch and further tests can be run without problem. However, if at any time a failure occurs then things get more complicated. For example, if the current test involves a series of bulk OUT transfers and the target detects that for one of these transfers it received less data than was expected then the test has failed, and the target will stop accepting data on this endpoint. However the host-side software may not have detected anything wrong and is now blocked trying to send the next lot of data.

The test code goes to considerable effort to recover from problems such as these. On the host-side separate threads are used for concurrent transfers, and on the target-side appropriate asynchronous I/O mechanisms are used. In addition there is a control thread on the host that checks the state of all the main host-side threads, and the state of the target using private control messages. If it discovers that one side has stopped sending or receiving data because of an error and the other side is blocked as a result, it will set certain flags and then cause one additional transfer to take place. That additional transfer will have the effect of unblocking the other side, which then discovers that an error has occurred by checking the appropriate flags. In this way both host and target should end up back in synch, and it is possible to move on to the next set of tests.

However, the above assumes that the testing has not triggered any serious hardware conditions. If instead the target-side hardware has been left in some strange state so that, for example, it will no longer raise an interrupt

for traffic on a particular endpoint then recovery is not currently possible, and the testing software will just hang.

A possible future enhancement to the testing software would allow the host-side to raise a USB reset signal whenever a failure occurs, in the hope that this would clear any remaining problems within the target-side USB hardware.

XXIX. eCos Support for USB Serial like Peripherals

Introduction

Name

Introduction — eCos support for USB Serial like Peripherals

Introduction

The eCos USB-Serial package provides additional support for USB peripherals that look like a serial port to the host. These can follow the ACM communication device specification or simpler devices which just have two bulk endpoints. Microsoft Windows requires ACM mode. Linux should operate with both modes, however ACM may cause problems since the eCos driver does not implement all the class descriptors, so generic mode is recommended.

The USB-Serial package is not tied to any specific hardware. It requires the presence of USB hardware on the target and a suitable device driver to make endpoints available for this code to use. The configuration system cannot load the eCos package automatically for specific targets, in the way that a USB device driver or an ethernet driver can be loaded automatically. Instead, the package has to be added explicitly. When using the command line tools this will involve an operation like the following:

```
$ ecosconfig add usbs_serial
```

Typically, this will automatically cause the USB device driver to become active.

Configuration

Name

Configuration — Configuration USB Serial like Peripherals

Configuration

The package requires a few basic configurations plus optionally some additional configuration options.

The driver needs two or three endpoints, depending if ACM communications or a more generic model is used. This is configured with `CYGDAT_IO_USB_SLAVE_CLASS_TYPE` which can take the value `ACM` or `generic`.

The `CYGDAT_IO_USB_SLAVE_SERIAL_EP0` must be configured with the control end point of the USB device. `CYGDAT_IO_USB_SLAVE_SERIAL_TX_EP` must be configured with the endpoint to be used for transmission and `CYGDAT_IO_USB_SLAVE_SERIAL_RX_EP` must be configured with the end point used for reception. Associated with these are `CYGNUM_IO_USB_SLAVE_SERIAL_RX_EP_NUM` and `CYGNUM_IO_USB_SLAVE_SERIAL_TX_EP_NUM` which are the endpoint numbers and are used during enumeration of the device. The TX and RX endpoints must operate in BULK mode.

If operation mode `ACM` is selected a third endpoint is needed. This must operate in interrupt mode and should be configured in `CYGNUM_IO_USB_SLAVE_SERIAL_INTR_EP` and `CYGNUM_IO_USB_SLAVE_SERIAL_INTR_EP_NUM`.

The USB serial device will make its vendor:product ID known to the host. This should be configured with `CYGNUM_IO_USB_SLAVE_SERIAL_VENDOR_ID` and `CYGNUM_IO_USB_SLAVE_SERIAL_PRODUCT_ID`. NOTE: The default configurations are not valid for products, but should work for testing.

The USB enumeration also contains text strings to describe the device. This text string can be set with `CYGDAT_IO_USB_SLAVE_SERIAL_PRODUCT_STR`.

The last configuration option of interest is `CYGPKG_IO_USB_SLAVE_SERIAL_EXAMPLES`. When true example programs will be built when the eCos tests are built. These are not pass/fail test like other eCos tests, but examples of how the eCos USB serial class can be used.

Host Configuration

Name

Host Configuration — Host Configuration for USB Serial like Peripherals

Host Configuration

Configuration for two hosts are listed here, Microsoft Windows and Linux. It should also be possible to use the eCos USB serial like peripheral driver with other hosts.

Linux

The eCos USB serial like peripheral driver can be used in Linux in one of two ways.

- Using the generic usbserial kernel module passing the vendor and product ID as module parameters. e.g.

```
modprobe usbserial vendor=0xabcd product=0x1234
```

would load the kernel module so that it would use a USB device abcd:1234 as a serial device.

- Using the mini driver provided with eCos in the `host/linux` directory. This driver must be edited and the correct vendor and product ID set to match the vendor and product ID used by the device. Once compiled this driver can be loaded with:

```
modprobe usbserial  
modprobe ecos_usbserial
```

This driver is known to compile with kernel versions 2.6.18 and probably works fine with other kernels. However it fails to compile with kernels after 2.6.25.

Both of these methods will result in the Linux Kernel making a new serial device available. This is typically named `/dev/ttyUSB0`.

Microsoft Windows

To install the device in a Microsoft Windows system make use of the INF file in `host/windows/eCosUsbSerial.inf`. Copy this INF file and `usbser.sys` from your version of Windows into an empty directory. Then plug in the USB device. When prompted to load a driver navigate to the INF file and select it.

API Function

Name

`usbs_serial_start`, `usbs_serial_init`, `usbs_serial_start`,
`usbs_serial_wait_until_configured`, `usbs_serial_is_configured`,
`usbs_serial_start_tx`, `usbs_serial_wait_for_tx`, `usbs_serial_tx`,
`usbs_serial_start_rx`, `usbs_serial_wait_for_rx`, `usbs_serial_rx`,
`usbs_serial_state_change_handler` — eCos USB Serial like Peripherals API

Synopsis

```
#include <cyg/io/usb/usbs_serial.h>

void usbs_serial_start (void);
void usbs_serial_init (usbs_serial * ser, usbs_tx_endpoint * tx_ep, usbs_rx_endpoint *
rx_ep);
void usbs_serial_wait_until_configured (void);
cyg_bool usbs_serial_is_configured (void);
void usbs_serial_start_tx (usbs_serial * ser, const void *buf, int * n);
int usbs_serial_wait_for_tx (usbs_serial * ser);
void usbs_serial_start_rx (usbs_serial * ser, const void *buf, int * n);
int usbs_serial_wait_for_rx (usbs_serial * ser);
int usbs_serial_rx (usbs_serial * ser, const void *buf, int * n);
void usbs_serial_state_change_handler (usbs_control_endpoint * ep, void * data,
usbs_state_change change, int prev_state);
```

Description

For examples of how to use this API see the files `.../tests/usbserial_echo.c` and `.../tests/usb2serial.c`

The first function that needs calling is `usbs_serial_start()`. This will initialise the eCos USB slave layer, creating all the enumeration data and then let the host know that the device exists.

Once the USB subsystem has been started it is necessary to wait for the host to configure the device using the function `usbs_serial_wait_until_configured()`. The host will assign the device an ID and then load the appropriate device driver in the host in order to make use the device.

Once the device is configured it is then possible to make use of it, i.e. send and receive data. This transfer of data can be accomplished either asynchronously or synchronously. It is also possible to mix asynchronously and synchronously between receiving and sending data.

To perform asynchronous operations the functions `usbs_serial_start_rx()` and `usbs_serial_start_tx()` is used to start the operation. These functions start the necessary actions and then return immediately. At a later time the functions `usbs_serial_wait_for_tx()` or `usbs_serial_wait_for_rx()` should be called. These will, if necessary, block and then return the status and any data for the previously started asynchronous call.

To perform synchronous operations the functions `usbs_serial_rx()` and `usbs_serial_tx()` are used. These functions will block until the requested action is complete.

XXX. eCos Synthetic Target

Overview

Name

The eCos synthetic target — Overview

Description

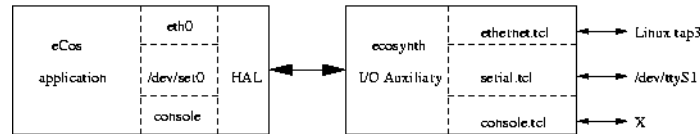
Usually eCos runs on either a custom piece of hardware, specially designed to meet the needs of a specific application, or on a development board of some sort that is available before the final hardware. Such boards have a number of things in common:

1. Obviously there has to be at least one processor to do the work. Often this will be a 32-bit processor, but it can be smaller or larger. Processor speed will vary widely, depending on the expected needs of the application. However the exact processor being used tends not to matter very much for most of the development process: the use of languages such as C or C++ means that the compiler will handle those details.
2. There needs to be memory for code and for data. A typical system will have two different types of memory. There will be some non-volatile memory such as flash, EPROM or masked ROM. There will also be some volatile memory such as DRAM or SRAM. Often the code for the final application will reside in the non-volatile memory and all of the RAM will be available for data. However updating non-volatile memory requires a non-trivial amount of effort, so for much of the development process it is more convenient to burn suitable firmware, for example RedBoot, into the non-volatile memory and then use that to load the application being debugged into RAM, alongside the application data and a small area reserved for use by the firmware.
3. The platform must provide certain minimal I/O facilities. Most eCos configurations require a clock signal of some sort. There must also be some way of outputting diagnostics to the user, often but not always via a serial port. Unless special debug hardware is being used, source level debugging will require bidirectional communication between a host machine and the target hardware, usually via a serial port or an ethernet device.
4. All the above is not actually very useful yet because there is no way for the embedded device to interact with the rest of the world, except by generating diagnostics. Therefore an embedded device will have additional I/O hardware. This may be fairly standard hardware such as an ethernet or USB interface, or special hardware designed specifically for the intended application, or quite often some combination. Standard hardware such as ethernet or USB may be supported by eCos device drivers and protocol stacks, whereas the special hardware will be driven directly by application code.

Much of the above can be emulated on a typical PC running Linux. Instead of running the embedded application being developed on a target board of some sort, it can be run as a Linux process. The processor will be the PC's own processor, for example an x86, and the memory will be the process' address space. Some I/O facilities can be emulated directly through system calls. For example clock hardware can be emulated by setting up a `SIGALRM` signal, which will cause the process to be interrupted at regular intervals. This emulation of real hardware will not be particularly accurate, the number of cpu cycles available to the eCos application between clock ticks will vary widely depending on what else is running on the PC, but for much development work it will be good enough.

Other I/O facilities are provided through an I/O auxiliary process, `ecosynth`, that gets spawned by the eCos application during startup. When an eCos device driver wants to perform some I/O operation, for example send out an ethernet packet, it sends a request to the I/O auxiliary. That is an ordinary Linux application so it has ready access to all normal Linux I/O facilities. To emulate a device interrupt the I/O auxiliary can

raise a `SIGIO` signal within the eCos application. The HAL's interrupt subsystem installs a signal handler for this, which will then invoke the standard eCos ISR/DSR mechanisms. The I/O auxiliary is based around Tcl scripting, making it easy to extend and customize. It should be possible to configure the synthetic target so that its I/O functionality is similar to what will be available on the final target hardware for the application being developed.



A key requirement for synthetic target code is that the embedded application must not be linked with any of the standard Linux libraries such as the GNU C library: that would lead to a confusing situation where both eCos and the Linux libraries attempted to provide functions such as `printf`. Instead the synthetic target support must be implemented directly on top of the Linux kernels' system call interface. For example, the kernel provides a system call for write operations. The actual function `write` is implemented in the system's C library, but all it does is move its arguments on to the stack or into certain registers and then execute a special trap instruction such as `int 0x80`. When this instruction is executed control transfers into the kernel, which will validate the arguments and perform the appropriate operation. Now, a synthetic target application cannot be linked with the system's C library. Instead it contains a function `cyg_hal_sys_write` which, like the C library's `write` function, pushes its arguments on to the stack and executes the trap instruction. The Linux kernel cannot tell the difference, so it will perform the I/O operation requested by the synthetic target. With appropriate knowledge of what system calls are available, this makes it possible to emulate the required I/O facilities. For example, spawning the `ecosynth` I/O auxiliary involves system calls `cyg_hal_sys_fork` and `cyg_hal_sys_execve`, and sending a request to the auxiliary uses `cyg_hal_sys_write`.

In many ways developing for the synthetic target is no different from developing for real embedded targets. eCos must be configured appropriately: selecting a suitable target such as **i386linux** will cause the configuration system to load the appropriate packages for this hardware; this includes an architectural HAL package and a platform-specific package; the architectural package contains generic code applicable to all Linux platforms, whereas the platform package is for specific Linux implementations such as the x86 version and contains any processor-specific code. Selecting this target will also bring in some device driver packages. Other aspects of the configuration such as which API's are supported are determined by the template, by adding and removing packages, and by fine-grained configuration.

In other ways developing for the synthetic target can be much easier than developing for a real embedded target. For example there is no need to worry about building and installing suitable firmware on the target hardware, and then downloading and debugging the actual application over a serial line or a similar connection. Instead an eCos application built for the synthetic target is mostly indistinguishable from an ordinary Linux program. It can be run simply by typing the name of the executable file at a shell prompt. Alternatively you can debug the application using whichever version of `gdb` is provided by your Linux distribution. There is no need to build or install special toolchains. Essentially using the synthetic target means that the various problems associated with real embedded hardware can be bypassed for much of the development process.

The eCos synthetic target provides emulation, not simulation. It is possible to run eCos in suitable architectural simulators but that involves a rather different approach to software development. For example, when running eCos on the `psim` PowerPC simulator you need appropriate cross-compilation tools that allow you to build PowerPC executables. These are then loaded into the simulator which interprets every instruction and attempts to simulate what would happen if the application were running on real hardware. This involves a lot of processing overhead, but depending on the functionality provided by the simulator it can give very accurate results. When developing for the synthetic target the executable is compiled for the PC's own processor and will be executed at full speed, with no need for a simulator or special tools. This will be much faster and somewhat simpler than using an architectural simulator, but no attempt is made to accurately match the behaviour of a

real embedded target.

Installation

Name

Installation — Preparing to use the synthetic target

Host-side Software

To get the full functionality of the synthetic target, users must build and install the I/O auxiliary ecosynth and various support files. It is possible to develop applications for the synthetic target without the auxiliary, but only limited I/O facilities will be available. The relevant code resides in the `host` subdirectory of the synthetic target architectural HAL package, and building it involves the standard **configure**, **make**, and **make install** steps.

There are two main ways of building the host-side software. It is possible to build both the generic host-side software and all package-specific host-side software, including the I/O auxiliary, in a single build tree. This involves using the **configure** script at the toplevel of the eCos repository, which will automatically search the `packages` hierarchy for host-side software. For more information on this, see the `README.host` file at the top of the repository. Note that if you have an existing build tree which does not include the synthetic target architectural HAL package then it will be necessary to rerun the toplevel configure script: the search for appropriate packages happens at configure time.

The alternative is to build just the host-side for this package. This involves creating a suitable build directory and running the **configure** script. Note that building directly in the source tree is not allowed.

```
$ cd <somewhere suitable>
$ mkdir synth_build
$ cd synth_build
$ <repo>/packages/hal/synth/arch/<version>/host/configure <options>
$ make
$ make install
```

The code makes extensive use of Tcl/Tk and requires version 8.3 or later. This is checked by the **configure** script. By default it will use the system's Tcl installation in `/usr`. If a different, more recent Tcl installation should be used then its location can be specified using the options `--with-tcl=<path>`, `--with-tcl-header=<path>` and `--with-tcl-lib=<path>`. For more information on these options see the `README.host` file at the toplevel of the eCos repository.

Some users may also want to specify the install location using a `--prefix=<path>` option. The default install location is `/usr/local`. It is essential that the `bin` subdirectory of the install location is on the user's search PATH, otherwise the eCos application will be unable to locate and execute the I/O auxiliary ecosynth.

Because ecosynth is run automatically by an eCos application rather than explicitly by the user, it is not installed in the `bin` subdirectory itself. Instead it is installed below `libexec`, together with various support files such as images. At configure time it is usually possible to specify an alternative location for `libexec` using `--exec-prefix=<path>` or `--libexecdir=<path>`. These options should not be used for this package because the eCos application is built completely separately and does not know how the host-side was configured.

Toolchain

When developing eCos applications for a normal embedded target it is necessary to use a suitable cross-compiler and related tools such as the linker. Developing for the synthetic target is easier because you can just use the standard GNU tools (`gcc`, `g++`, `ld`, ...) which were provided with your Linux distribution, or which

you used to build your own Linux setup. Any reasonably recent version of the tools, for example gcc 2.96 (Red Hat) as shipped with Red Hat Linux 7, should be sufficient.

There is one important limitation when using these tools: current gdb will not support debugging of eCos threads on the synthetic target. As far as gdb is concerned a synthetic target application is indistinguishable from a normal Linux application, so it assumes that any threads will be created by calls to the Linux `pthread_create` function provided by the C library. Obviously this is not the case since the application is never linked with that library. Therefore gdb never notices the eCos thread mechanisms and assumes the application is single-threaded. Fixing this is possible but would involve non-trivial changes to gdb.

Theoretically it is possible to develop synthetic target applications on, for example, a PC running Windows and then run the resulting executables on another machine that runs Linux. This is rarely useful: if a Linux machine is available then usually that machine will also be used for building ecos and the application. However, if for some reason it is necessary or desirable to build on another machine then this requires a suitable cross-compiler and related tools. If the application will be running on a typical PC with an x86 processor then a suitable configure triplet would be **i686-pc-linux-gnu**. The installation instructions for the various GNU tools should be consulted for further information.

Hardware Preparation

Preparing a real embedded target for eCos development can be tricky. Often the first step is to install suitable firmware, usually RedBoot. This means creating and building a special configuration for eCos with the RedBoot template, then somehow updating the target's flash chips with the resulting RedBoot image. Typically it will also be necessary to get a working serial connection, and possibly set up ethernet as well. Although usually none of the individual steps are particularly complicated, there are plenty of ways in which things can go wrong and it can be hard to figure out what is actually happening. Of course some board manufacturers make life easier for their developers by shipping hardware with RedBoot preinstalled, but even then it is still necessary to set up communication between host and target.

None of this is applicable to the synthetic target. Instead you can just build a normal eCos configuration, link your application with the resulting libraries, and you end up with an executable that you can run directly on your Linux machine or via gdb. A useful side effect of this is that application development can start before any real embedded hardware is actually available.

Typically the memory map for a synthetic target application will be set up such that there is a read-only ROM region containing all the code and constant data, and a read-write RAM region for the data. The default locations and sizes of these regions depend on the specific platform being used for development. Note that the application always executes out of ROM: on a real embedded target much of the development would involve running RedBoot firmware there, with application code and data loaded into RAM; usually this would change for the final system; the firmware would be replaced by the eCos application itself, configured for ROM bootstrap, and it would perform the appropriate hardware initialization. Therefore the synthetic target actually emulates the behaviour of a final system, not of a development environment. In practice this is rarely significant, although having the code in read-only memory can help catch some problems in application code.

Running a Synthetic Target Application

Name

Execution — Arguments and configuration files

Description

The procedure for configuring and building eCos and an application for the synthetic target is the same as for any other eCos target. Once an executable has been built it can be run like any Linux program, for example from a shell prompt,

```
$ ecos_hello <options>
```

or using gdb:

```
$ gdb --nw --quiet --args ecos_hello <options>
(gdb) run
Starting program: ecos_hello <options>
```

By default use of the I/O auxiliary is disabled. If its I/O facilities are required then the option `--io` must be used.

Note: In future the default behaviour may change, with the I/O auxiliary being started by default. The option `--nio` can be used to prevent the auxiliary from being run.

Command-line Arguments

The syntax for running a synthetic target application is:

```
$ <ecos_app> [options] [-- [app_options]]
```

Command line options up to the `--` are passed on to the I/O auxiliary. Subsequent arguments are not passed on to the auxiliary, and hence can be used by the eCos application itself. The full set of arguments can be accessed through the variables `cyg_hal_sys_argc` and `cyg_hal_sys_argv`.

The following options are accepted as standard:

`--io`

This option causes the eCos application to spawn the I/O auxiliary during HAL initialization. Without this option only limited I/O will be available.

`--nio`

This option prevents the eCos application from spawning the I/O auxiliary. In the current version of the software this is the default.

`-nw, --no-windows`

The I/O auxiliary can either provide a graphical user interface, or it can run in a text-only mode. The default is to provide the graphical interface, but this can be disabled with `-nw`. Emulation of some devices, for example buttons connected to digital inputs, requires the graphical interface.

`-w, --windows`

The `-w` causes the I/O auxiliary to provide a graphical user interface. This is the default.

`-v, --version`

The `-v` option can be used to determine the version of the I/O auxiliary being used and where it has been installed. Both the auxiliary and the eCos application will exit immediately.

`-h, --help`

`-h` causes the I/O auxiliary to list all accepted command-line arguments. This happens after all devices have been initialized, since the host-side support for some of the devices may extend the list of recognised options. After this both the auxiliary and the eCos application will exit immediately. This option implies `-nw`.

`-k, --keep-going`

If an error occurs in the I/O auxiliary while reading in any of the configuration files or initializing devices, by default both the auxiliary and the eCos application will exit. The `-k` option can be used to make the auxiliary continue in spite of errors, although obviously it may not be fully functional.

`-nr, --no-rc`

Normally the auxiliary processes two [user configuration files](#) during startup: `initrc.tcl` and `mainrc.tcl`. This can be suppressed using the `-nr` option.

`-x, --exit`

When providing a graphical user interface the I/O auxiliary will normally continue running even after the eCos application has exited. This allows the user to take actions such as saving the current contents of the main text window. If run with `-x` then the auxiliary will exit as soon the application exits.

`-nx, --no-exit`

When the graphical user interface is disabled with `-nw` the I/O auxiliary will normally exit immediately when the eCos application exits. Without the graphical frontend there is usually no way for the user to interact directly with the auxiliary, so there is no point in continuing to run once the eCos application will no longer request any I/O operations. Specifying the `-nx` option causes the auxiliary to continue running even after the application has exited.

`-V, --verbose`

This option causes the I/O auxiliary to output some additional information, especially during initialization.

`-l <file>, --logfile <file>`

Much of the output of the eCos application and the I/O auxiliary is simple text, for example resulting from eCos `printf` or `diag_printf` calls. When running in graphical mode this output goes to a central text window, and can be saved to a file or edited via menus. The `-l` can be used to automatically generate an additional logfile containing all the text. If graphical mode is disabled then by default all the text just goes to the current standard output. Specifying `-l` causes most of the text to go into a logfile instead, although some messages such as errors generated by the auxiliary itself will still go to stdout as well.

`-t <file>, --target <file>`

During initialization the I/O auxiliary reads in a target definition file. This file holds information such as which Linux devices should be used to emulate the various eCos devices. The `-t` option can be used to specify which target definition should be used for the current run, defaulting to `default.tdf`. It is not necessary to include the `.tdf` suffix, this will be appended automatically if necessary.

`-geometry <geometry>`

This option can be used to control the size and position of the main window, as per X conventions.

The I/O auxiliary loads support for the various devices dynamically and some devices may accept additional command line arguments. Details of these can be obtained using the `-h` option or by consulting the device-specific documentation. If an unrecognised command line argument is used then a warning will be issued.

The Target Definition File

The eCos application will want to access devices such as `eth0` or `/dev/ser0`. These need to be mapped on to Linux devices. For example some users may all traffic on the eCos `/dev/ser0` serial device to go via the Linux serial device `/dev/ttyS1`, while ethernet I/O for the eCos `eth0` device should be mapped to the Linux `ethertap` device `tap3`. Some devices may need additional configuration information, for example to limit the number of packets that should be buffered within the I/O auxiliary. The target definition file provides all this information.

By default the I/O auxiliary will look for a file `default.tdf`. An alternative target definition can be specified on the command line using `-t`, for example:

```
$ bridge_app --io -t twineth
```

A `.tdf` suffix will be appended automatically if necessary. If a relative pathname is used then the I/O auxiliary will search for the target definition file in the current directory, then in `~/ecos/synth/`, and finally in its install location.

A typical target definition file might look like this:

```
synth_device console {
    # appearance -foreground white -background black
    filter trace {^TRACE:.*} -foreground HotPink1 -hide 1
}

synth_device ethernet {
    eth0 real eth1
    eth1 ethertap tap4 00:01:02:03:FE:06

    ## Maximum number of packets that should be buffered per interface.
    ## Default 16
    #max_buffer 32

    ## Filters for the various recognised protocols.
    ## By default all filters are visible and use standard colours.
    filter ether -hide 0
    #filter arp -hide 1
    #filter ipv4 -hide 1
    #filter ipv6 -hide 1
}
```

A target definition file is actually a Tcl script that gets run in the main interpreter of the I/O auxiliary during initialization. This provides a lot of flexibility if necessary. For example the script could open a socket to a resource management server of some sort to determine which hardware facilities are already in use and adapt accordingly. Another possibility is to adapt based on [command line arguments](#). Users who are not familiar with Tcl programming should still be able to edit a simple target definition file without too much difficulty, using a mixture of cut'n'paste, commenting or uncommenting various lines, and making small edits such as changing `tap4` to `eth2`.

Each type of device will have its own entry in the target definition file, taking the form:

```
synth_device <device type> {  
    <options>  
}
```

The documentaton for each synthetic target device should provide details of the options available for that device, and often a suitable fragment that can be pasted into a target definition file and edited. There is no specific set of options that a given device will always provide. However in practice many devices will use common code exported by the main I/O auxiliary, or their implementation will involve some re-use of code for an existing device. Hence certain types of option are common to many devices.

A good example of this is filters, which control the appearance of text output. The above target definition file defines a filter `trace` for output from the eCos application. The regular expression will match output from the infrastructure package's tracing facilities when `CYGDBG_USE_TRACING` and `CYGDBG_INFRA_DEBUG_TRACE_ASSERT_SIMPLE` are enabled. With the current settings this output will not be visible by default, but can be made visible using the menu item **System Filters**. If made visible the trace output will appear in an unusual colour, so users can easily distinguish the trace output from other text. All filters accept the following options:

```
-hide [0|1]
```

This controls whether or not text matching this filter should be invisible by default or not. At run-time the visibility of each filter can be controlled using the **System Filters** menu item.

```
-foreground <colour>
```

This specifies the foreground colour for all text matching this filter. The colour can be specified using an RGB value such as `#F08010`, or a symbolic name such as `"light steel blue"`. The X11 utility `showrgb` can be used to find out about the available colours.

```
-background <colour>
```

This specifies the background colour for all text matching the filter. As with `-foreground` the colour can be specified using a symbolic name or an RGB value.

Some devices may create their own subwindows, for example to monitor ethernet traffic or to provide additional I/O facilities such as emulated LED's or buttons. Usually the target definition file can be used to control the [layout](#) of these windows.

The I/O auxiliary will not normally warn about **synth_device** entries in the target definition file for devices that are not actually needed by the current eCos application. This makes it easier to use a single file for several different applications. However it can lead to confusion if an entry is spelled incorrectly and hence does not actually get used. The `-v` command line option can be used to get warnings about unused device entries in the target definition file.

If the body of a **synth_device** command contains an unrecognised option and the relevant device is in use, the I/O auxiliary will always issue a warning about such options.

User Configuration Files

During initialization the I/O auxiliary will execute two user configuration files, `initrc.tcl` and `mainrc.tcl`. It will look for these files in the directory `~/ .ecos/synth/`. If that directory does not yet exist it will be created and populated with initial dummy files.

Both of these configuration files are Tcl scripts and will be run in the main interpreter used by the I/O auxiliary itself. This means that they have full access to the internals of the auxiliary including the various Tk widgets, and they can perform file or socket I/O if desired. The section [Writing New Devices - host](#) contains information

about the facilities available on the host-side for writing new device drivers, and these can also be used in the initialization scripts.

The `initrc.tcl` script is run before the auxiliary has processed any requests from the eCos application, and hence before any devices have been instantiated. At this point the generic command-line arguments has been processed, the target definition file has been read in, and the hooks functionality has been initialized. If running in graphical mode the main window will have been created, but has been withdrawn from the screen to allow new widgets to be added without annoying screen flicker. A typical `initrc.tcl` script could add some menu or toolbar options, or install a hook function that will be run when the eCos application exits.

The `mainrc.tcl` script is run after eCos has performed all its device initialization and after C++ static constructors have run, and just before the call to `cyg_start` which will end up transferring control to the application itself. A typical `mainrc.tcl` script could look at what interrupt vectors have been allocated to which devices and create a little monitor window that shows interrupt activity.

Session Information

When running in graphical mode, the I/O auxiliary will read in a file `~/.ecos/synth/guisession` containing session information. This file should not normally be edited manually, instead it gets updated automatically when the auxiliary exits. The purpose of this file is to hold configuration options that are manipulated via the graphical interface, for example which browser should be used to display online help.

Warning

GUI session functionality is not yet available in the current release. When that functionality is fully implemented it is possible that some target definition file options may be removed, to be replaced by graphical editing via a suitable preferences dialog, with the current settings saved in the session file.

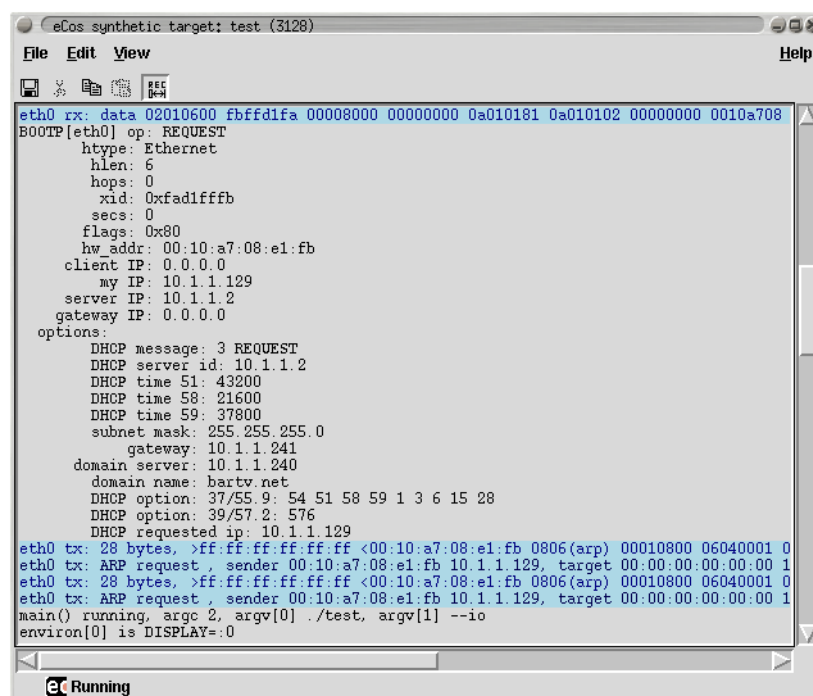
The I/O Auxiliary's User Interface

Name

User Interface — Controlling the I/O Auxiliary

Description

The synthetic target auxiliary is designed to support both extensions and user customization. Support for the desired devices is dynamically loaded, and each device can extend the user interface. For example it is possible for a device to add menu options, place new buttons on the toolbar, create its own sub-window within the overall layout, or even create entire new toplevel windows. These subwindows or toplevels could show graphs of activity such as interrupts or packets being transferred. They could also allow users to interact with the eCos application, for example by showing a number of buttons which will be mapped on to digital inputs in the eCos application. Different applications will have their own I/O requirements, changing the host-side support files that get loaded and that may modify the user interface. The I/O auxiliary also reads in user configuration scripts which can enhance the interface in the same way. Therefore the exact user interface will depend on the user and on the eCos application being run. However the overall layout is likely to remain the same.

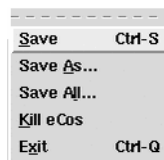


The title bar identifies the window as belonging to an eCos synthetic target application and lists both the application name and its process id. The latter is especially useful if the application was started directly from a shell prompt and the user now wants to attach a gdb session. The window has a conventional menu bar with the usual entries, plus a toolbar with buttons for common operations such as cut and paste. Balloon help is supported.

There is a central [text window](#), possibly surrounded by various sub-windows for various devices. For example there could be a row of emulated LED's above the text window, and monitors of ethernet traffic and interrupt activity on the right. At the bottom of the window is a status line, including a small animation that shows whether or not the eCos application is still running.

Menus and the Toolbar

Usually there will be four menus on the menu bar: File, Edit, View and Help.

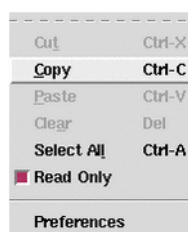


On the **File** menu there are three entries related to saving the current contents of the central text window. **Save** is used to save the currently visible contents of the text window. Any text that is hidden because of filters will not be written to the savefile. If there has been a previous **Save** or **Save As** operation then the existing savefile will be re-used, otherwise the user will be asked to select a suitable file. **Save As** also saves just the currently visible contents but will always prompt the user for a filename. **Save All** can be used to save the full contents of the text window, including any text that is currently hidden. It will always prompt for a new filename, to avoid confusion with partial savefiles.

Usually the eCos application will be run from inside gdb or from a shell prompt. Killing off the application while it is being debugged in a gdb session is not a good idea, it would be better to use gdb's own **kill** command. Alternatively the eCos application itself can use the `CYG_TEST_EXIT` or `cyg_hal_sys_exit` functionality. However it is possible to terminate the application from the I/O auxiliary using **Kill eCos**. A clean shutdown will be attempted, but that can fail if the application is currently halted inside gdb or if it has crashed completely. As a last resort `SIGKILL` will be used.

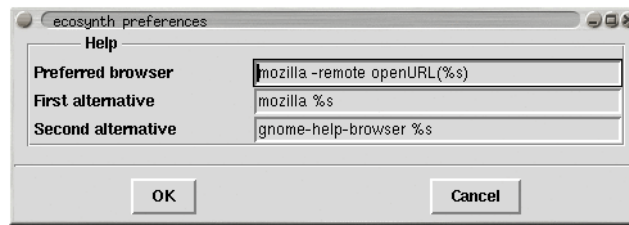
When operating in graphical mode the I/O auxiliary will normally continue to run even after the eCos application has exited. This allows the user to examine the last few lines of output, and perhaps perform actions such as saving the output to a file. The **Exit** menu item can be used to shut down the auxiliary. Note that this behaviour can be changed with command line arguments `--exit` and `--no-exit`.

If **Exit** is used while the eCos application is still running then the I/O auxiliary will first attempt to terminate the application cleanly, and then exit.

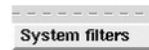


The **Edit** menu contains the usual entries for text manipulation: **Cut**, **Copy**, **Paste**, **Clear** and **Select All**. These all operate on the central text window. By default this window cannot be edited so the cut, paste and clear operations are disabled. If the user wants to edit the contents of the text window then the **Read Only** checkbox should be toggled.

The **Preferences** menu item brings up a miscellaneous preferences dialog. One of the preferences relates to online help: the I/O auxiliary does not currently have a built-in html viewer; instead it will execute an external browser of some sort. With the example settings shown, the I/O auxiliary will first attempt to interact with an existing mozilla session. If that fails it will try to run a new mozilla instance, or as a last result use the Gnome help viewer.



The View menu contains the System Filters entry, used to edit the settings for the current [filters](#).



The Help menu can be used to activate online help for eCos generally, for the synthetic target as a whole, and for specific devices supported by the generic target. The Preferences dialog can be used to select the browser that will be used.



Note: At the time of writing there is no well-defined toplevel index file for all eCos documentation. Hence the relevant menu item is disabled. Documentation for the synthetic target and the supported devices is stored as part of the package itself so can usually be found fairly easily. It may be necessary to set the ECOS_REPOSITORY environment variable.

The Main Text Window

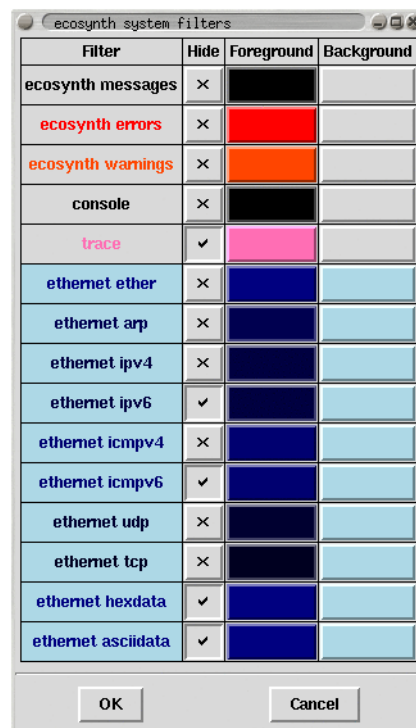
The central text window holds the console output from the eCos application: the screen shot above shows DHCP initialization data from the TCP/IP stack, and some output from the `main` thread at the bottom. Some devices can insert text of their own, for example the ethernet device support can be configured to show details of incoming and outgoing packets. Mixing the output from the eCos application and the various devices can make it easier to understand the order in which events occur.

The appearance of text from different sources can be controlled by means of filters, and it is also possible to hide some of the text. For example, if tracing is enabled in the eCos configuration then the trace output can be given its own colour scheme, making it stand out from the rest of the output. In addition the trace output is generally voluminous so it can be hidden by default, made visible only to find out more about what was happening when a particular problem occurred. Similarly the ethernet device support can output details of the various packets being transferred, and using a different background colour for this output again makes it easier to distinguish from console output.

The default appearance for most filters is controlled via the [target definition file](#). An example entry might be:

```
filter trace {^TRACE:.*} -foreground HotPink1 -hide 1
```

The various colours and the hide flag for each filter can be changed at run-time, using the System Filters item on the View menu. This will bring up a dialog like the following:



It should be noted that the text window is line-oriented, not character-oriented. If an eCos application sends a partial line of text then that will remain buffered until a newline character is received, rather than being displayed immediately. This avoids confusion when there is concurrent output from several sources.

By default the text window is read-only. This means it will not allow cut, paste and clear operations, and keyboard input will be ignored. The Edit menu has a checkbox **Read Only** which can be toggled to allow write operations. For example, a user could type in a reminder of what was happening at this time, or paste in part of a gdb session. Such keyboard input does not get forwarded to the eCos application: if the latter requires keyboard input then that should happen via a separate keyboard device.

Positioning Optional Windows

Some devices may create their own subwindows, for example to monitor ethernet traffic or to provide additional I/O facilities such as emulated LED's or buttons. Usually the target definition file can be used to control the [layout](#) of these windows. This requires an understanding of the overall layout of the display.

		.menubar	
.menubar.file	.menubar.edit	.menubar.view	.menubar.help
.toolbar			
.main.nw	.main.n		.main.ne
.main.w	.main.centre.text		.main.e
.main.sw	.main.s		.main.se
		.status.text	

Subwindows are generally packed in one of eight frames surrounding the central text window: `.main.nw`, `.main.n`, `.main.ne`, `.main.w`, `.main.e`, `.main.sw`, `.main.s`, and `.main.se`. To position a row of LED's above the text window and towards the left, a target definition file could contain an entry such as:

```
synth_device led {  
    pack -in .main.n -side left  
    ...  
}
```

Similarly, to put a traffic monitor window on the right of the text window would involve something like:

```
...  
monitor_pack -in .main.e -side bottom  
...
```

Often it will be sufficient to specify a container frame and one of `left`, `right`, `top` or `bottom`. Full control over the positioning requires an understanding of Tcl/Tk and in particular the packing algorithm, and an appropriate reference work should be consulted.

Global Settings

Note: This section still to be written - it should document the interaction between X resources and `ecosynth`, and how users can control settings such as the main foreground and background colours.

The Console Device

Name

The console device — Show output from the eCos application

Description

The eCos application can generate text output in a variety of ways, including calling `printf` or `diag_printf`. When the I/O auxiliary is enabled the eCos startup code will instantiate a console device to process all such output. If operating in text mode the output will simply go to standard output, or to a logfile if the `-l` command line option is specified. If operating in graphical mode the output will go to the central text window, and optionally to a logfile as well. In addition it is possible to control the appearance of the main text via the target definition file, and to install extra filters for certain types of text.

It should be noted that the console device is line-oriented, not character-oriented. This means that outputting partial lines is not supported, and some functions such as `fflush` and `setvbuf` will not operate as expected. This limitation prevents much possible confusion when using filters to control the appearance of the text window, and has some performance benefits - especially when the eCos application generates a great deal of output such as when tracing is enabled. For most applications this is not a problem, but it is something that developers should be aware of.

The console device is output-only, it does not provide any support for keyboard input. If the application requires keyboard input then that should be handled by a separate eCos device package and matching host-side code.

Installation

The eCos side of the console device is implemented by the architectural HAL itself, in the source file `synth_diag.c`, rather than in a separate device package. Similarly the host-side implementation, `console.tcl`, is part of the architectural HAL's host-side support. It gets installed automatically alongside the I/O auxiliary itself, so no separate installation procedure is required.

Target Definition File

The [target definition file](#) can contain a number of entries related to the console device. These are all optional, they only control the appearance of text output. If such control is desired then the relevant options should appear in the body of a **synth_device** entry:

```
synth_device console {  
    ...  
}
```

The first option is **appearance**, used to control the appearance of any text generated by the eCos application that does not match one of the installed filters. This option takes the same argument as any other filter, for example:

```
synth_device console {  
    appearance -foreground white -background black  
    ...  
}
```

Any number of additional filters can be created with a **filter** option, for example:

```
synth_device console {  
    ...  
    filter trace {^TRACE:.*} -foreground HotPink1 -hide 1  
    ...  
}
```

The first argument gives the new filter a name which will be used in the [filters dialog](#). Filter names should be unique. The second argument is a Tcl regular expression. The console support will match each line of eCos output against this regular expression, and if a match is found then the filter will be used for this line of text. The above example matches any line of output that begins with `TRACE:`, which corresponds to the eCos infrastructure's tracing facilities. The remaining options control the desired appearance for matched text. If some eCos output matches the regular expressions for several different filters then only the first match will be used.

Target-side Configuration Options

There are no target-side configuration options related to the console device.

Command Line Arguments

The console device does not use any command-line arguments.

Hooks

The console device does not provide any hooks.

Additional Tcl Procedures

The console device does not provide any additional Tcl procedures that can be used by other scripts.

System Calls

Name

`cyg_hal_sys_xyz` — Access Linux system facilities

Synopsis

```
#include <cyg/hal/hal_io.h>

int cyg_hal_sys_xyzzy(...);
```

Description

On a real embedded target eCos interacts with the hardware by peeking and poking various registers, manipulating special regions of memory, and so on. The synthetic target does not access hardware directly. Instead I/O and other operations are emulated by making appropriate Linux system calls. The HAL package exports a number of functions which allow other packages, or even application code, to make these same system calls. However this facility must be used with care: any code which calls, for example, `cyg_hal_sys_write` will only ever run on the synthetic target; that functionality is obviously not provided on any real hardware because there is no underlying Linux kernel to implement it.

The synthetic target only provides a subset of the available system calls, specifically those calls which have proved useful to implement I/O emulation. This subset can be extended fairly easily if necessary. All of the available calls, plus associated data structures and macros, are defined in the header file `cyg/hal/hal_io.h`. There is a simple convention: given a Linux system call such as `open`, the synthetic target will prefix `cyg_hal_sys` and provide a function with that name. The second argument to the `open` system call is a set of flags such as `O_RDONLY`, and the header file will define a matching constant `CYG_HAL_SYS_O_RDONLY`. There are also data structures such as `cyg_hal_sys_sigset_t`, matching the Linux data structure `sigset_t`.

In most cases the functions provided by the synthetic target behave as per the documentation for the Linux system calls, and section 2 of the Linux man pages can be consulted for more information. There is one important difference: typically the documentation will say that a function returns `-1` to indicate an error, with the actual error code held in `errno`; the actual underlying system call and hence the `cyg_hal_sys_xyz` provided by eCos instead returns a negative number to indicate an error, with the absolute value of that number corresponding to the error code; usually it is the C library which handles this and manipulates `errno`, but of course synthetic target applications are not linked with that Linux library.

However, there are some exceptions. The Linux kernel has evolved over the years, and some of the original system call interfaces are no longer appropriate. For example the original `select` system call has been superseded by `_newselect`, and that is what the `select` function in the C library actually uses. The old call is still available to preserve binary compatibility but, like the C library, eCos makes use of the new one because it provides the appropriate functionality. In an attempt to reduce confusion the eCos function is called `cyg_hal_sys__newselect`, in other words it matches the official system call naming scheme. The authoritative source of information on such matters is the Linux kernel sources themselves, and especially its header files.

eCos packages and applications should never `#include` Linux header files directly. For example, doing a `#include </usr/include/fcntl.h>` to access additional macros or structure definitions, or alternatively manipulating the header file search path, will lead to problems because the Linux header files are likely to

duplicate and clash with definitions in the eCos headers. Instead the appropriate functionality should be extracted from the Linux headers and moved into either `cyg/hal/hal_io.h` or into application code, with suitable renaming to avoid clashes with eCos names. Users should be aware that large-scale copying may involve licensing complications.

Adding more system calls is usually straightforward and involves adding one or more lines to the platform-specific file in the appropriate platform HAL, for example `syscall-i386-linux-1.0.S`. However it is necessary to do some research first about the exact interface implemented by the system call, because of issues such as old system calls that have been superseded. The required information can usually be found fairly easily by searching through the Linux kernel sources and possibly the GNU C library sources.

Writing New Devices - target

Name

Writing New Devices — extending the synthetic target, target-side

Synopsis

```
#include <cyg/hal/hal_io.h>

int synth_auxiliary_instantiate(const char* package, const char* version, const char*
device, const char* instance, const char* data);
void synth_auxiliary_xchgmsg(int device_id, int request, int arg1, int arg2, const
unsigned char* txdata, int txlen, int* reply, unsigned char* rxdata, int* rxlen, int
max_rxlen);
```

Description

In some ways writing a device driver for the synthetic target is very similar to writing one for a real target. Obviously it has to provide the standard interface for that class of device, so for example an ethernet device has to provide `can_send`, `send`, `recv` and similar functions. Many devices will involve interrupts, so the driver contains ISR and DSR functions and will call `cyg_drv_interrupt_create`, `cyg_drv_interrupt_acknowledge`, and related functions.

In other ways writing a device driver for the synthetic target is very different. Usually the driver will not have any direct access to the underlying hardware. In fact for some devices the I/O may not involve real hardware, instead everything is emulated by widgets on the graphical display. Therefore the driver cannot just peek and poke device registers, instead it must interact with host-side code by exchanging message. The synthetic target HAL provides a function `synth_auxiliary_xchgmsg` for this purpose.

Initialization of a synthetic target device driver is also very different. On real targets the device hardware already exists when the driver's initialization routine runs. On the synthetic target it is first necessary to instantiate the device inside the I/O auxiliary, by a call to `synth_auxiliary_instantiate`. That function performs a special message exchange with the I/O auxiliary, causing it to load a Tcl script for the desired type of device and run an instantiation procedure within that script.

Use of the I/O auxiliary is optional: if the user does not specify `--io` on the command line then the auxiliary will not be started and hence most I/O operations will not be possible. Device drivers should allow for this possibility, for example by just discarding any data that gets written. The HAL exports a flag `synth_auxiliary_running` which should be checked.

Instantiating a Device

Device instantiation should happen during the C++ prioritized static constructor phase of system initialization, before control switches to `cyg_user_start` and general application code. This ensures that there is a clearly defined point at which the I/O auxiliary knows that all required devices have been loaded. It can then perform various consistency checks and clean-ups, run the user's `mainrc.tcl` script, and make the main window visible.

For standard devices generic eCos I/O code will call the device initialization routines at the right time, iterating through the `DEVTAB` table in a static constructor. The same holds for network devices and file systems. For more custom devices code like the following can be used:

```
#include <cyg/infra/cyg_type.h>
class mydev_init {
public:
    mydev_init() {
        ...
    }
};
static mydev_init mydev_init_object CYGBLD_ATTRIB_INIT_PRI(CYG_INIT_IO);
```

Some care has to be taken because the object `mydev_init_object` will typically not be referenced by other code, and hence may get eliminated at link-time. If the code is part of an eCos package then problems can be avoided by putting the relevant file in `libextras.a`:

```
cbl_package CYGPKG_DEVS_MINE {
    ...
    compile -library=libextras.a init.cxx
}
```

For devices inside application code the same can be achieved by linking the relevant module as a `.o` file rather than putting it in a `.a` library.

In the device initialization routine the main operation is a call to `synth_auxiliary_instantiate`. This takes five arguments, all of which should be strings:

`package`

For device drivers which are eCos packages this should be a directory path relative to the eCos repository, for example `devs/eth/synth/ecosynth`. This will allow the I/O auxiliary to find the various host-side support files for this package within the install tree. If the device is application-specific and not part of an eCos package then a `NULL` pointer can be used, causing the I/O auxiliary to search for the support files in the current directory and then in `~/ecos/synth` instead.

`version`

For eCos packages this argument should be the version of the package that is being used, for example `current`. A simple way to get this version is to use the `SYNTH_MAKESTRING` macro on the package name. If the device is application-specific then a `NULL` pointer should be used.

`device`

This argument specifies the type of device being instantiated, for example `ethernet`. More specifically the I/O auxiliary will append a `.tcl` suffix, giving the name of a Tcl script that will handle all I/O requests for the device. If the application requires several instances of a type of device then the script will only be loaded once, but the script will contain an instantiation procedure that will be called for each device instance.

`instance`

If it is possible to have multiple instances of a device then this argument identifies the particular instance, for example `eth0` or `eth1`. Otherwise a `NULL` pointer can be used.

`data`

This argument can be used to pass additional initialization data from eCos to the host-side support. This is useful for devices where eCos configury must control certain aspects of the device, rather than host-side

configury such as the target definition file, because eCos has compile-time dependencies on some or all of the relevant options. An example might be an emulated frame buffer where eCos has been statically configured for a particular screen size, orientation and depth. There is no fixed format for this string, it will be interpreted only by the device-specific host-side Tcl script. However the string length should be limited to a couple of hundred bytes to avoid possible buffer overflow problems.

Typical usage would look like:

```
if (!synth_auxiliary_running) {
    return;
}
id = synth_auxiliary_instantiate("devs/eth/synth/ecosynth",
    SYNTH_MAKESTRING(CYGPKG_DEVS_ETH_ECOSYNTH),
    "ethernet",
    "eth0",
    (const char*) 0);
```

The return value will be a device identifier which can be used for subsequent calls to `synth_auxiliary_xchgmsg`. If the device could not be instantiated then `-1` will be returned. It is the responsibility of the host-side software to issue suitable diagnostics explaining what went wrong, so normally the target-side code should fail silently.

Once the desired device has been instantiated, often it will be necessary to do some additional initialization by a message exchange. For example an ethernet device might need information from the host-side about the MAC address, the [interrupt vector](#), and whether or not multicasting is supported.

Communicating with a Device

Once a device has been instantiated it is possible to perform I/O by sending messages to the appropriate Tcl script running inside the auxiliary, and optionally getting back replies. I/O operations are always initiated by the eCos target-side, it is not possible for the host-side software to initiate data transfers. However the host-side can raise interrupts, and the interrupt handler inside the target can then exchange one or more messages with the host.

There is a single function to perform I/O operations, `synth_auxiliary_xchgmsg`. This takes the following arguments:

`device_id`

This should be one of the identifiers returned by a previous call to `synth_auxiliary_instantiate`, specifying the particular device which should perform some I/O.

`request`

Request are just signed 32-bit integers that identify the particular I/O operation being requested. There is no fixed set of codes, instead each type of device can define its own.

`arg1`

`arg2`

For some requests it is convenient to pass one or two additional parameters alongside the request code. For example an ethernet device could define a multicast-all request, with `arg1` controlling whether this mode should be enabled or disabled. Both `arg1` and `arg2` should be signed 32-bit integers, and their values are interpreted only by the device-specific Tcl script.

`txdata`
`txlen`

Some I/O operations may involve sending additional data, for example an ethernet packet. Alternatively a control operation may require many more parameters than can easily be encoded in `arg1` and `arg2`, so those parameters have to be placed in a suitable buffer and extracted at the other end. `txdata` is an arbitrary buffer of `txlen` bytes that should be sent to the host-side. There is no specific upper bound on the number of bytes that can be sent, but usually it is a good idea to allocate the transmit buffer statically and keep transfers down to at most several kilobytes.

`reply`

If the host-side is expected to send a reply message then `reply` should be a pointer to an integer variable and will be updated with a reply code, a simple 32-bit integer. The synthetic target HAL code assumes that the host-side and target-side agree on the protocol being used: if the host-side will not send a reply to this message then the `reply` argument should be a NULL pointer; otherwise the host-side must always send a reply code and the `reply` argument must be valid.

`rxdata`
`rxlen`

Some operations may involve additional data coming from the host-side, for example an incoming ethernet packet. `rxdata` should be a suitably-sized buffer, and `rxlen` a pointer to an integer variable that will end up containing the number of bytes that were actually received. These arguments will only be used if the host-side is expected to send a reply and hence the `reply` argument was not NULL.

`max_rxlen`

If a reply to this message is expected and that reply may involve additional data, `max_rxlen` limits the size of that reply. In other words, it corresponds to the size of the `rxdata` buffer.

Most I/O operations involve only some of the arguments. For example transmitting an ethernet packet would use the `request`, `txdata` and `txlen` fields (in addition to `device_id` which is always required), but would not involve `arg1` or `arg2` and no reply would be expected. Receiving an ethernet packet would involve `request`, `rxdata`, `rxlen` and `max_rxlen`; in addition `reply` is needed to get any reply from the host-side at all, and could be used to indicate whether or not any more packets are buffered up. A control operation such as enabling multicast mode would involve `request` and `arg1`, but none of the remaining arguments.

Interrupt Handling

Interrupt handling in the synthetic target is much the same as on a real target. An interrupt object is created using `cyg_drv_interrupt_create`, attached, and unmasked. The emulated device - in other words the Tcl script running inside the I/O auxiliary - can raise an interrupt. Subject to interrupts being disabled and the appropriate vector being masked, the system will invoke the specified ISR function. The synthetic target HAL implementation does have some limitations: there is no support for nested interrupts, interrupt priorities, or a separate interrupt stack. Supporting those might be appropriate when targetting a simulator that attempts to model real hardware accurately, but not for the simple emulation provided by the synthetic target.

Of course the actual implementation of the ISR and DSR functions will be rather different for a synthetic target device driver. For real hardware the device driver will interact with the device by reading and writing device registers, managing DMA engines, and the like. A synthetic target driver will instead call `synth_auxiliary_xchgmsg` to perform the I/O operations.

There is one other significant difference between interrupt handling on the synthetic target and on real hardware. Usually the eCos code will know which interrupt vectors are used for which devices. That information is fixed when the target hardware is designed. With the synthetic target interrupt vectors are assigned to devices

on the host side, either via the target definition file or dynamically when the device is instantiated. Therefore the initialization code for a target-side device driver will need to request interrupt vector information from the host-side, via a message exchange. Such interrupt vectors will be in the range 1 to 31 inclusive, with interrupt 0 being reserved for the real-time clock.

Writing New Devices - host

Name

Writing New Devices — extending the synthetic target, host-side

Description

On the host-side adding a new device means writing a Tcl/Tk script that will handle instantiation and subsequent requests from the target-side. These scripts all run in the same full interpreter, extended with various commands provided by the main I/O auxiliary code, and running in an overall GUI framework. Some knowledge of programming with Tcl/Tk is required to implement host-side device support.

Some devices can be implemented entirely using a Tcl/Tk script. For example, if the final system will have some buttons then those can be emulated in the synthetic target using a few Tk widgets. A simple emulation could just have the right number of buttons in a row. A more advanced emulation could organize the buttons with the right layout, perhaps even matching the colour scheme, the shapes, and the relative sizes. With other devices it may be necessary for the Tcl script to interact with an external program, because the required functionality cannot easily be accessed from a Tcl script. For example interacting with a raw ethernet device involves some `ioctl` calls, which is easier to do in a C program. Therefore the `ethernet.tcl` script which implements the host-side ethernet support spawns a separate program `rawether`, written in C, that performs the low-level I/O. Raw ethernet access usually also requires root privileges, and running a small program `rawether` with such privileges is somewhat less of a security risk than the whole eCos application, the I/O auxiliary, and various dynamically loaded Tcl scripts.

Because all scripts run in a single interpreter, some care has to be taken to avoid accidental sharing of global variables. The best way to avoid problems is to have each script create its own Tcl namespace, so for example the `ethernet.tcl` script creates a namespace `ethernet::` and all variables and procedures reside in this namespace. Similarly the I/O auxiliary itself makes use of a `synth::` namespace.

Building and Installation

When an eCos device driver or application code instantiates a device, the I/O auxiliary will attempt to load a matching Tcl script. The third argument to `synth_auxiliary_instantiate` specifies the type of device, for example `ethernet`, and the I/O auxiliary will append a `.tcl` suffix and look for a script `ethernet.tcl`.

If the device being instantiated is application-specific rather than part of an eCos package, the I/O auxiliary will look first in the current directory, then in `~/ecos/synth`. If it is part of an eCos package then the auxiliary will expect to find the Tcl script and any support files below `libexec/ecos` in the install tree - note that the same install tree must be used for the I/O auxiliary itself and for any device driver support. The directory hierarchy below `libexec/ecos` matches the structure of the eCos repository, allowing multiple versions of a package to be installed to allow for incompatible protocol changes.

The preferred way to build host-side software is to use **autoconf** and **automake**. Usually this involves little more than copying the `acinclude.m4`, `configure.in` and `Makefile.am` files from an existing package, for example the synthetic target ethernet driver, and then making minor edits. In `acinclude.m4` it may be necessary to adjust the path to the root of the repository. `configure.in` may require a similar change, and the `AC_INIT` macro invocation will have to be changed to match one of the files in the new package. A critical macro in this file is `ECOS_PACKAGE_DIRS` which will set up the correct install directory. `Makefile.am` may require some more changes, for example to specify the data files that should be installed (including the Tcl script). These files should then be processed using **aclocal**, **autoconf** and **automake** in that order. Actually building the soft-

ware then just involves **configure**, **make** and **make install**, as per the instructions in the toplevel `README.host` file.

To assist developers, if the environment variable `ECOSYNTH_DEVEL` is set then a slightly different algorithm is used for locating device Tcl scripts. Instead of looking only in the install tree the I/O auxiliary will also look in the source tree, and if the script there is more recent than the installed version it will be used in preference. This allows developers to modify the master copy without having to run **make install** all the time.

If a script needs to know where it has been installed it can examine the Tcl variable `synth::device_install_dir`. This variable gets updated whenever a script is loaded, so if the value may be needed later it should be saved away in a device-specific variable.

Instantiation

The I/O auxiliary will **source** the device-specific Tcl script when the eCos application first attempts to instantiate a device of that type. The script should return a procedure that will be invoked to instantiate a device.

```
namespace eval ethernet {
    ...
    proc instantiate { id instance data } {
        ...
        return ethernet::handle_request
    }
}
return ethernet::instantiate
```

The `id` argument is a unique identifier for this device instance. It will also be supplied on subsequent calls to the request handler, and will match the return value of `synth_auxiliary_instantiate` on the target side. A common use for this value is as an array index to support multiple instances of this types of device. The `instance` and `data` arguments match the corresponding arguments to `synth_auxiliary_instantiate` on the target side, so a typical value for `instance` would be `eth0`, and `data` is used to pass arbitrary initialization parameters from target to host.

The actual work done by the instantiation procedure is obviously device-specific. It may involve allocating an [interrupt vector](#), adding a device-specific subwindow to the display, opening a real Linux device, establishing a socket connection to some server, spawning a separate process to handle the actual I/O, or a combination of some or all of the above.

If the device is successfully instantiated then the return value should be a handler for subsequent I/O requests. Otherwise the return value should be an empty string, and on the target-side the `synth_auxiliary_instantiate` call will return `-1`. The script is responsible for providing [diagnostics](#) explaining why the device could not be instantiated.

Handling Requests

When the target-side calls `synth_auxiliary_xchgmsg`, the I/O auxiliary will end up calling the request handler for the appropriate device instance returned during instantiation:

```
namespace eval ethernet {
    ...
    proc handle_request { id request arg1 arg2 txdata txlen max_rxlen } {
        ...
        if { <some condition> } {
            synth::send_reply <error code> 0 ""
            return
        }
    }
}
```

```

    }
    ...
    synth::send_reply <reply code> $packet_len $packet
  }
  ...
}

```

The `id` argument is the same device id that was passed to the `instantiate` function, and is typically used as an array index to access per-device data. The `request`, `arg1`, `arg2`, and `max_rxlen` are the same values that were passed to `synth_auxiliary_xchgmsg` on the target-side, although since this is a Tcl script obviously the numbers have been converted to strings. The `txdata` buffer is raw data as transmitted by the target, or an empty string if the I/O operation does not involve any additional data. The Tcl procedures **binary scan**, **string index** and **string range** may be found especially useful when manipulating this buffer. `txlen` is provided for convenience, although **string length \$txdata** would give the same information.

The code for actually processing the request is of course device specific. If the target does not expect a reply then the request handler should just return when finished. If a reply is expected then there should be a call to **synth::send_reply**. The first argument is the reply code, and will be turned into a 32-bit integer on the target side. The second argument specifies the length of the reply data, and the third argument is the reply data itself. For some devices the Tcl procedure **binary format** may prove useful. If the reply involves just a code and no additional data, the second and third arguments should be 0 and an empty string respectively.

Attempts to send a reply when none is expected, fail to send a reply when one is expected, or send a reply that is larger than the target-side expects, will all be detected by the I/O auxiliary and result in run-time error messages.

It is not possible for the host-side code to send unsolicited messages to the target. If host-side code needs attention from the target, for example because some I/O operation has completed, then an interrupt should be raised.

Interrupts

The I/O auxiliary provides a number of procedures for interrupt handling.

```

synth::interrupt_allocate <name>
synth::interrupt_get_max
synth::interrupt_get_devicename <vector>
synth::interrupt_raise <vector>

```

synth::interrupt_allocate is normally called during device instantiation, and returns the next free interrupt vector. This can be passed on to the target-side device driver in response to a suitable request, and it can then install an interrupt handler on that vector. Interrupt vector 0 is used within the target-side code for the real-time clock, so the allocated vectors will start at 1. The argument identifies the device, for example `eth0`. This is not actually used internally, but can be accessed by user-initialization scripts that provide some sort of interrupt monitoring facility (typically via the `interrupt hook`). It is possible for a single device to allocate multiple interrupt vectors, but the synthetic target supports a maximum of 32 such vectors.

synth::interrupt_get_max returns the highest interrupt vector that has been allocated, or 0 if there have been no calls to **synth::interrupt_allocate**. **synth::interrupt_get_devicename** returns the string that was passed to **synth::interrupt_allocate** when the vector was allocated.

synth::interrupt_raise can be called any time after initialization. The argument should be the vector returned by **synth::interrupt_allocate** for this device. It will activate the normal eCos interrupt handling mechanism so, subject to interrupts being enabled and this particular interrupt not being masked out, the appropriate ISR will run.

Note: At this time it is not possible for a device to allocate a specific interrupt vector. The order in which interrupt vectors are assigned to devices effectively depends on the order in which the eCos devices get initialized, and that may change if the eCos application is rebuilt. A future extension may allow devices to allocate specific vectors, thus making things more deterministic. However that will introduce new problems, in particular the code will have to start worrying about requests for vectors that have already been allocated.

Flags and Command Line Arguments

The generic I/O auxiliary code will process the standard command line arguments, and will set various flag variables accordingly. Some of these should be checked by device-specific scripts.

`synth::flag_gui`

This is set when the I/O auxiliary is operating in graphical mode rather than text mode. Some functionality such as filters and the GUI layout are only available in graphical mode.

```
if { $synth::flag_gui } {  
    ...  
}
```

`synth::flag_verbose`

The user has requested additional information during startup. Each device driver can decide how much additional information, if any, should be produced.

`synth::flag_keep_going`

The user has specified `-k` or `--keep-going`, so even if an error occurs the I/O auxiliary and the various device driver scripts should continue running if at all possible. Diagnostics should still be generated.

Some scripts may want to support additional command line arguments. This facility should be used with care since there is no way to prevent two different scripts from trying to use the same argument. The following Tcl procedures are available:

```
synth::argv_defined <name>  
synth::argv_get_value <name>
```

synth::argv_defined returns a boolean to indicate whether or not a particular argument is present. If the argument is the name part of a name/value pair, an `=` character should be appended. Typical uses might be:

```
if { [synth::argv_defined "-o13"] } {  
    ...  
}  
  
if { [synth::argv_defined "-mark="] } {  
    ...  
}
```

The first call checks for a flag `-o13` or `--o13` - the code treats options with single and double hyphens interchangeably. The second call checks for an argument of the form `-mark=<value>` or a pair of arguments `-mark <value>`. The value part of a name/value pair can be obtained using **synth::argv_get_value**;

```
variable speed 1  
if { [synth::argv_defined "-mark="] } {  
    set mark [synth::argv_get_value "-mark="]
```



```

        if { ![string is integer $mark] || ($mark < 1) || ($mark > 9) } {
            <issue diagnostic>
        } else {
            set speed $mark
        }
    }
}

```

synth::argv_get_value should only be used after a successful call to **synth::argv_defined**. At present there is no support for some advanced forms of command line argument processing. For example it is not possible to repeat a certain option such as `-v` or `--verbose`, with each occurrence increasing the level of verbosity.

If a script is going to have its own set of command-line arguments then it should give appropriate details if the user specifies `--help`. This involves a hook function:

```

namespace eval my_device {
    proc help_hook { } {
        puts " -ol3           : activate the omega 13 device"
        puts " -mark <speed> : set speed. Valid values are 1 to 9."
    }

    synth::hook_add "help" my_device::help_hook
}

```

The Target Definition File

Most device scripts will want to check entries in the target definition file for run-time configuration information. The Tcl procedures for this are as follows:

```

synth::tdf_has_device <name>
synth::tdf_get_devices
synth::tdf_has_option <devname> <option>
synth::tdf_get_option <devname> <option>
synth::tdf_get_options <devname> <option>
synth::tdf_get_all_options <devname>

```

synth::tdf_has_device can be used to check whether or not the target definition file had an entry `synth_device <name>`. Usually the name will match the type of device, so the `console.tcl` script will look for a target definition file entry `console`. **synth::tdf_get_devices** returns a list of all device entries in the target definition file.

Once it is known that the target definition file has an entry for a certain device, it is possible to check for options within the entry. **synth::tdf_has_option** just checks for the presence, returning a boolean:

```

if { [synth::tdf_has_option "console" "appearance"] } {
    ...
}

```

synth::tdf_get_option returns a list of all the arguments for a given option. For example, if the target definition file contains an entry:

```

synth_device console {
    appearance -foreground white -background black
    filter trace {^TRACE:.*} -foreground HotPink1 -hide 1
    filter xyzzy {.*xyzzy.*} -foreground PapayaWhip
}

```

A call **synth::tdf_get_option console appearance** will return the list `{-foreground white -background black}`. This list can be manipulated using standard Tcl routines such as **llength** and **lindex**. Some options can

occur multiple times in one entry, for example `filter` in the `console` entry. **`synth::tdf_get_options`** returns a list of lists, with one entry for each option occurrence. **`synth::tdf_get_all_options`** returns a list of lists of all options. This time each entry will include the option name as well.

The I/O auxiliary will not issue warnings about entries in the target definition file for devices which were not loaded, unless the `-v` or `--verbose` command line argument was used. This makes it easier to use a single target definition file for different applications. However the auxiliary will issue warnings about options within an entry that were ignored, because often these indicate a typing mistake of some sort. Hence a script should always call **`synth::tdf_has_option`**, **`synth::tdf_get_option`** or **`synth::tdf_get_options`** for all valid options, even if some of the options preclude the use of others.

Hooks

Some scripts may want to take action when particular events occur, for example when the eCos application has exited and there is no need for further I/O. This is supported using hooks:

```
namespace eval my_device {
    ...
    proc handle_ecos_exit { arg_list } {
        ...
    }
    synth::hook_add "ecos_exit" my_device::handle_ecos_exit
}
```

It is possible for device scripts to add their own hooks and call all functions registered for those hooks. A typical use for this is by user initialization scripts that want to monitor some types of I/O. The available Tcl procedures for manipulating hooks are:

```
synth::hook_define <name>
synth::hook_defined <name>
synth::hook_add <name> <function>
synth::hook_call <name> <args>
```

`synth::hook_define` creates a new hook with the specified name. This hook must not already exist. **`synth::hook_defined`** can be used to check for the existence of a hook. **`synth::hook_add`** allows other scripts to register a callback function for this hook, and **`synth::hook_call`** allows the owner script to invoke all such callback functions. A hook must already be defined before a callback can be attached. Therefore typically device scripts will only use standard hooks and their own hooks, not hooks created by some other device, because the order of device initialization is not sufficiently defined. User scripts run from `mainrc.tcl` can use any hooks that have been defined.

`synth::hook_call` takes an arbitrary list of arguments, for example:

```
synth::hook_call "ethernet_rx" "eth0" $packet
```

The callback function will always be invoked with a single argument, a list of the arguments that were passed to **`synth::hook_call`**:

```
proc rx_callback { arg_list } {
    set device [lindex $arg_list 0]
    set packet [lindex $arg_list 1]
}
```

Although it might seem more appropriate to use Tcl's **`eval`** procedure and have the callback functions invoked with the right number of arguments rather than a single list, that would cause serious problems if any of the

data contained special characters such as `[]` or `$`. The current implementation of hooks avoids such problems, at the cost of minor inconvenience when writing callbacks.

A number of hooks are defined as standard. Some devices will add additional hooks, and the device-specific documentation should be consulted for those. User scripts can add their own hooks if desired.

`exit`

This hook is called just before the I/O auxiliary exits. Hence it provides much the same functionality as `atexit` in C programs. The argument list passed to the callback function will be empty.

`ecos_exit`

This hook is called when the eCos application has exited. It is used mainly to shut down I/O operations: if the application is no longer running then there is no point in raising interrupts or storing incoming packets. The callback argument list will be empty.

`ecos_initialized`

The synthetic target HAL will send a request to the I/O auxiliary once the static constructors have been run. All devices should now have been instantiated. A script could now check how many instances there are of a given type of device, for example ethernet devices, and create a little monitor window showing traffic on all the devices. The `ecos_initialized` callbacks will be run just before the user's `mainrc.tcl` script. The callback argument list will be empty.

`help`

This hook is also invoked once static constructors have been run, but only if the user specified `-h` or `--help`. Any scripts that add their own command line arguments should add a callback to this hook which outputs details of the additional arguments. The callback argument list will be empty.

`interrupt`

Whenever a device calls **`synth::interrupt_raise`** the `interrupt` hook will be called with a single argument, the interrupt vector. The main use for this is to allow user scripts to monitor interrupt traffic.

Output and Filters

Scripts can use conventional facilities for sending text output to the user, for example calling **`puts`** or directly manipulating the central text widget `.main.centre.text`. However in nearly all cases it is better to use output facilities provided by the I/O auxiliary itself:

```
synth::report <msg>
synth::report_warning <msg>
synth::report_error <msg>
synth::internal_error <msg>
synth::output <msg> <filter>
```

`synth::report` is intended for messages related to the operation of the I/O auxiliary itself, especially additional output resulting from `-v` or `--verbose`. If running in text mode the output will go to standard output. If running in graphical mode the output will go to the central text window. In both modes, use of `-l` or `--logfile` will modify the behaviour.

`synth::report_warning`, **`synth::report_error`** and **`synth::internal_error`** have the obvious meaning, including prepending strings such as `Warning:` and `Error:`. When the eCos application informs the I/O auxiliary that all static constructors have run, if at that point there have been any calls to **`synth::error`** then the I/O auxiliary will exit. This can be suppressed with command line arguments `-k` or `--keep-going`. **`synth::internal_error`**

will output some information about the current state of the I/O auxiliary and then exit immediately. Of course it should never be necessary to call this function.

synth::output is the main routine for outputting text. The second argument identifies a filter. If running in text mode the filter is ignored, but if running in graphical mode the filter can be used to control the appearance of this output. A typical use would be:

```
synth::output $line "console"
```

This outputs a single line of text using the `console` filter. If running in graphical mode the default appearance of this text can be modified with the `appearance` option in the **synth_device console** entry of the target definition file. The **System filters** menu option can be used to change the appearance at run-time.

Filters should be created before they are used. The procedures available for this are:

```
synth::filter_exists <name>
synth::filter_get_list
synth::filter_add <name> [options]
synth::filter_parse_options <options> <parsed_options> <message>
synth::filter_add_parsed <name> <parsed_options>
```

synth::filter_exists can be used to check whether or not a particular filter already exists: creating two filters with the same name is not allowed. **synth::filter_get_list** returns a list of the current known filters. **synth::filter_add** can be used to create a new filter. The first argument names the new filter, and the remaining arguments control the initial appearance. A typical use might be:

```
synth::filter_add "my_device_tx" -foreground yellow -hide 1
```

It is assumed that the supplied arguments are valid, which typically means that they are hard-wired in the script. If instead the data comes out of a configuration file and hence may be invalid, the I/O auxiliary provides a parsing utility. Typical usage would be:

```
array set parsed_options [list]
set message ""
if { ![synth::filter_parse_options $console_appearance parsed_options message] } {
    synth::report_error \
        "Invalid entry in target definition file $synth::target_definition\
        \n synth_device \"console\", entry \"appearance\" \n$message"
} else {
    synth::filter_add_parsed "console" parsed_options
}
```

On success `parsed_options` will be updated with an internal representation of the desired appearance, which can then be used in a call to **synth::filter_add_parsed**. On failure `message` will be updated with details of the parsing error that occurred.

The Graphical Interface

When the I/O auxiliary is running in graphical mode, many scripts will want to update the user interface in some way. This may be as simple as adding another entry to the help menu for the device, or adding a new button to the toolbar. It may also involve adding new subwindows, or even creating entire new toplevel windows. These may be simple monitor windows, displaying additional information about what is going on in the system in a graphical format. Alternatively they may emulate actual I/O operations, for example button widgets could be used to emulate real physical buttons.

The I/O auxiliary does not provide many procedures related to the graphical interface. Instead it is expected that scripts will just update the widget hierarchy directly.

		.menubar	
.menubar.file	.menubar.edit	.menubar.view	.menubar.help
.toolbar			
.main.nw	.main.n		.main.ne
.main.w	.main.centre.text		.main.e
.main.sw	.main.s		.main.se
		.status.text	

So adding a new item to the **Help** menu involves a **.menubar.help add** operation with suitable arguments. Adding a new button to the toolbar involves creating a child window in `.toolbar` and packing it appropriately. Scripts can create their own subwindows and then pack it into one of `.main.nw`, `.main.n`, `.main.ne`, `.main.w`, `.main.e`, `.main.sw`, `.main.s` or `.main.se`. Normally the user should be allowed to [control](#) this via the target definition file. The central window `.main.centre` should normally be left alone by other scripts since it gets used for text output.

The following graphics-related utilities may be found useful:

```
synth::load_image <image name> <filename>
synth::register_balloon_help <widget> <message>
synth::handle_help <URL>
```

synth::load_image can be used to add a new image to the current interpreter. If the specified file has a `.xbm` extension then the image will be a monochrome bitmap, otherwise it will be a colour image of some sort. A boolean will be returned to indicate success or failure, and suitable diagnostics will be generated if necessary.

synth::register_balloon_help provides balloon help for a specific widget, usually a button on the toolbar.

synth::handle_help is a utility routine that can be installed as the command for displaying online help, for example:

```
.menubar.help add command -label "my device" -command \
    [list synth::handle_help "file://$path"]
```


Porting

Name

Porting — Adding support for other hosts

Description

The initial development effort of the eCos synthetic target happened on x86 Linux machines. Porting to other platforms involves addressing a number of different issues. Some ports should be fairly straightforward, for example a port to Linux on a processor other than an x86. Porting to Unix or Unix-like operating systems other than Linux may be possible, but would involve more effort. Porting to a completely different operating system such as Windows would be very difficult. The text below complements the eCos Porting Guide.

Other Linux Platforms

Porting the synthetic target to a Linux platform that uses a processor other than x86 should be straightforward. The simplest approach is to copy the existing `i386linux` directory tree in the `hal/synth` hierarchy, then rename and edit the ten or so files in this package. Most of the changes should be pretty obvious, for example on a 64-bit processor some new data types will be needed in the `basetype.h` header file. It will also be necessary to update the toplevel `ecos.db` database with an entry for the new HAL package, and a new target entry will be needed.

Obviously a different processor will have different register sets and calling conventions, so the code for saving and restoring thread contexts and for implementing `setjmp` and `longjmp` will need to be updated. The exact way of performing Linux system calls will vary: on x86 linux this usually involves pushing some registers on the stack and then executing an `int 0x080` trap instruction, but on a different processor the arguments might be passed in registers instead and certainly a different trap instruction will be used. The startup code is written in assembler, but needs to do little more than extract the process' argument and environment variables and then jump to the main `linux_entry` function provided by the architectural synthetic target HAL package.

The header file `hal_io.h` provided by the architectural HAL package provides various structure definitions, function prototypes, and macros related to system calls. These are correct for x86 linux, but there may be problems on other processors. For example a structure field that is currently defined as a 32-bit number may in fact may be a 64-bit number instead.

The synthetic target's memory map is defined in two files in the `include/pkgconf` subdirectory. For x86 the default memory map involves eight megabytes of read-only memory for the code at location `0x1000000` and another eight megabytes for data at `0x2000000`. These address ranges may be reserved for other purposes on the new architecture, so may need changing. There may be some additional areas of memory allocated by the system for other purposes, for example the startup stack and any environment variables, but usually eCos applications can and should ignore those.

Other HAL functionality such as interrupt handling, diagnostics, and the system clock are provided by the architectural HAL package and should work on different processors with few if any changes. There may be some problems in the code that interacts with the I/O auxiliary because of lurking assumptions about endianness or the sizes of various data types.

When porting to other processors, a number of sources of information are likely to prove useful. Obviously the Linux kernel sources and header files constitute the ultimate authority on how things work at the system call level. The GNU C library sources may also prove very useful: for a normal Linux application it is the C library that provides the startup code and the system call interface.

Other Unix Platforms

Porting to a Unix or Unix-like operating system other than Linux would be somewhat more involved. The first requirement is toolchains: the GNU compilers, gcc and g++, must definitely be used; use of other GNU tools such as the linker may be needed as well, because eCos depends on functionality such as prioritizing C++ static constructors, and other linkers may not implement this or may implement it in a different and incompatible way. A closely related requirement is the use of ELF format for binary executables: if the operating system still uses an older format such as COFF then there are likely to be problems because they do not provide the flexibility required by eCos.

In the architectural HAL there should be very little code that is specific to Linux. Instead the code should work on any operating system that provides a reasonable implementation of the POSIX standard. There may be some problems with program startup, but those could be handled at the architectural level. Some changes may also be required to the exception handling code. However one file which will present a problem is `hal_io.h`, which contains various structure definitions and macros used with the system call interface. It is likely that many of these definitions will need changing, and it may well be appropriate to implement variant HAL packages for the different operating systems where this information can be separated out. Another possible problem is that the generic code assumes that system calls such as `cyg_hal_sys_write` are available. On an operating system other than Linux it is possible that some of these are not simple system calls, and instead wrapper functions will need to be implemented at the variant HAL level.

The generic I/O auxiliary code should be fairly portable to other Unix platforms. However some of the device drivers may contain code that is specific to Linux, for example the `PF_PACKET` socket address family and the ethernet virtual tunnelling interface. These may prove quite difficult to port.

The remaining porting task is to implement one or more platform HAL packages, one per processor type that is supported. This should involve much the same work as a port to [another processor running Linux](#).

When using other Unix operating systems the kernel source code may not be available, which would make any porting effort more challenging. However there is still a good chance that the GNU C library will have been ported already, so its source code may contain much useful information.

Windows Platforms

Porting the current synthetic target code to some version of Windows or to another non-Unix platform is likely to prove very difficult. The first hurdle that needs to be crossed is the file format for binary executables: current Windows implementations do not use ELF, instead they use their own format PE which is a variant of the rather old and limited COFF format. It may well prove easier to first write an ELF loader for Windows executables, rather than try to get eCos to work within the constraints of PE. Of course that introduces new problems, for example existing source-level debuggers will still expect executables to be in PE format.

Under Linux a synthetic target application is not linked with the system's C library or any other standard system library. That would cause confusion, for example both eCos and the system's C library might try to define the `printf` function, and introduce complications such as working with shared libraries. For much the same reasons, a synthetic target application under Windows should not be linked with any Windows DLL's. If an ELF loader has been specially written then this may not be much of a problem.

The next big problem is the system call interface. Under Windows system calls are generally made via DLL's, and it is not clear that the underlying trap mechanism is well-documented or consistent between different releases of Windows.

The current code depends on the operating system providing an implementation of POSIX signal handling. This is used for I/O purposes, for example `SIGALRM` is used for the system clock, and for exceptions. It is not known what equivalent functionality is available under Windows.

Given the above problems a port of the synthetic target to Windows may or may not be technically feasible, but it would certainly require a very large amount of effort.

XXXI. SA11X0 USB Device Driver

SA11X0 USB Device Driver

Name

SA11X0 USB Support — Device driver for the on-chip SA11X0 USB device

SA11X0 USB Hardware

The Intel StrongARM SA11x0 family of processors is supplied with an on-chip USB slave device, the UDC (USB Device Controller). This supports three endpoints. Endpoint 0 can only be used for control messages. Endpoint 1 can only be used for bulk transfers from host to peripheral. Endpoint 2 can only be used for bulk transfers from peripheral to host. Isochronous and interrupt transfers are not supported.

Caution

Different revisions of the SA11x0 silicon have had various problems with the USB support. The device driver has been tested primarily against stepping B4 of the SA1110 processor, and may not function as expected with other revisions. Application developers should obtain the manufacturer's current errata sheets and specification updates. The B4 stepping still has a number of problems, but the device driver can work around these. However there is a penalty in terms of extra code, extra cpu cycles, and increased dispatch latency because extra processing is needed at DSR level. Interrupt latency should not be affected.

There is one specific problem inherent in the UDC design of which application developers should be aware: the hardware cannot fully implement the USB standard for bulk transfers. A bulk transfer typically consists of some number of full-size 64-byte packets and is terminated by a packet less than the full size. If the amount of data transferred is an exact multiple of 64 bytes then this requires a terminating packet of 0 bytes of data (plus header and checksum). The SA11x0 USB hardware does not allow a 0-byte packet to be transmitted, so the device driver is forced to substitute a 1-byte packet and the host receives more data than expected. Protocol support is needed so that the appropriate host-side device driver can allow buffer space for the extra byte, detect when it gets sent, and discard it. Consequently certain standard USB class protocols cannot be implemented using the SA11x0, and therefore custom host-side device drivers will generally have to be provided, rather than re-using existing ones that understand the standard protocol.

Endpoint Data Structures

The SA11x0 USB device driver can provide up to three data structures corresponding to the three endpoints: a `usbs_control_endpoint` structure `usbs_sa11x0_ep0`; a `usbs_rx_endpoint` `usbs_sa11x0_ep1`; and a `usbs_tx_endpoint` `usbs_sa11x0_ep2`. The header file `cyg/io/usb/usbs_sa11x0.h` provides declarations for these.

Not all applications will require support for all the endpoints. For example, if the intended use of the UDC only involves peripheral to host transfers then `usbs_sa11x0_ep1` is redundant. The device driver provides configuration options to control the presence of each endpoint:

1. Endpoint 0 is controlled by `CYGFUN_DEVS_USB_SA11X0_EP0`. This defaults to enabled if there are any higher-level packages that require USB hardware or if the global preference `CYGGLO_IO_USB_SLAVE_APPLICATION` is enabled, otherwise it is disabled. Usually this has the desired

effect. It may be necessary to override this in special circumstances, for example if the target board uses an external USB chip in preference to the UDC and it is that external chip's device driver that should be used rather than the on-chip UDC. It is not possible to disable endpoint 0 and at the same time enable one or both of the other endpoints, since a USB device is only usable if it can process the standard control messages.

2. Endpoint 1 is controlled by `CYGPKG_DEVS_USB_SA11X0_EP1`. By default it is enabled whenever endpoint 0 is enabled, but it can be disabled manually when not required.
3. Similarly endpoint 2 is controlled by `CYGPKG_DEVS_USB_SA11X0_EP2`. This is also enabled by default whenever endpoint 0 is enabled, but it can be disabled manually.

The SA11X0 USB device driver implements the interface specified by the common eCos USB Slave Support package. The documentation for that package should be consulted for further details. There is only one major deviation: when there is a peripheral to host transfer on endpoint 2 which is an exact multiple of the bulk transfer packet size (usually 64 bytes) the device driver has to pad the transfer with one extra byte. This is because of a hardware limitation: the UDC is incapable of transmitting 0-byte packets as required by the USB specification. Higher-level code, including the host-side device driver, needs to be aware of this and adapt accordingly.

The device driver assumes a bulk packet size of 64 bytes, so this value should be used in the endpoint descriptors in the enumeration data provided by application code. There is experimental code for running with [DMA disabled](#), in which case the packet size will be 16 bytes rather than 64.

Devtab Entries

In addition to the endpoint data structures the SA11X0 USB device driver can also provide devtab entries for each endpoint. This allows higher-level code to use traditional I/O operations such as `open/read/write` rather than the USB-specific non-blocking functions like `usbs_start_rx_buffer`. These devtab entries are optional since they are not always required. The relevant configuration options are `CYGVAR_DEVS_USB_SA11X0_EP0_DEVTAB_ENTRY`, `CYGVAR_DEVS_USB_SA11X0_EP1_DEVTAB_ENTRY` and `CYGVAR_DEVS_USB_SA11X0_EP2_DEVTAB_ENTRY`. By default these devtab entries are provided if the global preference `CYGGLO_USB_SLAVE_PROVIDE_DEVTAB_ENTRIES` is enabled, which is usually the case. Obviously a devtab entry for a given endpoint will only be provided if the underlying endpoint is enabled. For example, there will not be a devtab entry for endpoint 1 if `CYGPKG_DEVS_USB_SA11X0_EP1` is disabled.

The names for the three devtab entries are determined by using a configurable base name and appending `0c`, `1r` or `2w`. The base name is determined by the configuration option `CYGDAT_DEVS_USB_SA11X0_DEVTAB_BASENAME` and has a default value of `/dev/usbs`, so the devtab entry for endpoint 1 would default to `/dev/usbs1r`. If the target hardware involves multiple USB devices then application developers may have to change the base name to prevent a name clash.

DMA Engines

The SA11X0 UDC provides only limited fifos for bulk transfers on endpoints 1 and 2; smaller than the normal 64-byte bulk packet size. Therefore a typical transfer requires the use of DMA engines. The SA11x0 provides six DMA engines that can be used for this, and the endpoints require one each (assuming both endpoints are enabled). At the time of writing there is no arbitration mechanism to control access to the DMA engines. By default the device driver will use DMA engine 4 for endpoint 1 and DMA engine 5 for endpoint 2, and it assumes that no other code uses these particular engines.

The exact DMA engines that will be used are determined by the configuration options `CYGNUM_DEVS_USB_SA11X0_EP1_DMA_CHANNEL` and `CYGNUM_DEVS_USB_SA11X0_EP2_DMA_CHANNEL`.

These options have the booldata flavor, allowing the use of DMA to be disabled completely in addition to controlling which DMA engines are used. If DMA is disabled then the device driver will attempt to work purely using the fifos, and the packet size will be limited to only 16 bytes. This limit should be reflected in the appropriate endpoint descriptors in the enumeration data. The code for driving the endpoints without DMA should be considered experimental. At best it will be suitable only for applications where the amount of data transferred is relatively small, because four times as many interrupts will be raised and performance will suffer accordingly.

XXXII. NEC uPD985xx USB Device Driver

NEC uPD985xx USB Device Driver

Name

NEC uPD985xx USB Support — Device driver for the on-chip NEC uPD985xx USB device

NEC uPD985xx USB Hardware

The NEC uPD985xx family of processors is supplied with an on-chip USB slave device, the UDC (USB Device Controller). This supports seven endpoints. Endpoint 0 can only be used for control messages. Endpoints 1 and 2 are for isochronous transmits and receives respectively. Endpoints 3 and 4 support bulk transmits and receives. Endpoints 5 and 6 normally support interrupt transmits and receives, but endpoint 5 can also be configured to support bulk transmits. At this time only the control endpoint 0, the bulk endpoints 3 and 4, and the interrupt endpoint 5 are supported.

Endpoint Data Structures

The uPD985xx USB device driver can provide up to four data structures corresponding to the four supported endpoints: a `usbs_control_endpoint` structure `usbs_upd985xx_ep0`; `usbs_tx_endpoint` structures `usbs_upd985xx_ep3` and `usbs_upd985xx_ep5`; and a `usbs_rx_endpoint` `usbs_upd985xx_ep4`. The header file `cyg/io/usb/usbs_nec_upd985xx.h` provides declarations for these.

Not all applications will require support for all the endpoints. For example, if the intended use of the UDC only involves peripheral to host transfers then `usbs_upd985xx_ep4` is redundant. The device driver provides configuration options to control the presence of each endpoint:

1. Endpoint 0 is controlled by `CYGFUN_DEVS_USB_UPD985XX_EP0`. This defaults to enabled if there are any higher-level packages that require USB hardware or if the global preference `CYGGLO_IO_USB_SLAVE_APPLICATION` is enabled, otherwise it is disabled. Usually this has the desired effect. It may be necessary to override this in special circumstances, for example if the target board uses an external USB chip in preference to the UDC and it is that external chip's device driver that should be used rather than the on-chip UDC. It is not possible to disable endpoint 0 and at the same time enable one or both of the other endpoints, since a USB device is only usable if it can process the standard control messages.
2. Endpoint 3 is controlled by `CYGPKG_DEVS_USB_UPD985XX_EP3`. By default this endpoint is disabled: according to NEC erratum U3 there may be problems when attempting bulk transfers of 192 bytes or greater. As an alternative the device driver provides support for endpoint 5, configured to allow bulk transfers. Endpoint 3 can be enabled if the application only requires bulk transfers of less than 192 bytes, or if this erratum is not applicable to the system being developed for other reasons.
3. Endpoint 4 is controlled by `CYGPKG_DEVS_USB_UPD985XX_EP4`. This is enabled by default whenever endpoint 0 is enabled, but it can be disabled manually.
4. Endpoint 5 is controlled by `CYGPKG_DEVS_USB_UPD985XX_EP5`. This is enabled by default whenever endpoint 0 is enabled, but it can be disabled manually. There is also a configuration option `CYGIMP_DEVS_USB_UPD985XX_EP5_BULK`, enabled by default. This option allows the endpoint to be used for bulk transfers rather than interrupt transfers.

The uPD985xx USB device driver implements the interface specified by the common eCos USB Slave Support package. The documentation for that package should be consulted for further details.

The device driver assumes a bulk packet size of 64 bytes, so this value should be used in the endpoint descriptors in the enumeration data provided by application code. The device driver also assumes a control packet size of eight bytes, and again this should be reflected in the enumeration data. If endpoint 5 is configured for interrupt rather than bulk transfers then the maximum packet size is limited to 64 bytes by the USB standard.

Devtab Entries

In addition to the endpoint data structures the uPD985xx USB device driver can also provide devtab entries for each endpoint. This allows higher-level code to use traditional I/O operations such as `open/read/write` rather than the USB-specific non-blocking functions like `usbs_start_rx_buffer`. These devtab entries are optional since they are not always required. The relevant configuration options are `CYGVAR_DEVS_USB_UPD985XX_EP0_DEVTAB_ENTRY`, `CYGVAR_DEVS_USB_UPD985XX_EP3_DEVTAB_ENTRY`, `CYGVAR_DEVS_USB_UPD985XX_EP4_DEVTAB_ENTRY`, and `CYGVAR_DEVS_USB_UPD985XX_EP5_DEVTAB_ENTRY`. By default these devtab entries are provided if the global preference `CYGGLO_USB_SLAVE_PROVIDE_DEVTAB_ENTRIES` is enabled, which is usually the case. Obviously a devtab entry for a given endpoint will only be provided if the underlying endpoint is enabled. For example, there will not be a devtab entry for endpoint 4 if `CYGPKG_DEVS_USB_UPD985XX_EP4` is disabled.

The names for the devtab entries are determined by using a configurable base name and appending `0c`, `3w`, `4r` or `5w`. The base name is determined by the configuration option `CYGDAT_DEVS_USB_UPD985XX_DEVTAB_BASENAME` and has a default value of `/dev/usbs`, so the devtab entry for endpoint 4 would default to `/dev/usbs4r`. If the target hardware involves multiple USB devices then application developers may have to change the base name to prevent a name clash with other USB device drivers.

Restrictions

The current device driver imposes a restriction on certain bulk receives on endpoint 4. If the protocol being used involves variable-length transfers, in other words if the host is allowed to send less data than a maximum-sized transfer, then the buffer passed to the device driver for receives must be aligned to a 16-byte cacheline boundary and it must be a multiple of this 16-byte cacheline size. This restriction does not apply if the protocol only involves fixed-size transfers.

Optional Hardware Workarounds

The NEC errata list a number of other problems that affect the USB device driver. The device driver contains workarounds for these, which are enabled by default but can be disabled if the application developer knows that the errata are not relevant to the system being developed.

Erratum S1 lists a possible problem if the device driver attempts multiple writes to the USB hardware. This is circumvented by a dummy read operation after every write. If the workaround is not required then the configuration option `CYGIMP_DEVS_USB_UPD985XX_IBUS_WRITE_LIMIT` can be disabled.

Errata U3 and U4 describe various problems related to concurrent transmissions on different endpoints. By default the device driver works around this by serializing all transmit operations. For example if the device driver needs to send a response to a control message on endpoint 0 while there is an ongoing bulk transfer on endpoint 5, the response is delayed until the bulk transfer has completed. Under typical operating conditions this does not cause any problems: endpoint 0 traffic usually happens only during initialization, when the target is connected to the host, while endpoint 5 traffic only happens after initialization. However if transmit serial-

ization is inappropriate for the system being developed then it can be disabled using the configuration option `CYGIMP_DEVS_USB_UPD985XX_SERIALIZE_TRANSMITS`.

Platform Dependencies

On some platforms it is necessary for the low-level USB device driver to perform some additional operations during start-up. For example it may be necessary to manipulate one of the processor's GPIO lines before the host can detect a new USB peripheral and attempt to communicate with it. This avoids problems if the target involves a significant amount of work prior to device driver initialization, for example a power-on self-test sequence. If the USB host attempted to contact the target before the USB device driver had been initialized, it would fail to get the expected responses and conclude that the target was not a functional USB peripheral.

Platform-specific initialization code can be provided via a macro `UPD985XX_USB_PLATFORM_INIT`. Typically this macro would be defined in the platform HAL's header file `cyg/hal/plf_io.h`. If the current platform defines such a macro, the USB device driver will invoke it during the endpoint 0 start-up operation.

XXXIII. Synthetic Target Ethernet Driver

Synthetic Target Ethernet Driver

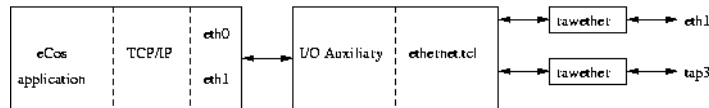
Name

Synthetic Target Ethernet Support — Allow synthetic target applications to perform ethernet I/O

Overview

The synthetic target ethernet package can provide up to four network devices, `eth0` to `eth3`. These can be used directly by the eCos application or, more commonly, by a TCP/IP stack that is linked with the eCos application. Each eCos device can be mapped on to a real Linux network device. For example, if the Linux PC has two ethernet cards and `eth1` is not currently being used by Linux itself, then one of the eCos devices can be mapped on to this Linux device. Alternatively, it is possible to map some or all of the eCos devices on to the ethertap support provided by the Linux kernel.

The ethernet package depends on the I/O auxiliary provided by the synthetic target architectural HAL package. During initialization the eCos application will attempt to instantiate the desired devices, by sending a request to the auxiliary. This will load a Tcl script `ethernet.tcl` that is responsible for handling the instantiation request and subsequent I/O operations, for example transmitting an ethernet packet. However, some of the low-level I/O operations cannot conveniently be done by a Tcl script so `ethernet.tcl` will actually run a separate program **rawether** to interact with the Linux network device.



On the target-side there are configuration options to control which network devices should be present. For many applications a single device will be sufficient, but if the final eCos application is something like a network bridge then the package can support multiple devices. On the host-side each eCos network device needs to be mapped on to a Linux one, either a real ethernet device or an ethertap device. This is handled by an entry in the target definition file:

```
synth_device ethernet {
    eth0 real eth1
    eth1 ethertap tap3 00:01:02:03:FE:05
    ...
}
```

The ethernet package also comes with support for packet logging, and provides various facilities for use by user Tcl scripts.

Installation

Before a synthetic target eCos application can access ethernet devices it is necessary to build and install host-side support. The relevant code resides in the `host` subdirectory of the synthetic target ethernet package, and building it involves the standard **configure**, **make** and **make install** steps. The build involves a new executable **rawether** which must be able to access a raw Linux network device. This is achieved by installing it `suid root`, so the **make install** step has to be run with superuser privileges.

Caution

Installing **rawether** `suid root` introduces a potential security problem. Although normally **rawether** is executed only by the I/O auxiliary, theoretically it can be run by any program. Effectively it gives any user the ability to monitor all ethernet traffic and to inject arbitrary packets into the network. Also, as with any `suid root` programs there may be as yet undiscovered exploits. Users and system administrators should consider the risks before running **make install**.

There are two main ways of building the host-side software. It is possible to build both the generic host-side software and all package-specific host-side software, including the ethernet support, in a single build tree. This involves using the **configure** script at the toplevel of the eCos repository. For more information on this, see the `README.host` file at the top of the repository. Note that if you have an existing build tree which does not include the synthetic target ethernet support then it will be necessary to rerun the toplevel `configure` script: the search for appropriate packages happens at configure time.

The alternative is to build just the host-side for this package. This requires a separate build directory, building directly in the source tree is disallowed. The **configure** options are much the same as for a build from the toplevel, and the `README.host` file can be consulted for more details. It is essential that the ethernet support be configured with the same `--prefix` option as other eCos host-side software, especially the I/O auxiliary provided by the architectural synthetic target HAL package, otherwise the I/O auxiliary will be unable to locate the ethernet support.

Target-side Configuration Options

The target-side code can be configured to support up to four ethernet devices, `eth0` to `eth3`. By default `eth0` is enabled if the configuration includes a TCP/IP stack, otherwise it is disabled. The other three devices are always disabled by default. If any of the devices are enabled then there will also be the usual configuration options related to building this package. Other options related to network devices, for example whether or not to use DHCP, are provided by the generic network device package.

Real Ethernet

One obvious way of providing a synthetic target eCos application with ethernet I/O is to use a real ethernet device in the PC: transmitted packets go out on a real network, and packets on the network addressed to the right MAC address are passed on to eCos. This way synthetic target networking behaves just like networking on a real target with ethernet hardware. For example, if there is a DHCP server anywhere on the network then eCos will be able to contact it during networking startup and get hold of IP address information.

Configuring the ethernet support to use a real ethernet device requires a simple entry in the target definition file:

```
synth_device ethernet {
    <eCos device> real <linux device>
    ...
}
```

For example, to map the eCos network device `eth0` to the Linux device `eth1`:

```
synth_device ethernet {
    eth0 real eth1
    ...
}
```

It is not possible for an ethernet device to be shared by both the eCos TCP/IP stack and the Linux one: there would be no simple way to work out which stack incoming packets are intended for. In theory it might be possible to do some demultiplexing using distinct IP addresses, but it would be impossible to support some functionality such as DHCP. Therefore the **rawether** program will refuse to access any ethernet device already in use. On a typical Linux system `eth0` will be used for Linux networking, and the PC will have to be equipped with additional ethernet devices for use by eCos.

The **rawether** program will access the hardware via the appropriate Linux device driver, so it is important that the system is set up such that the relevant module will be automatically loaded or is already loaded. The details of this will depend on the installed distribution and version, but typically it will involve an entry in `/etc/modules.conf`.

Ethertap

The Linux kernel's ethertap facility provides a virtual network interface. A Linux application, for example the **rawether** program, can open a special character device `/dev/net/tun`, perform various `ioctl` calls, and then write and read ethernet packets. When the device is opened the Linux kernel automatically creates a new network interface, for example `tap0`. The Linux TCP/IP stack can be made to use this network interface like any other interface, receiving and transmitting ethernet packets. The net effect is a virtual network connecting just the Linux and eCos TCP/IP stacks, with no other nodes attached. By default all traffic remains inside this virtual network and is never forwarded to a real network.

Support for the ethertap facility may or may not be provided automatically, depending on your Linux distribution and version. If your system does not have a device `/dev/net/tun` or a module `tun.o` then the appropriate kernel documentation should be consulted, for example `/usr/src/linux-2.4/Documentation/networking/tuntap.txt`. If you are using an old Linux kernel then the ethertap functionality may be missing completely. When the **rawether** program is configured and built, the **configure** script will check for a file `/usr/include/linux/if_tun.h`. If that file is missing then **rawether** will be built without ethertap functionality, and only real ethernet interfaces will be supported.

The target definition file is used to map eCos network devices on to ethertap devices. The simplest usage is:

```
synth_device ethernet {
    eth0 ethertap
    ...
}
```

The Linux kernel will automatically allocate the next available tap network interface. Usually this will be `tap0` but if other software is using the ethertap facility, for example to implement a VPN, then a different number may be allocated. Usually it will be better to specify the particular tap device that should be used for each eCos device, for example:

```
synth_device ethernet {
    eth0 ethertap tap3
    eth1 ethertap tap4
    ...
}
```

The user now knows exactly which eCos device is mapped onto which Linux device, avoiding much potential confusion. Because the virtual devices are emulated ethernet devices, they require MAC addresses. There is no physical hardware to provide these addresses, so normally MAC addresses will be invented. That means that each time the eCos application is run it will have different MAC addresses, which makes it more difficult to compare the results of different runs. To get more deterministic behaviour it is possible to specify the MAC addresses in the target definition file:

```
synth_device ethernet {
    eth0 ethertap tap3 00:01:02:03:FE:05
    eth1 ethertap tap4 00:01:02:03:FE:06
    ...
}
```

During the initialization phase the eCos application will instantiate the various network devices. This will cause the I/O auxiliary to load the `ethernet.tcl` script and spawn **rawether** processes, which in turn will open `/dev/net/tun` and perform the appropriate `ioctl` calls. On the Linux side there will now be new network interfaces such as `tap3`, and these can be configured like any other network interface using commands such as **ifconfig**. In addition, if the Linux system is set up with hotplug support then it may be possible to arrange for the network interface to become active automatically. On a Red Hat Linux system this would require files such as `/etc/sysconfig/network-scripts/ifcfg-tap3`, containing data like:

```
DEVICE="tap3"
BOOTPROTO="none"
BROADCAST=10.2.2.255
IPADDR="10.2.2.1"
NETMASK="255.255.255.0"
NETWORK=10.2.2.0
ONBOOT="no"
```

This gives the Linux interface the address 10.2.2.1 on the network 10.2.2.0. The eCos network device should be configured with a compatible address. One way of doing this would be to enable `CYGHWR_NET_DRIVER_ETH0_ADDRS`, set `CYGHWR_NET_DRIVER_ETH0_ADDRS_IP` to 10.2.2.2, and similarly update the `NETMASK`, `BROADCAST`, `GATEWAY` and `SERVER` configuration options.

It should be noted that the `ethertap` facility provides a virtual network, and any packets transmitted by the eCos application will not appear on a real network. Therefore usually there will no accessible DHCP server, and eCos cannot use DHCP or BOOTP to obtain IP address information. Instead the eCos configuration should use manual or static addresses.

When **rawether** exits, the tap interface is removed by the kernel. By adding the parameter persistent **rawether** will set the persistent flag on the tap device.

```
synth_device ethernet {
    eth0 ethertap tap3 00:01:02:03:FE:05
    eth1 ethertap tap4 00:01:02:03:FE:06 persistent
    ...
}
```

With this flag set the kernel will not remove the interface when **rawether** exits. This means applications such as **dhcpcd**, **radvd**, and **tcpdump** will continue to run on the interface between invocations of synthetic targets. As a result the target can dynamically obtain its IP addresses from these daemons. Note it is a good idea to specify a MAC address otherwise a different random MAC address will be used each time and the `dhcpcd` daemon will not be able to reissue the same IP address.

Host daemons like `dhcpcd`, `ntpd`, `radvd` etc are started at boot time. Since the tap device does not exist at this point in time it is not possible for these daemons to bind to the tap device. A simple solution is to use the program **install/bin/mktap**. This takes one parameter, the name of the tap device it should create. eg, `tap3`.

An alternative approach would be to set up the Linux box as a network bridge, using commands like **brctl** to connect the virtual network interface `tap3` to a physical network interface such as `eth0`. Any packets sent by the eCos application will get forwarded automatically to the real network, and some packets on the real network will get forwarded over the virtual network to the eCos application. Note that the eCos application might also get some packets that were not intended for it, but usually those will just be discarded by the eCos TCP/IP stack. The exact details of setting up a network bridge are left as an exercise to the reader.

Packet Logging

The ethernet support comes with support for logging the various packets that are transferred, including a simple protocol analyser. This generates simple text output using the filter mechanisms provided by the I/O auxiliary, so it is possible to control the appearance and visibility of different types of output. For example the user might want to see IPv4 headers and all ICMPv4 and ARP operations, but not TCP headers or any of the packet data.

The protocol analyser is not intended to be a fully functional analyser with knowledge of many different TCP/IP protocols, advanced search facilities, graphical traffic displays, and so on. Functionality like that is already provided by other tools such as *ethereal* and *tcpdump*. Achieving similar levels of functionality would require a lot of work, for very little gain. It is still useful to have some protocol analysis functionality available because the output will be interleaved with other output, for example `printf` calls from the application. That may make it easier to understand the sequence of events.

One problem with logging ethernet traffic is that it can involve very large amounts of data. If the application is expected to run for a long time or is very I/O intensive then it is easy to end up with many megabytes. When running in graphical mode all the logging data will be held in memory, even data that is not currently visible. At some point the system will begin to run low on memory and performance will suffer. To avoid problems, the ethernet script maintains a flag that controls whether or not packet logging is active. The default is to run with logging disabled, but this can be changed in the target definition file:

```
synth_device ethernet {
    ...
    logging 1
}
```

The ethernet script will add a toolbar button that allows this flag to be changed at run-time, allowing the user to capture traffic for certain periods of time while the application continues running.

The target definition file can contain the following entries for the various packet logging filters:

```
synth_device ethernet {
    ...
    filter ether -hide 0 -background LightBlue -foreground "#000080"
    filter arp -hide 0 -background LightBlue -foreground "#000050"
    filter ipv4 -hide 0 -background LightBlue -foreground "#000040"
    filter ipv6 -hide 1 -background LightBlue -foreground "#000040"
    filter icmpv4 -hide 0 -background LightBlue -foreground "#000070"
    filter icmpv6 -hide 1 -background LightBlue -foreground "#000070"
    filter udp -hide 0 -background LightBlue -foreground "#000030"
    filter tcp -hide 0 -background LightBlue -foreground "#000020"
    filter hexdata -hide 1 -background LightBlue -foreground "#000080"
    filter asciidata -hide 1 -background LightBlue -foreground "#000080"
}
```

All output will show the eCos network device, for example `eth0`, and the direction relative to the eCos application. Some of the filters will show packet headers, for example `ether` gives details of the ethernet packet header and `tcp` gives information about TCP headers such as whether or not the SYN flag is set. The TCP and UDP filters will also show source and destination addresses, using numerical addresses and if possible host names. However, host names will only be shown if the host appears in `/etc/hosts`: doing full DNS lookups while the data is being captured would add significantly to complexity and overhead. The `hexdata` and `asciidata` filters show the remainder of the packets after the ethernet, IP and TCP or UDP headers have been stripped.

Some of the filters will provide raw dumps of some of the packet data. Showing up to 1500 bytes of data for each packet would be expensive, and often the most interesting information is near the start of the packet. Therefore it is possible to set a limit on the number of bytes that will be shown using the target definition file. The default limit is 64 bytes.

```
synth_device ethernet {  
    ...  
    max_show 128  
}
```

User Interface Additions

When running in graphical mode the ethernet script extends the user interface in two ways: a button is added to the toolbar so that users can enable or disable packet logging; and an entry is added to the **Help** menu for the ethernet-specific documentation.

Command Line Arguments

The synthetic target ethernet support does not use any command line arguments. All configuration is handled through the target definition file.

Hooks

The ethernet support defines two hooks that can be used by other scripts, especially user scripts: `ethernet_tx` and `ethernet_rx`. The tx hook is called whenever eCos tries to transmit a packet. The rx hook is called whenever an incoming packet is passed to the eCos application. Note that this may be a little bit after the packet was actually received by the I/O auxiliary since it can buffer some packets. Both hooks are called with two arguments, the name of the network device and the packet being transferred. Typical usage might look like:

```
proc my_tx_hook { arg_list } {  
    set dev [lindex $arg_list 0]  
    incr :my_ethernet_tx_packets($dev)  
    incr :my_ethernet_tx_bytes($dev) [string length [lindex $arg_list 1]]  
}  
proc my_rx_hook { arg_list } {  
    set dev [lindex $arg_list 0]  
    incr :my_ethernet_rx_packets($dev)  
    incr :my_ethernet_rx_bytes($dev) [string length [lindex $arg_list 1]]  
}  
synth::hook_add "ethernet_tx" my_tx_hook  
synth::hook_add "ethernet_rx" my_rx_hook
```

The global arrays `my_ethernet_tx_packets` etc. will now be updated whenever there is ethernet traffic. Other code, probably running at regular intervals by use of the Tcl **after** procedure, can then use this information to update a graphical monitor of some sort.

Additional Tcl Procedures

The ethernet support provides one additional Tcl procedure that can be used by other scripts;

```
ethernet::devices_get_list
```

This procedure returns a list of the ethernet devices that have been instantiated, for example `{eth0 eth1}`.

XXXIV. Synthetic Target Watchdog Device

Synthetic Target Watchdog Device

Name

Synthetic Target Watchdog Device — Emulate watchdog hardware in the synthetic target

Overview

Some target hardware comes equipped with a watchdog timer. Application code can start this timer and after a certain period of time, typically a second, the watchdog will trigger. Usually this causes the hardware to reboot. The application can prevent this by regularly resetting the watchdog. An automatic reboot can be very useful when deploying hardware in the field: a hardware glitch could cause the unit to hang; or the software could receive an unexpected sequence of inputs, never seen in the laboratory, causing the system to lock up. Often the hardware is still functional, and a reboot sorts out the problem with only a brief interruption in service.

The synthetic target watchdog package emulates watchdog hardware. During system initialization watchdog device will be instantiated, and the `watchdog.tcl` script will be loaded by the I/O auxiliary. When the eCos application starts the watchdog device, the `watchdog.tcl` script will start checking the state of the eCos application at one second intervals. A watchdog reset call simply involves a message to the I/O auxiliary. If the `watchdog.tcl` script detects that a second has [elapsed](#) without a reset then it will send a `SIGPWR` signal to the eCos application, causing the latter to terminate. If `gdb` is being used to run the application, the user will get a chance to investigate what is happening. This behaviour is different from real hardware in that there is no automatic reboot, but the synthetic target is used only for development purposes, not deployment in the field: if a reboot is desired then this can be achieved very easily by using `gdb` commands to run another instance of the application.

Installation

Before a synthetic target eCos application can use a watchdog device it is necessary to build and install host-side support. The relevant code resides in the `host` subdirectory of the synthetic target watchdog package, and building it involves the standard **configure**, **make** and **make install** steps. The implementation of the watchdog support does not require any executables, just a Tcl script `watchdog.tcl` and some support files, so the **make** step is a no-op.

There are two main ways of building the host-side software. It is possible to build both the generic host-side software and all package-specific host-side software, including the watchdog support, in a single build tree. This involves using the **configure** script at the toplevel of the eCos repository. For more information on this, see the `README.host` file at the top of the repository. Note that if you have an existing build tree which does not include the synthetic target watchdog support then it will be necessary to rerun the toplevel configure script: the search for appropriate packages happens at configure time.

The alternative is to build just the host-side for this package. This requires a separate build directory, building directly in the source tree is disallowed. The **configure** options are much the same as for a build from the toplevel, and the `README.host` file can be consulted for more details. It is essential that the watchdog support be configured with the same `--prefix` option as other eCos host-side software, especially the I/O auxiliary provided by the architectural synthetic target HAL package, otherwise the I/O auxiliary will be unable to locate the watchdog support.

Target-side Configuration

The watchdog device depends on the generic watchdog support, `CYGPKG_IO_WATCHDOG`: if the generic support is absent then the watchdog device will be inactive. Some templates include this generic package by default, but not all. If the configuration does not include the generic package then it can be added using the eCos configuration tools, for example:

```
$ ecosconfig add CYGPKG_IO_WATCHDOG
```

By default the configuration will use the hardware-specific support, i.e. this package. However the generic watchdog package contains an alternative implementation using the kernel alarm facility, and that implementation can be selected if desired. However usually it will be better to rely on an external watchdog facility as provided by the I/O auxiliary and the `watchdog.tcl` script: if there are serious problems within the application, for example memory corruption, then an internal software-only implementation will not be reliable.

The watchdog resolution is currently fixed to one second: if the device does not receive a reset signal at least once a second then the watchdog will trigger and the eCos application will be terminated with a `SIGPWR` signal. The current implementation does not allow this resolution to be changed.

On some targets the watchdog device does not perform a hard reset. Instead the device works more or less via the interrupt subsystem, allowing application code to install action routines that will be called when the watchdog triggers. The synthetic target watchdog support effectively does perform a hard reset, by sending a `SIGPWR` signal to the eCos application, and there is no support for action routines.

The synthetic target watchdog package provides some configuration options for manipulating the compiler flags used for building the target-side code. That code is fairly simple, so for nearly all applications the default flags will suffice.

It should be noted that the watchdog device is subject to selective linking. Unless some code explicitly references the device, for example by calling the start and reset functions, the watchdog support will not appear in the final executable. This is desirable because a watchdog device has no effect until started.

Wallclock versus Elapsed Time

On real hardware the watchdog device uses wallclock time: if the device does not receive a reset signal within a set period of time then the watchdog will trigger. When developing for the synthetic target this is not always appropriate. There may be other processes running, using up some or most of the cpu time. For example, the application may be written such that it will issue a reset after some calculations which are known to complete within half a second, well within the one-second resolution of the watchdog device. However if other Linux processes are running then the synthetic target application may get timesliced, and half a second of computation may take several seconds of wallclock time.

Another problem with using wallclock time is that it interferes with debugging: if the application hits a breakpoint then it is unlikely that the user will manage to restart it in less than a second, and the watchdog will not get reset in time.

To avoid these problems the synthetic target watchdog normally uses consumed cpu time rather than wallclock time. If the application is timesliced or if it is halted inside gdb then it does not consume any cpu time. The application actually has to spend a whole second's worth of cpu cycles without issuing a reset before the watchdog triggers.

However using consumed cpu time is not a perfect solution either. If the application makes blocking system calls then it is not using cpu time. Interaction with the I/O auxiliary involves system calls, but these should take only a short amount of time so their effects can be ignored. If the application makes direct system calls such as `cyg_hal_sys_read` then the system behaviour becomes undefined. In addition by default the idle thread will make blocking `select` system calls, effectively waiting until an interrupt occurs. If an application spends

much of its time idle then the watchdog device may take much longer to trigger than expected. It may be desirable to enable the synthetic target HAL configuration option `CYGIMP_HAL_IDLE_THREAD_SPIN`, causing the idle thread to spin rather than block, at the cost of wasted cpu cycles.

The default is to use consumed cpu time, but this can be changed in the target definition file:

```
synth_device watchdog {
    use wallclock_time
    ...
}
```

User Interface

When the synthetic target is run in graphical mode the watchdog device extends the user interface in two ways. The **Help** menu is extended with an entry for the watchdog-specific documentation. There is also a graphical display of the current state of the watchdog. Initially the watchdog is asleep:



When application code starts the device the watchdog will begin to keep an eye on things (or occasionally both eyes).



If the watchdog triggers the display will change again, and optionally the user can receive an audible alert. The location of the watchdog display within the I/O auxiliary's window can be controlled via a **watchdog_pack** entry in the target definition file. For example the following can be used to put the watchdog display to the right of the central text window:

```
synth_device watchdog {
    watchdog_pack -in .main.e -side top
    ...
}
```

The user interface section of the generic synthetic target HAL documentation can be consulted for more information on window packing.

By default the watchdog support will not generate an audible alert when the watchdog triggers, to avoid annoying colleagues. Sound can be enabled in the target definition file, and two suitable files `sound1.au` and `sound2.au` are supplied as standard:

```
synth_device watchdog {
    sound sound1.au
    ...
}
```

An absolute path can be specified if desired:

```
synth_device watchdog {  
    sound /usr/share/emacs/site-lisp/emacspeak/sounds/default-8k/alarm.au  
    ...  
}
```

Sound facilities are not built into the I/O auxiliary itself, instead an external program is used. The default player is **play**, a front-end to the sox application shipped with some Linux distributions. If another player should be used then this can be specified in the target definition file:

```
synth_device watchdog {  
    ...  
    sound_player my_sound_player
```

The specified program will be run in the background with a single argument, the sound file.

Command Line Arguments

The watchdog support does not use any command line arguments. All configuration is handled through the target definition file.

Hooks

The watchdog support does not provide any hooks for use by other scripts. There is rarely any need for customizing the system's behaviour when a watchdog triggers because those should be rare events, even during application development.

Additional Tcl Procedures

The watchdog support does not provide any additional Tcl procedures or variables for use by other scripts.

XXXV. Dallas DS1307 Wallclock Device Driver

Dallas DS1307 Wallclock Device Driver

Name

CYGPKG_DEVICES_WALLCLOCK_DALLAS_DS1307 — eCos Support for the Dallas DS1307 Serial Real-Time Clock

Description

This package `CYGPKG_DEVICES_WALLCLOCK_DALLAS_DS1307` provides a device driver for the wallclock device in the Dallas DS1307 Serial Real-Time Clock chips. This combines a real-time clock and 56 bytes of battery-backed RAM in a single package. The driver can also be used with any other chips that provide the same interface to the clock hardware.

The package will usually be loaded into the configuration automatically whenever selecting a target which contains a compatible chip. By default it will provide the standard eCos wallclock device, although another implementation such as software emulation may be selected if desired. The only other configuration options related to this package allow users to change the compiler flags. If the application does not actually use the wallclock device, directly or indirectly, then the code should get removed automatically at link-time to ensure that the application does not suffer any unnecessary overheads.

Functionality

This wallclock device driver package implements the standard functionality required by the generic wallclock support `CYGPKG_IO_WALLCLOCK`. The functionality is not normally accessed directly. Instead it is used by the C library time package to implement standard calls such as `time` and `gmtime`. The eCos C library also provides a non-standard function `cyg_libc_time_settime` for changing the current wallclock setting. In addition RedBoot provides a **date** command which interacts with the wallclock device.

Porting

DS1307 platform support can be implemented in one of two ways. The preferred approach involves the generic I2C API, as defined by the package `CYGPKG_IO_I2C`. The platform HAL can just provide a `cyg_i2c_device` structure `cyg_i2c_wallclock_ds1307` and implement the CDL interface `CYGINT_DEVICES_WALLCLOCK_DALLAS_DS1307_I2C`. The DS1307 driver will now use I2C rx and tx operations to interact with the chip.

Alternatively the DS1307 driver can use macros or functions provided by another package to access the chip. This is intended primarily for older platforms that predate the `CYGPKG_IO_I2C` package. The other package should export a header file containing macros `DS_GET` and `DS_PUT` that transfer the eight bytes corresponding to the chip's clock registers. It should also export the name of this header via a `#define` `CYGDAT_DEVS_WALLCLOCK_DS1307_INL` in the global configuration header `pkgconf/system.h`. For full details see the source code.

In addition the DS1307 device driver package `CYGPKG_DEVICES_WALLCLOCK_DALLAS_DS1307` should be included in the CDL target entry so that it gets loaded automatically whenever eCos is configured for that target.

XXXVI. Synthetic Target Framebuffer Device

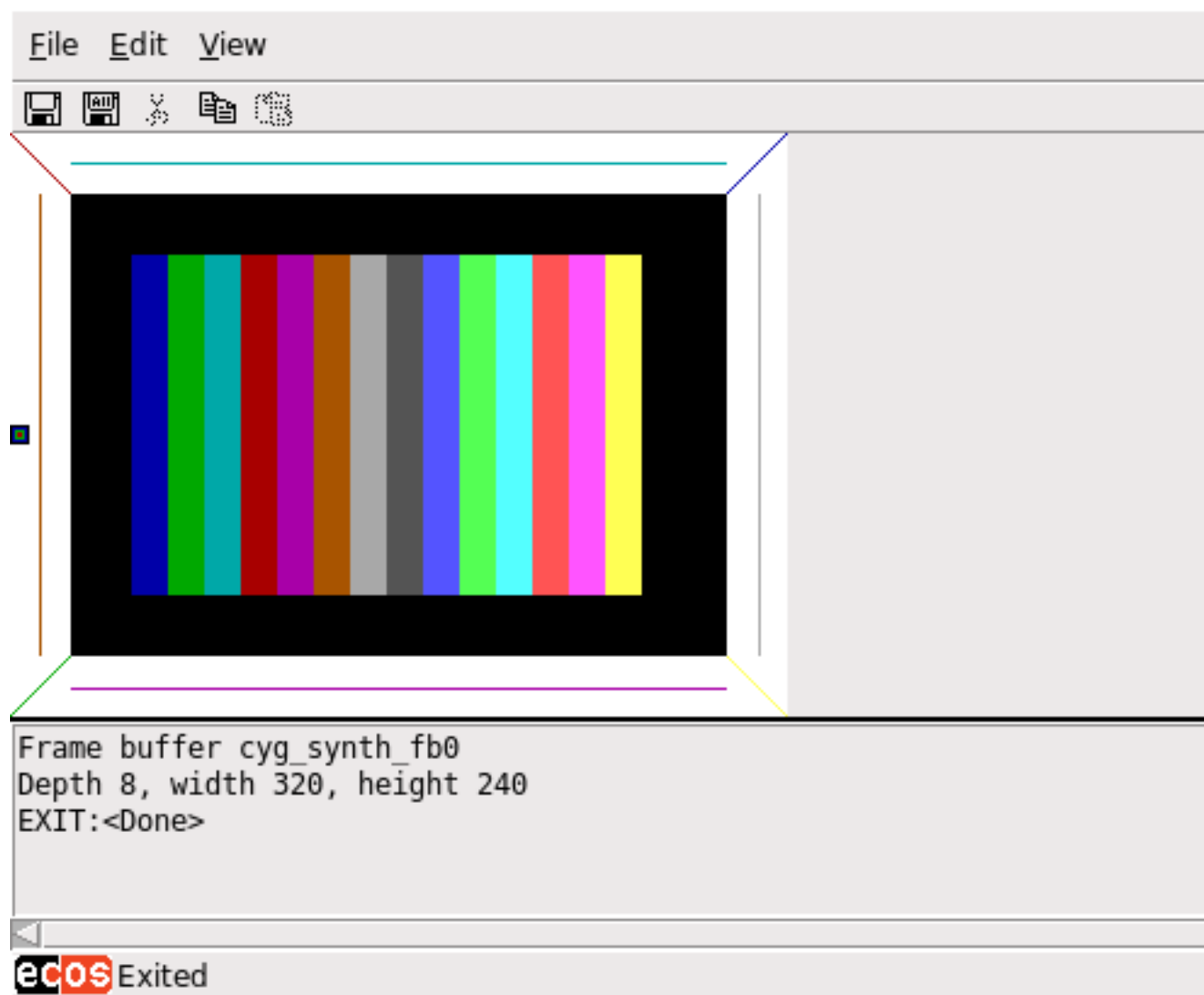
Synthetic Target Framebuffer Device

Name

Synthetic Target Framebuffer Device — Emulate framebuffer hardware in the synthetic target

Overview

This package `CYGPKG_DEVS_FRAMEBUFFER_SYNTH` provides a framebuffer device driver for the eCos synthetic target.



The driver supports up to four framebuffer devices `fb0`, `fb1`, `fb2` and `fb3`. The width, height, depth, and display format of each framebuffer can be controlled via configuration options. It is also possible to set a viewport for each device and to enable page flipping.

To use the framebuffer support the eCos application must run inside an X session, not from the console, and it must be started with `--io` to enable the I/O auxiliary. The I/O auxiliary will start a separate instance of a host-side utility `framebuf` for each target-side framebuffer device. The `framebuf` utility can access the eCos

framebuffer data via a shared memory region and draw it to the screen using X library calls. It needs the X server to run with a TrueColor visual and a display of depth of 24 or 32 bits per pixel.

Installation

The synthetic target framebuffer driver depends on host-side support which must be built and installed. The relevant code resides in the `host` subdirectory of the synthetic target framebuffer package, and building it involves the standard **configure**, **make** and **make install** steps. This will build and install a utility program `framebuf` that does the actual drawing of the eCos framebuffer contents to the host-side X display. It will also install a Tcl script and some support files. `framebuf` is an X11 application so can only be built on Linux systems with the appropriate X11 development package or packages.

There are two main ways of building the host-side software. It is possible to build both the generic host-side software and all package-specific host-side software, including the framebuffer support, in a single build tree. This involves using the **configure** script at the toplevel of the eCos repository. For more information on this, see the `README.host` file at the top of the repository. Note that if you have an existing build tree which does not include the synthetic target framebuffer support then it will be necessary to rerun the toplevel configure script: the search for appropriate packages happens at configure time.

The alternative is to build just the host-side for this package. This requires a separate build directory, building directly in the source tree is disallowed. The **configure** options are much the same as for a build from the toplevel, and the `README.host` file can be consulted for more details. It is essential that the framebuffer support be configured with the same `--prefix` option as other eCos host-side software, especially the I/O auxiliary provided by the architectural synthetic target HAL package, otherwise the I/O auxiliary will be unable to locate the framebuffer support.

Configuration

The package is loaded automatically when creating a configuration for the synthetic target. However it is inactive unless the generic framebuffer support `CYGPKG_IO_FRAMEBUFFER` is also added to the configuration, for example by `ecosconfig add framebuf`.

By default the package enables a single framebuffer device `fb0` with a corresponding `cyg_fb` data structure `cyg_synth_fb0`. The default settings for this device are 320 by 240 pixels, a depth of 8 bits per pixel, a paletted display, no viewport support, and no page flipping. All of these settings can be changed by configuration options inside the CDL component `CYGPKG_DEVS_FRAMEBUFFER_SYNTH_FB0`. The supported display formats are: 8 bpp paletted; 8bpp true colour 332; 16bpp true 565; 16bpp true 555; and 32bpp 0888. This allows the synthetic target to match the actual display capabilities of the hardware that is being emulated. If the actual hardware has more than one framebuffer device then this can be emulated by enabling additional components `CYGPKG_DEVS_FRAMEBUFFER_SYNTH_FB1` ..., and setting the appropriate options.

Customization

In addition to the target-side configurability it is possible to customize the host-side behaviour. For example, the default behaviour is for `fb0` to be drawn inside the I/O auxiliary's main window, if it is not too large. `fb1`, `fb2` and `fb3` will be drawn inside separate toplevel windows, as will `fb0` if that has been configured too large for embedding in the main window. This behaviour can be changed by providing a custom Tcl/Tk procedure that creates the containing frame for the framebuffer device.

Customization involves adding a `synth_device framebuf` section to the `.tdf` target definition file, usually `default.tdf` or `~/ecos/synth/default.tdf`.

```

proc my_framebuf_create_frame { ... } {
    ...
}

synth_device framebuffer {
    fb2_magnification    2
    create_frame_proc    my_framebuf_create_frame
}

```

The pixel size on the host display may be rather smaller than on the final hardware, causing a serious mismatch between the application's appearance when using synthetic target emulation and when using real hardware. To reduce this problem the host-side can magnify the target-side framebuffer devices. In the example above each target-side pixel in device `fb2` will be drawn using 2*2 pixels on the host side. Valid magnifications are 1, 2, 3 and 4. With a magnification of 4 an eCos framebuffer device of 320*240 pixels will be drawn in an X window of 1280*960 pixels.

The `create_frame_proc` entry can be used to specify a custom Tcl/Tk procedure that will create the containing Tk frames for the host-side displays. This procedure can be written for a specific configuration, but it is supplied with all the parameters associated with the framebuffer device so can be more generic. An example is supplied in the package's `misc` subdirectory:

1. Create a configuration for the synthetic target with the default template.
2. Import the `example.ecm` configuration fragment from the `misc` subdirectory. This will add the generic framebuffer support package, enable all four framebuffer devices, and configure each device. Build the resulting configuration.
3. Compile the `example.c` program and link it against the eCos configuration.
4. Incorporate the `example.tdf` fragment into the appropriate target definition file, typically `default.tdf` or `~/ecos/synth/default.tdf`.
5. Run the example executable. The four framebuffer devices should get instantiated in a separate window in a single column. `FB0` just contains a static display. `FB1` supports two pages, one with vertical stripes and one with horizontal stripes, and the two pages are flipped at regular intervals. `FB2` has a static display similar to `FB0`, but is drawn in a viewport of only 160x120 pixels. However `example.tdf` magnifies this by 2 so it appears the same size as the other devices. The application moves the viewport around the underlying framebuffer device. `FB3` is also a static display, a simple set of vertical stripes. However this framebuffer is paletted and the palette is changed at regular intervals, causing apparent movement.

XXXVII. AMD AM29xxxxx Flash Device Driver

Overview

Name

Overview — eCos Support for AMD AM29xxxxx Flash Devices and Compatibles

Description

The `CYGPKG_DEVS_FLASH_AMD_AM29XXXXX_V2` AMD AM29xxxxx V2 flash driver package implements support for the AM29xxxxx family of flash devices and compatibles. Normally the driver is not accessed directly. Instead application code will use the API provided by the generic flash driver package `CYGPKG_IO_FLASH`, for example by calling functions like `cyg_flash_program`.

The driver imposes one restriction on application code which developers should be aware of: when programming the flash the destination addresses must be aligned to a bus boundary. For example if the target hardware has a single flash device attached to a 16-bit bus then program operations must involve a multiple of 16-bit values aligned to a 16-bit boundary. Note that it is the bus width that matters, not the device width. If the target hardware has two 16-bit devices attached to a 32-bit bus then program operations must still be aligned to a 32-bit boundary, even though in theory a 16-bit boundary would suffice. In practice this is rarely an issue, and requiring the larger boundary greatly simplifies the code and improves performance.

Note: Many eCos targets with AM29xxxxx or compatible flash devices will still use the older driver package `CYGPKG_DEVS_FLASH_AMD_AM29XXXXX`. Only newer ports and some older ports that have been converted will use the V2 driver. This documentation only applies to the V2 driver.

Configuration Options

The AM29xxxxx flash driver package will be loaded automatically when configuring eCos for a target with suitable hardware. However the driver will be inactive unless the generic flash package `CYGPKG_IO_FLASH` is loaded. It may be necessary to add this generic package to the configuration explicitly before the driver functionality becomes available. There should never be any need to load or unload the AM29xxxx driver package.

The driver contains a small number of configuration options which application developers may wish to tweak. `CYGNUM_DEVS_FLASH_AMD_AM29XXXXX_V2_PROGRAM_BURST_SIZE` controls the program operation. On typical hardware programming the flash requires disabling interrupts and the cache for an extended period of time. Some or all of the flash hardware will be unusable while each word is programmed, and disabling interrupts is the only reliable way of ensuring that no interrupt handler or other thread will try to access the flash in the middle of an operation. This can have a major impact on the real-time responsiveness of the typical applications. To ameliorate this the driver will perform writes in small bursts, briefly re-enabling the cache and interrupts between each burst. The number of words written per burst is controlled by this configuration operation: reducing the value will improve real-time response but will add overhead, so the actual flash program operation will take longer; conversely more writes per burst will worsen response times but reduce overhead.

Similarly erasing a block of flash safely requires disabling interrupts and the cache. Erasing a block can easily take a second or so, and disabling interrupts for such a long period of time is usually undesirable. Hence the driver can also perform the erase in bursts, using the hardware's suspend and resume capabilities. `CYGNUM_DEVS_FLASH_STRATA_V2_ERASE_BURST_DURATION` controls the number of polling loops during which interrupts are disabled. Reducing its value improves responsiveness at the cost of performance, and increasing its value has the opposite effect. Note that too low a value may prevent the erase operation from

working at all: the chip will be spending its time suspending and resuming, rather than actually performing the erase. The minimum value will depend on the specific hardware.

There are a number of other options, relating mostly to hardware characteristics. It is very rare that application developers need to change any of these. For example the option `CYGNUM_DEVS_FLASH_AMD_AM29XXXXX_V2_ERASE_REGIONS` may need a non-default value if the flash devices used on the target have an unusual boot block layout. If so the platform HAL will impose a requires constraint on this option and the configuration system will resolve the constraint. The only time it might be necessary to change the value manually is if the actual board being used is a variant of the one supported by the platform HAL and uses a different flash chip.

Instantiating an AM29xxxxx Device

Name

Instantiating — including the driver in an eCos target

Synopsis

```
#include <cyg/io/am29xxxxx_dev.h>

int cyg_am29xxxxx_init_check_devid_XX(struct cyg_flash_dev* device);
int cyg_am29xxxxx_init_cfi_XX(struct cyg_flash_dev* device);
int cyg_am29xxxxx_erase_XX(struct cyg_flash_dev* device, cyg_flashaddr_t addr);
int cyg_am29xxxxx_program_XX(struct cyg_flash_dev* device, cyg_flashaddr_t addr, const
void* data, size_t len);
int cyg_at49xxxxx_softlock(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
int cyg_at49xxxxx_hardlock(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
int cyg_at49xxxxx_unlock(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
int cyg_am29xxxxx_read_devid_XX(struct cyg_flash_dev* device);
```

Description

The AM29xxxxx family contains some hundreds of different flash devices, all supporting the same basic set of operations but with various common or uncommon extensions. The devices vary in capacity, performance, boot block layout, and width. There are also platform-specific issues such as how many devices are actually present on the board and where they are mapped in the address space. The AM29xxxxx driver package cannot know the details of every chip and every platform. Instead it is the responsibility of another package, usually the platform HAL, to supply the necessary information by instantiating some data structures. Two pieces of information are especially important: the bus configuration and the boot block layout.

Flash devices are typically 8-bits, 16-bits, or 32-bits wide (64-bit devices are not yet in common use). Most 16-bit devices will also support 8-bit accesses, but not all. Similarly 32-bit devices can be accessed 16-bits at a time or 8-bits at a time. A board will have one or more of these devices on the bus. For example there may be a single 16-bit device on a 16-bit bus, or two 16-bit devices on a 32-bit bus. The processor's bus logic determines which combinations are possible, and there will be a trade off between cost and performance: two 16-bit devices in parallel can provide twice the memory bandwidth of a single device. The driver supports the following combinations:

8

A single 8-bit flash device on an 8-bit bus.

16

A single 16-bit flash device on a 16-bit bus.

32

A single 32-bit flash device on an 32-bit bus.

88

Two parallel 8-bit devices on an 16-bit bus.

8888

Four parallel 8-bit devices on a 32-bit bus.

1616

Two parallel 16-bit devices on a 32-bit bus, with one device providing the bottom two bytes of each 32-bit datum and the other device providing the top two bytes.

16as8

A single 16-bit flash device connected to an 8-bit bus.

These configuration all require slightly different code to manipulate the hardware. The AM29xxxxx driver package provides separate functions for each configuration, for example `cyg_am29xxxxx_erase_16` and `cyg_am29xxxxx_program_1616`.

Caution

At the time of writing not all the configurations have been tested.

The second piece of information is the boot block layout. Flash devices are subdivided into blocks (also known as sectors - both terms are in common use). Some operations such as erase work on a whole block at a time, and for most applications a block is the smallest unit that gets updated. A typical block size is 64K. It is inefficient to use an entire 64K block for small bits of configuration data and similar information, so many flash devices also support a number of smaller boot blocks. A typical 2MB flash device could have a single 16K block, followed by two 8K blocks, then a 32K block, and finally 31 full-size 64K blocks. The boot blocks may appear at the bottom or the top of the device. So-called uniform devices do not have boot blocks, just full-size ones. The driver needs to know the boot block layout. With modern devices it can work this out at run-time, but often it is better to provide the information statically.

Example

In most cases flash support is specific to a platform. Even if two platforms happen to use the same flash device there are likely to be differences such as the location in the address map. Hence there is little possibility of re-using the platform-specific code, and this code should be placed in the platform HAL rather than in a separate package. Typically this involves a separate file and a corresponding compile property in the platform HAL's CDL:

```
cdl_package CYGPKG_HAL_M68K_ALAIA {  
    ...  
    compile -library=libextras.a alaia_flash.c  
    ...  
}
```

The contents of this file will not be accessed directly, only indirectly via the generic flash API, so normally it would be removed by link-time garbage collection. To avoid this the object file has to go into `libextras.a`.

The actual file `alaia_flash.c` will look something like:

```
#include <pkgconf/system.h>  
#ifdef CYGPKG_DEVS_FLASH_AMD_AM29XXXX_V2
```

```

#include <cyg/io/flash.h>
#include <cyg/io/flash_dev.h>
#include <cyg/io/am29xxxx_dev.h>

static const CYG_FLASH_FUNS(hal_alalaia_flash_amd_funs,
    &cyg_am29xxxx_init_check_devid_16,
    &cyg_flash_devfn_query_nop,
    &cyg_am29xxxx_erase_16,
    &cyg_am29xxxx_program_16,
    (int (*)(struct cyg_flash_dev*, const cyg_flashaddr_t, void*, size_t))0,
    &cyg_flash_devfn_lock_nop,
    &cyg_flash_devfn_unlock_nop);

static const cyg_am29xxxx_dev hal_alalaia_flash_priv = {
    .devid      = 0x45,
    .block_info = {
        { 0x00004000, 1 },
        { 0x00002000, 2 },
        { 0x00008000, 1 },
        { 0x00010000, 63 }
    }
};

CYG_FLASH_DRIVER(hal_alalaia_flash,
    &hal_alalaia_flash_amd_funs,
    0,
    0xFFC00000,
    0xFFFFFFFF,
    4,
    hal_alalaia_flash_priv.block_info,
    &hal_alalaia_flash_priv
);
#endif

```

The bulk of the file is protected by an `#ifdef` for the AM29xxxx flash driver. That driver will only be active if the generic flash support is enabled. Without that support there will be no way of accessing the device so instantiating the data structures would serve no purpose. The rest of the file is split into three structure definitions. The first supplies the functions which will be used to perform the actual flash accesses, using a macro provided by the generic flash code in `cyg/io/flash_dev.h`. The relevant ones have an `_16` suffix, indicating that on this board there is a single 16-bit flash device on a 16-bit bus. The second provides information specific to AM29xxxx flash devices. The third provides the `cyg_flash_dev` structure needed by the generic flash code, which contains pointers to the previous two.

Functions

All eCos flash device drivers must implement a standard interface, defined by the generic flash code `CYGPKG_IO_FLASH`. This interface includes a table of seven function pointers for various operations: initialization, query, erase, program, read, locking and unlocking. The query operation is optional and the generic flash support provides a dummy implementation `cyg_flash_devfn_query_nop`. AM29xxxx flash devices are always directly accessible so there is no need for a separate read function. The remaining functions are more complicated.

Usually the table can be declared `const`. In a ROM startup application this avoids both ROM and RAM copies of the table, saving a small amount of memory. `const` should not be used if the table may be modified by a platform-specific initialization routine.

Initialization

There is a choice of three main initialization functions. The simplest is `cyg_flash_devfn_init_nop`, which does nothing. It can be used if the `cyg_am29xxxx_dev` and `cyg_flash_dev` structures are fully initialized statically and the flash will just work without special effort. This is useful if it is guaranteed that the board will always be manufactured using the same flash chip, since the nop function involves the smallest code size and run-time overheads.

The next step up is `cyg_am29xxxx_init_check_devid_xx`, where `xx` will be replaced by the suffix appropriate for the bus configuration. It is still necessary to provide all the device information statically, including the `devid` field in the `cyg_am29xxxx_dev` structure. This initialization function will attempt to query the flash device and check that the provided device id matches the actual hardware. If there is a mismatch the device will be marked uninitialized and subsequent attempts to manipulate the flash will fail.

If the board may end up being manufactured with any of a number of different flash chips then the driver can perform run-time initialization, using a `cyg_am29xxxx_init_cfi_xx` function. This queries the flash device as per the Common Flash Memory Interface Specification, supported by all current devices (although not necessarily by older devices). The `block_info` field in the `cyg_am29xxxx_dev` structure and the `end` and `num_block_infos` fields in the `cyg_flash_dev` structure will be filled in. It is still necessary to supply the `start` field statically since otherwise the driver will not know how to access the flash device. The main disadvantage of using CFI is that it increases the code size.

Caution

If CFI is used then the `cyg_am29xxxx_dev` structure must not be declared `const`. The CFI code will attempt to update the structure and will fail if the structure is held in read-only memory. This would leave the flash driver non-functional.

A final option is to use a platform-specific initialization function. This may be useful if the board may be manufactured with one of a small number of different flash devices and the platform HAL needs to adapt to this. The AM29xxxx driver provides a utility function to read the device id, `cyg_am29xxxx_read_devid_xx`:

```
static int
alaia_flash_init(struct cyg_flash_dev* dev)
{
    int devid = cyg_am29xxxx_read_devid_1616(dev);
    switch(devid) {
        case 0x0042 :
            ...
        case 0x0084 :
            ...
        default:
            return CYG_FLASH_ERR_DRV_WRONG_PART;
    }
}
```

There are many other possible uses for a platform-specific initialization function. For example initial prototype boards might have only supported 8-bit access to a 16-bit flash device rather than 16-bit access, but this problem was fixed in the next revision. The platform-specific initialization function can figure out which model board it is running on and replace the default `16as8` functions with faster 16 ones.

Erase and Program

The AM29xxxxx driver provides erase and program functions appropriate for the various bus configurations. On most targets these can be used directly. On some targets it may be necessary to do some extra work before and after the erase and program operations. For example if the hardware has an MMU then the part of the address map containing the flash may have been set to read-only, in an attempt to catch spurious memory accesses. Erasing or programming the flash requires write-access, so the MMU settings have to be changed temporarily. As another example some flash device may require a higher voltage to be applied during an erase or program operation. or a higher voltage may be desirable to make the operation proceed faster. A typical platform-specific erase function would look like this:

```
static int
alaia_flash_erase(struct cyg_flash_dev* dev, cyg_flashaddr_t addr)
{
    int result;
    ... // Set up the hardware for an erase
    result = cyg_am29xxxxx_erase_32(dev, addr);
    ... // Revert the hardware change
    return result;
}
```

There are two configurations which affect the erase and program functions, and which a platform HAL may wish to change: `CYGNUM_DEVS_FLASH_AMD_AM29XXXXX_V2_ERASE_TIMEOUT` and `CYGNUM_DEVS_FLASH_AMD_AM29XXXXX_V2_PROGRAM_TIMEOUT`. The erase and program operations both involve polling for completion, and these timeout impose an upper bound on the polling loop. Normally these operations should never take anywhere close to the timeout period, so a timeout indicates a catastrophic failure that should really be handled by a watchdog reset. A reset is particularly appropriate because there will be no clean way of aborting the flash operation. The main reason for the timeouts is to help with debugging when porting to new hardware. If there is a valid reason why a particular platform needs different timeouts then the platform HAL's CDL can require appropriate values for these options.

Locking

There is no single way of implementing the block lock and unlock operations on all AM29xxxxx devices. If these operations are supported at all then usually they involve manipulating the voltages on certain pins. This would not be able to be handled by generic driver code since it requires knowing how these pins can be manipulated via the processor's GPIO lines. Therefore the AM29xxxxx driver does not usually provide lock and unlock functions, and instead the generic dummy functions `cyg_flash_devfn_lock_nop` and `cyg_flash_devfn_unlock_nop` should be used. An [exception](#) exists for the AT49xxxx family of devices which are sufficiently AMD compatible in other respects. Otherwise, if a platform does provide a way of implementing the locking then this can be handled by platform-specific functions.

```
static int
alaia_lock(struct cyg_flash_dev* dev, const cyg_flashaddr_t addr)
{
    ...
}

static int
alaia_unlock(struct cyg_flash_dev* dev, const cyg_flashaddr_t addr)
{
    ...
}
```

If real locking functions are implemented then the platform HAL's CDL script should implement the CDL interface `CYGHWR_IO_FLASH_BLOCK_LOCKING`. Otherwise the generic flash package may believe that none of the flash drivers in the system provide locking functionality and disable the interface functions.

AT49xxxx locking

As locking is standardised across the AT49xxxx family of AMD AM29xxxx compatible Flash parts, a method supporting this is included within this driver. `cyg_at49xxxx_softlock_XX` provides a means of locking a Flash sector such that it may be subsequently unlocked. `cyg_at49xxxx_hardlock_XX` locks a sector such that it cannot be unlocked until after reset or a power cycle. `cyg_at49xxxx_unlock_XX` unlocks a sector that has previously been softlocked. At power on or Flash device reset, all sectors default to being softlocked.

Other

The driver provides a set of functions `cyg_am29xxxxx_read_devid_XX`, one per supported bus configuration. These functions take a single argument, a pointer to the `cyg_flash_dev` structure, and return the chip's device id. For older devices this id is a single byte. For more recent devices the id is a 3-byte value, 0x7E followed by a further two bytes that actually identify the device. `cyg_am29xxxxx_read_devid_XX` is usually called only from inside a platform-specific driver initialization routine, allowing the platform HAL to adapt to the actual device present on the board.

Device-Specific Structure

The `cyg_am29xxxxx_dev` structure provides information specific to AM29xxxxx flash devices, as opposed to the more generic flash information which goes into the `cyg_flash_dev` structure. There are only two fields: *devid* and *block_info*.

devid is only needed if the driver's initialization function is set to `cyg_am29xxxxx_init_check_devid_XX`. That function will extract the actual device info from the flash chip and compare it with the *devid* field. If there is a mismatch then subsequent operations on the device will fail.

The *block_info* field consists of one or more pairs of the block size in bytes and the number of blocks of that size. The order must match the actual hardware device since the flash code will use the table to determine the start and end locations of each block. The table can be initialized in one of three ways:

1. If the driver initialization function is set to `cyg_flash_devfn_init_nop` or `cyg_am29xxxxx_init_check_devid_XX` then the block information should be provided statically. This is appropriate if the board will also be manufactured using the same flash chip.
2. If `cyg_am29xxxxx_init_cfi_XX` is used then this will fill in the block info table. Hence there is no need for static initialization.
3. If a platform-specific initialization function is used then either this should fill in the block info table, or the info should be provided statically.

The size of the *block_info* table is determined by the configuration option `CYGNUM_DEVS_FLASH_AMD_AM29XXXXX_V2_ERASE_REGIONS`. This has a default value of 4, which should suffice for nearly all AM29xxxxx flash devices. If more entries are needed then the platform HAL's CDL script should require a larger value.

If the `cyg_am29xxxx_dev` structure is statically initialized then it can be `const`. This saves a small amount of memory in ROM startup applications. If the structure is updated at run-time, either by `cyg_am29xxxx_init_cfi_xx` or by a platform-specific initialization routine, then it cannot be `const`.

Flash Structure

Internally the generic flash code works in terms of `cyg_flash_dev` structures, and the platform HAL should define one of these. The structure should be placed in the `cyg_flashdev` table. The following fields need to be provided:

funcs

This should point at the table of functions.

start

The base address of the flash in the address map. On some board the flash may be mapped into memory several times, for example it may appear in both cached and uncached parts of the address space. The *start* field should correspond to the cached address.

end

The address of the last byte in the flash. It can either be statically initialized, or `cyg_am29xxxx_init_cfi_xx` will calculate its value at run-time.

num_block_infos

This should be the number of entries in the *block_info* table. It can either be statically initialized or it will be filled in by `cyg_am29xxxx_init_cfi_xx`.

block_info

The table with the block information is held in the `cyg_am29xxxx_dev` structure, so this field should just point into that structure.

priv

This field is reserved for use by the device driver. For the AM29xxxx driver it should point at the appropriate `cyg_am29xxxx_dev` structure.

The `cyg_flash_dev` structure contains a number of other fields which are manipulated only by the generic flash code. Some of these fields will be updated at run-time so the structure cannot be declared `const`.

Multiple Devices

A board may have several flash devices in parallel, for example two 16-bit devices on a 32-bit bus. It may also have several such banks to increase the total amount of flash. If each device provides 2MB, there could be one bank of 2 parallel flash devices at 0xFF800000 and another bank at 0xFFC00000, giving a total of 8MB. This setup can be described in several ways. One approach is to define two `cyg_flash_dev` structures. The table of function pointers can usually be shared, as can the `cyg_am29xxxx_dev` structure. Another approach is to define a single `cyg_flash_dev` structure but with a larger *block_info* table, covering the blocks in both banks of devices. The second approach makes more efficient use of memory.

Many variations are possible, for example a small slow flash device may be used for initial bootstrap and holding the configuration data, while there is also a much larger and faster device to hold a file system. Such variations are usually best described by separate `cyg_flash_dev` structures.

If more than one `cyg_flash_dev` structure is instantiated then the platform HAL's CDL script should implement the CDL interface `CYGHWR_IO_FLASH_DEVICE` once for every device past the first. Otherwise the generic code may default to the case of a single flash device and optimize for that.

Platform-Specific Macros

The AM29xxxxx driver source code includes the header files `cyg/hal/hal_arch.h` and `cyg/hal/hal_io.h`, and hence indirectly the corresponding platform header files (if defined). Optionally these headers can define macros which are used inside the driver, thus giving the HAL limited control over how the driver works.

Cache Management

By default the AM29xxxxx driver assumes that the flash can be accessed uncached, and it will use the HAL `CYGARC_UNCACHED_ADDRESS` macro to map the cached address in the `start` field of the `cyg_flash_dev` structure into an uncached address. If for any reason this HAL macro is inappropriate for the flash then an alternative macro `HAL_AM29XXXXX_UNCACHED_ADDRESS` can be defined instead. However fixing the `CYGARC_UNCACHED_ADDRESS` macro is normally the better solution.

If there is no way of bypassing the cache then the platform HAL should implement the CDL interface `CYGHWR_DEVS_FLASH_AMD_AM29XXXXX_V2_CACHED_ONLY`. The flash driver will now disable and re-enable the cache as required. For example a program operation will involve the following:

```
AM29_INTSCACHE_STATE;
AM29_INTSCACHE_BEGIN();
while ( ! finished ) {
    write a burst of CYGNUM_DEVS_FLASH_AMD_AM29XXXXX_V2_PROGRAM_BURST_SIZE
    AM29_INTSCACHE_SUSPEND();
    AM29_INTSCACHE_RESUME();
}
AM29_INTSCACHE_END();
```

The default implementations of these INTSCACHE macros are as follows: `STATE` defines any local variables that may be needed, e.g. to save the current interrupt state; `BEGIN` disables interrupts, synchronizes the data caches, disables it, and invalidates the current contents; `SUSPEND` re-enables the data cache and then interrupts; `RESUME` disables interrupts and the data cache; `END` re-enables the cache and then interrupts. The cache is only disabled when interrupts are disabled, so there is no possibility of an interrupt handler running or a context switch occurring while the cache is disabled, potentially leaving the system running very slowly. The data cache synchronization ensures that there are no dirty cache lines, so when the cache is disabled the low-level flash write code will not see stale data in memory. The invalidate ensures that at the end of the operation higher-level code will not pick up stale cache contents instead of the newly written flash data. The `SUSPEND` and `RESUME` macros only re-enable and disable the data cache. An interrupt and possibly a context switch may occur between these macros and use the cache normally. It is assumed that any code which runs at this time will not touch the memory being used by the flash operation, so as far as the low-level program code is concerned it can just continue to use the uncached memory contents as set up by the `BEGIN` macro. If any code modifies the const data currently being written to a flash block or tries to read the flash block being modified then the system's behaviour is undefined. Theoretically a more robust approach is possible, synchronizing and invalidating the cache again in every `RESUME`. However these cache operations can be expensive and `RESUME` may get invoked some thousands of times for every flash block, so this alternative approach would cripple the driver's performance.

Some implementations of the HAL cache macros may not provide the exact semantics required by the flash driver. For example `HAL_DCACHE_DISABLE` may have an unwanted side effect, or it may do more work than is needed here. The driver will check for alternative macros `HAL_AM29XXXXX_INTSCACHE_STATE`, `HAL_AM29XXXXX_INTSCACHE_BEGIN`, `HAL_AM29XXXXX_INTSCACHE_SUSPEND`, `HAL_AM29XXXXX_INTSCACHE_RESUME` and `HAL_AM29XXXXX_INTSCACHE_END`, using these instead of the defaults.

XXXVIII. Intel Strata Flash Device Driver

Overview

Name

Overview — eCos Support for Intel Strata Flash Devices and Compatibles

Description

The `CYGPKG_DEVS_FLASH_STRATA_V2` flash driver package implements support for the Intel Strata family of flash devices and compatibles. The driver is not normally accessed directly. Instead application code will use the API provided by the generic flash driver package `CYGPKG_IO_FLASH`, for example by calling functions like `cyg_flash_program`. There are a small number of [additional functions](#) specific to Strata devices.

The driver imposes one restriction on application code which developers should be aware of: when programming the flash the destination addresses must be aligned to a bus boundary. For example if the target hardware has a single flash device attached to a 16-bit bus then program operations must involve a multiple of 16-bit values aligned to a 16-bit boundary. Note that it is the bus width that matters, not the device width. If the target hardware has two 16-bit devices attached to a 32-bit bus then program operations must still be aligned to a 32-bit boundary, even though in theory a 16-bit boundary would suffice. In practice this is rarely an issue, and requiring the larger boundary greatly simplifies the code and improves performance.

Note: Many eCos targets with Strata or compatible flash devices will still use the older driver package `CYGPKG_DEVS_FLASH_STRATA`. Only newer ports and some older ports that have been converted will use the V2 driver. This documentation only applies to the V2 driver.

Configuration Options

The Strata flash driver package will be loaded automatically when configuring eCos for a target with suitable hardware. However the driver will be inactive unless the generic flash package `CYGPKG_IO_FLASH` is loaded. It may be necessary to add this generic package to the configuration explicitly before the driver functionality becomes available. There should never be any need to load or unload the Strata driver package.

The Strata flash driver package contains a small number of configuration options which application developers may wish to tweak. `CYGNUM_DEVS_FLASH_STRATA_V2_PROGRAM_BURST_SIZE` controls the program operation. On typical hardware programming the flash requires disabling interrupts and possibly the cache for an extended period of time. If the hardware does not provide any way of bypassing the cache when writing to the flash then the cache must be disabled or the commands written to the flash may get stuck inside the cache instead of going directly to the flash chip. Some or all of the flash hardware will be unusable while each word is programmed, and disabling interrupts is the only reliable way of ensuring that no interrupt handler or other thread will try to access the flash in the middle of an operation. This can have a major impact on the real-time responsiveness of the typical applications. To ameliorate this the driver will perform writes in small bursts, briefly re-enabling the cache and interrupts between each burst. The number of words written per burst is controlled by this configuration operation: reducing the value will improve real-time response but will add overhead, so the actual flash program operation will take longer; conversely more writes per burst will worsen response times but reduce overhead. For flash devices which support buffered writes the driver will always try to use a full buffer so there is no point in reducing the burst size to less than the buffer size, but setting the burst size to a larger value is permitted.

Similarly erasing a block of flash safely requires disabling interrupts and possibly the cache. Erasing a block can easily take a second or so, and disabling interrupts for such a long period of time is usually undesirable.

Hence the driver can also perform the erase in bursts, using the hardware's suspend and resume capabilities. `CYGNUM_DEVS_FLASH_STRATA_V2_ERASE_BURST_DURATION` controls the number of polling loops during which interrupts are disabled. Reducing its value improves responsiveness at the cost of performance, and increasing its value has the opposite effect. Note that too low a value may prevent the erase operation from working at all: the chip will be spending its time suspending and resuming, rather than actually performing the erase. The minimum value will depend on the specific hardware.

There are a number of other options, relating mostly to hardware characteristics. It is very rare that application developers need to change any of these. For example the option `CYGNUM_DEVS_FLASH_STRATA_V2_ERASE_REGIONS` may need a non-default value if the flash devices used on the target have an unusual boot block layout. If so the platform HAL will impose a requires constraint on this option and the configuration system will resolve the constraint. The only time it might be necessary to change the value manually is if the actual board being used is a variant of the one supported by the platform HAL and uses a different flash chip.

Instantiating a Strata Device

Name

Instantiating — including the driver in an eCos target

Synopsis

```
#include <cyg/io/strata_dev.h>

int cyg_strata_init_nop(struct cyg_flash_dev* device);
int cyg_strata_init_check_devid_XX(struct cyg_flash_dev* device);
int cyg_strata_init_cfi_XX(struct cyg_flash_dev* device);
int cyg_strata_erase_XX(struct cyg_flash_dev* device, cyg_flashaddr_t addr);
int cyg_strata_program_XX(struct cyg_flash_dev* device, cyg_flashaddr_t addr, const
void* data, size_t len);
int cyg_strata_bufprogram_XX(struct cyg_flash_dev* device, cyg_flashaddr_t addr, const
void* data, size_t len);
int cyg_strata_lock_j3_XX(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
int cyg_strata_unlock_j3_XX(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
int cyg_strata_lock_k3_XX(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
int cyg_strata_unlock_k3_XX(struct cyg_flash_dev* device, const cyg_flashaddr_t addr);
```

Description

The Strata family contains a number of different devices, all supporting the same basic set of operations but with various common or uncommon extensions. The range includes:

28FxxxB3 Boot Block

These support 8 8K boot blocks as well as the usual 64K blocks. There is no buffered write capability. The only locking mechanism available involves manipulating voltages on certain pins.

28FxxxC3

These also have boot blocks. There is no buffered write capability. Individual blocks can be locked and unlocked in software.

28FxxxJ3

These are uniform devices where all blocks are 128K. Buffered writes are supported. Blocks can be locked individually, but the only unlock operation is a global unlock-all.

28FxxxK3

These are also uniform devices with 128K blocks. Buffered writes are supported. Individual blocks can be locked and unlocked in software.

Each of these comes in a range of sizes and bus widths. There are also platform-specific issues such as how many devices are actually present on the board and where they are mapped in the address space. The Strata driver package cannot know all this information. Instead it is the responsibility of another package, usually the

platform HAL, to instantiate some flash device structures. Two pieces of information are especially important: the bus configuration and the boot block layout.

Flash devices are typically 8-bits, 16-bits, or 32-bits wide (64-bit devices are not yet in common use). Most 16-bit devices will also support 8-bit accesses, but not all. Similarly 32-bit devices can be accessed 16-bits at a time or 8-bits at a time. A board will have one or more of these devices on the bus. For example there may be a single 16-bit device on a 16-bit bus, or two 16-bit devices on a 32-bit bus. The processor's bus logic determines which combinations are possible, and usually there will be a trade off between cost and performance. For example two 16-bit devices in parallel can provide twice the memory bandwidth of a single device. The driver supports the following combinations:

8

A single 8-bit flash device on an 8-bit bus.

16

A single 16-bit flash device on a 16-bit bus.

32

A single 32-bit flash device on an 32-bit bus.

88

Two parallel 8-bit devices on an 16-bit bus.

8888

Four parallel 8-bit devices on a 32-bit bus.

1616

Two parallel 16-bit devices on a 32-bit bus, with one device providing the bottom two bytes of each 32-bit datum and the other device providing the upper two bytes.

16as8

A single 16-bit flash device connected to an 8-bit bus.

These configuration all require slightly different code to manipulate the hardware. The Strata driver package provides separate functions for each configuration, for example `cyg_strata_erase_16` and `cyg_strata_program_1616`.

Caution

At the time of writing not all the configurations have been tested.

The second piece of information is the boot block layout. Flash devices are subdivided into blocks (also known as sectors, both terms are in common use). Some operations such as erase work on a whole block at a time, and for most applications a block is the smallest unit that gets updated. A typical block size is 64K. It is inefficient to use an entire 64K block for small bits of configuration data and similar information, so some flash devices also support a number of smaller boot blocks. A typical 2MB flash device could have eight 8K blocks and 31 full-size 64K blocks. The boot blocks may appear at the bottom or the top of the device. So-called uniform devices do not have boot blocks, just full-size ones. The driver needs to know the boot block layout. With modern devices it can work this out at run-time, but often it is better to provide the information statically.

Example

Flash support is usually specific to each platform. Even if two platforms happen to use the same flash device there are likely to be differences such as the location in the address map. Hence there is little possibility of re-using the platform-specific code, and this code is generally placed in the platform HAL rather than in a separate package. Typically this involves a separate file and a corresponding compile property in the platform HAL's CDL:

```
cdl_package CYGPKG_HAL_M68K_KIKOO {
    ...
    compile -library=libextras.a kikoo_flash.c
    ...
}
```

The contents of this file will not be accessed directly, only indirectly via the generic flash API, so normally it would be removed by link-time garbage collection. To avoid this the object file has to go into `libextras.a`.

The actual file `kikoo_flash.c` will look something like:

```
#include <pkgconf/system.h>
#ifdef CYGPKG_DEVS_FLASH_STRATA_V2

#include <cyg/io/flash.h>
#include <cyg/io/strata_dev.h>

static const CYG_FLASH_FUNS(hal_kikoo_flash_strata_funs,
    &cyg_strata_init_check_devid_16,
    &cyg_flash_devfn_query_nop,
    &cyg_strata_erase_16,
    &cyg_strata_bufprogram_16,
    (int (*)(struct cyg_flash_dev*, const cyg_flashaddr_t, void*, size_t))0,
    &cyg_strata_lock_j3_16,
    &cyg_strata_unlock_j3_16);

static const cyg_strata_dev hal_kikoo_flash_priv = {
    .manufacturer_code = CYG_FLASH_STRATA_MANUFACTURER_INTEL,
    .device_code = 0x0017,
    .bufsize = 16,
    .block_info = {
        { 0x00020000, 64 } // 64 * 128K blocks
    }
};

CYG_FLASH_DRIVER(hal_kikoo_flash,
    &hal_kikoo_flash_strata_funs,
    0,
    0x60000000,
    0x601FFFFF,
    1,
    hal_kikoo_flash_priv.block_info,
    &hal_kikoo_flash_priv
);
#endif
```

The bulk of the file is protected by an `ifdef` for the Strata flash driver. That driver will only be active if the generic flash support is enabled. Without that support there will be no way of accessing the device so there is no point in instantiating the device. The rest of the file is split into three definitions. The first supplies the functions which will be used to perform the actual flash accesses, using a macro provided by the generic

flash code in `cyg/io/flash_dev.h`. The relevant ones have an `_16` suffix, indicating that on this board there is a single 16-bit flash device on a 16-bit bus. The second definition provides information specific to Strata flash devices. The third provides the `cyg_flash_dev` structure needed by the generic flash code, which contains pointers to the previous two.

Functions

All eCos flash device drivers must implement a standard interface, defined by the generic flash code `CYGPKG_IO_FLASH`. This interface includes a table of 7 function pointers for various operations: initialization, query, erase, program, read, locking and unlocking. The query operation is optional and the generic flash support provides a dummy implementation `cyg_flash_devfn_query_nop`. Strata flash devices are always directly accessible so there is no need for a separate read function. The remaining functions are more complicated.

Usually the table can be declared `const`. In a ROM startup application this avoids both ROM and RAM copies of the table, saving a small amount of memory. `const` should not be used if the table may be modified by a platform-specific initialization routine.

Initialization

There is a choice of three main initialization functions. The simplest is `cyg_flash_devfn_init_nop`, which does nothing. It can be used if the `cyg_strata_dev` and `cyg_flash_dev` structures are fully initialized statically and the flash will just work without special effort. This is useful if it is guaranteed that the board will always be manufactured using the same flash chip, since the nop function involves the smallest code size and run-time overheads.

The next step up is `cyg_strata_init_check_devid_xx`, where `xx` will be replaced by the suffix appropriate for the bus configuration. It is still necessary to provide all the device information statically, including the `devid` field in the `cyg_strata_dev` structure. However this initialization function will attempt to query the flash device and check that the provided manufacturer and device codes matches the actual hardware. If there is a mismatch the device will be marked uninitialized and subsequent attempts to manipulate the flash will fail.

If the board may end up being manufactured with any of a number of different flash chips then the driver can perform run-time initialization, using a `cyg_strata_init_cfi_xx` function. This queries the flash device as per the Common Flash Memory Interface Specification, supported by all current devices (although not necessarily by older devices). The `block_info` field in the `cyg_strata_dev` structure and the `end` and `num_block_infos` fields in the `cyg_flash_dev` structure will be filled in. It is still necessary to supply the `start` field statically since otherwise the driver will not know how to access the flash device. The main disadvantage of using CFI is that it will increase the code size.

A final option is to use a platform-specific initialization function. This may be useful if the board may be manufactured with one of a small number of different flash devices and the platform HAL needs to adapt to this. The Strata driver provides a utility function to read the device id, `cyg_strata_read_devid_XX`:

```
static int
kikoo_flash_init(struct cyg_flash_dev* dev)
{
    int manufacturer_code, device_code;
    cyg_strata_read_devid_1616(dev, &manufacturer_code, &device_code);
    if (manufacturer_code != CYG_FLASH_STRATA_MANUFACTURER_STMICRO) {
        return CYG_FLASH_ERR_DRV_WRONG_PART;
    }
    switch(device_code) {
        case 0x0042 :
            ...
        
```

```

        case 0x0084 :
            ...
        default:
            return CYG_FLASH_ERR_DRV_WRONG_PART;
    }
}

```

There are many other possible uses for a platform-specific initialization function. For example initial prototype boards might have only supported 8-bit access to a 16-bit flash device rather than 16-bit access, but this was fixed in the next revision. The platform-specific initialization function could figure out which model board it is running on and replace the default 16as8 functions with 16 ones.

Erase and Program

The Strata driver provides erase and program functions appropriate for the various bus configurations. On most targets these can be used directly. On some targets it may be necessary to do some extra work before and after the erase and program operations. For example if the hardware has an MMU then the part of the address map containing the flash may have been set to read-only, in an attempt to catch spurious memory accesses. Erasing or programming the flash requires write-access, so the MMU settings have to be changed temporarily. For another example some flash device may require a higher voltage to be applied during an erase or program operation. or a higher voltage may be desirable to make the operation proceed faster. A typical platform-specific erase function would look like this:

```

static int
kikoo_flash_erase(struct cyg_flash_dev* dev, cyg_flashaddr_t addr)
{
    int result;
    ... // Set up the hardware for an erase
    result = cyg_strata_erase_32(dev, addr);
    ... // Revert the hardware change
    return result;
}

```

There are two versions of the program function. `cyg_strata_bufprogram_xx` uses the buffered write capability of some strata chips. This allows the flash chip to perform the writes in parallel, thus greatly improving performance. It requires that the `bufsize` field of the `cyg_strata_dev` structure is set correctly to the number of words in the write buffer. The usual value for this is 16, corresponding to a 32-byte write buffer. The alternative `cyg_strata_program_xx` writes the data one word at a time so is significantly slower. It should be used only with strata chips that do not support buffered writes, for example the b3 and c3 series.

There are two configuration options which affect the erase and program functions, and which a platform HAL may wish to change: `CYGNUM_DEVS_FLASH_STRATA_V2_ERASE_TIMEOUT` and `CYGNUM_DEVS_FLASH_STRATA_V2_PROGRAM_TIMEOUT`. The erase and program operations both involve polling for completion, and these timeout impose an upper bound on the polling loop. Normally these operations should never take anywhere close to the timeout period, and hence a timeout probably indicates a catastrophic failure that should really be handled by a watchdog reset. A reset is particularly appropriate because there will be no clean way of aborting the flash operation. The main reason for the timeouts is to help with debugging when porting to new hardware. If there is a valid reason why a particular platform needs different timeouts then the platform HAL's CDL can require appropriate values for these options.

Locking

Current Strata devices implement locking in three different ways, requiring different sets of functions:

28FxxxB3

There is no software locking support. The `cyg_flash_devfn_lock_nop` and `cyg_flash_devfn_unlock_nop` functions should be used.

28FxxxC3

28FxxxK3

These support locking and unlocking individual blocks. The `cyg_strata_lock_k3_XX` and `cyg_strata_unlock_k3_XX` functions should be used. All blocks are locked following power-up or reset, so the unlock function must be used before any erase or program operation. Theoretically the lock function is optional and `cyg_flash_devfn_lock_nop` can be used instead, saving a small amount of code space.

28FxxxJ3

Individual blocks can be locked using `cyg_strata_lock_j3_XX`, albeit using a slightly different algorithm from the C3 and K3 series. However the only unlock support is a global unlock of all blocks. Hence the only way to unlock a single block is to check the locked status of every block, unlock them all, and relock the ones that should still be locked. This time-consuming operation is implemented by `cyg_strata_unlock_j3_XX`. Worse, unlocking all blocks can take approximately a second. During this time the flash is unusable so normally interrupts have to be disabled, affecting real-time responsiveness. There is no way of suspending this operation.

Unlike the C3 and K3 chips, on a J3 blocks are not automatically locked following power-up or reset. Hence lock and unlock support is optional, and `cyg_flash_devfn_lock_nop` and `cyg_flash_devfn_unlock_nop` can be used.

If real locking functions are used then the platform HAL's CDL script should implement the CDL interface `CYGHWR_IO_FLASH_BLOCK_LOCKING`. Otherwise the generic flash package may believe that none of the flash drivers in the system provide locking functionality and disable the interface functions.

Device-Specific Structure

The `cyg_strata_dev` structure provides information specific to Strata flash devices, as opposed to the more generic flash information which goes into the `cyg_flash_dev` structure. There are only two fields: *dev_id* and *block_info*.

manufacturer_code and *device_code* are needed only if the driver's initialization function is set to `cyg_strata_init_check_dev_id_XX`. That function will extract the actual device info from the flash chip and compare it with these fields. If there is a mismatch then subsequent operations on the device will fail. Definitions of `CYG_FLASH_STRATA_MANUFACTURER_INTEL` and `CYG_FLASH_STRATA_MANUFACTURER_STMICRO` are provided for convenience.

The *bufsize* field is needed only if a buffered program function `cyg_strata_bufprogram_XX` is used. It should give the size of the buffer in words. Typically Strata devices have a 32-byte buffer, so when attached to an 8-bit bus *bufsize* should be 32 and when attached to a 16-bit bus it should be 16.

The *block_info* field consists of one or more pairs of the block size in bytes and the number of blocks of that size. The order must match the actual hardware device since the flash code will use the table to determine the start and end locations of each block. The table can be initialized in one of three ways:

1. If the driver initialization function is set to `cyg_strata_init_nop` or `cyg_strata_init_check_devid_xx` then the block information should be provided statically. This is appropriate if the board will also be manufactured using the same flash chip.
2. If `cyg_strata_init_cfi_xx` is used then this will fill in the block info table. Hence there is no need for static initialization.
3. If a platform-specific initialization function is used then either this should fill in the block info table, or the info should be provided statically.

The size of the *block_info* table is determined by the configuration option `CYGNUM_DEVS_FLASH_STRATA_V2_ERASE_REGIONS`. This has a default value of 2, which should suffice for nearly all Strata flash devices. If more entries are needed then the platform HAL's CDL script should require a larger value.

If the `cyg_strata_dev` structure is statically initialized then it can be `const`. This saves a small amount of memory in ROM startup applications. If the structure may be updated at run-time, either by `cyg_strata_init_cfi_xx` or by a platform-specific initialization routine, then it cannot be `const`.

Flash Structure

Internally the flash code works in terms of `cyg_flash_dev` structures, and the platform HAL should define one of these. The structure should be placed in the `cyg_flashdev` table. The following fields need to be provided:

funs

This should point at the table of functions.

start

The base address of the flash in the address map. On some board the flash may be mapped into memory several times, for example it may appear in both cached and uncached parts of the address space. The *start* field should correspond to the cached address.

end

The address of the last byte in the flash. It can either be statically initialized, or `cyg_strata_init_cfi_xx` will calculate its value at run-time.

num_block_infos

This should be the number of entries in the *block_info* table. It can either be statically initialized or it will be filled in by `cyg_strata_init_cfi_xx`.

block_info

The table with the block information is held in the `cyg_strata_dev` structure, so this field should just point into that structure.

priv

This field is reserved for use by the device driver. For the Strata driver it should point at the appropriate `cyg_strata_dev` structure.

The `cyg_flash_dev` structure contains a number of other fields which are manipulated only by the generic flash code. Some of these fields will be updated at run-time so the structure cannot be declared `const`.

Multiple Devices

A board may have several flash devices in parallel, for example two 16-bit devices on a 32-bit bus. It may also have several such banks to increase the total amount of flash. If each device provides 2MB, there could be one bank of 2 parallel flash devices at 0xFF800000 and another bank at 0xFFC00000, giving a total of 8MB. This setup can be described in several ways. One approach is to define two `cyg_flash_dev` structures. The table of function pointers can usually be shared, as can the `cyg_strata_dev` structure. Another approach is to define a single `cyg_flash_dev` structure but with a larger *block_info* table, covering the blocks in both banks of devices. The second approach makes more efficient use of memory.

Many variations are possible, for example a small slow flash device may be used for initial bootstrap and holding the configuration data, while there is also a much larger and faster device to hold a file system. Such variations are usually best described by separate `cyg_flash_dev` structures.

If more than one `cyg_flash_dev` structure is instantiated then the platform HAL's CDL script should implement the CDL interface `CYGHWR_IO_FLASH_DEVICE` once for every device past the first. Otherwise the generic code may default to the case of a single flash device and optimize for that.

Platform-Specific Macros

The Strata driver source code includes the header files `cyg/hal/hal_arch.h` and `cyg/hal/hal_io.h`, and hence indirectly the corresponding platform header files (if defined). Optionally these headers can define macros which are used inside the driver, thus giving the HAL limited control over how the driver works.

Cache Management

By default the strata driver assumes that the flash can be accessed uncached, and it will use the HAL `CYGARC_UNCACHED_ADDRESS` macro to map the cached address in the *start* field of the `cyg_flash_dev` structure into an uncached address. If for any reason this HAL macro is inappropriate for the flash then an alternative macro `HAL_STRATA_UNCACHED_ADDRESS` can be defined instead. However fixing the `CYGARC_UNCACHED_ADDRESS` macro is normally the better solution.

If there is no way of bypassing the cache then the platform HAL should implement the CDL interface `CYGHWR_DEVS_FLASH_STRATA_V2_CACHED_ONLY`. The flash driver will now disable and re-enable the cache as required. For example a program operation will involve the following:

```
STRATA_INTSCACHE_STATE;
STRATA_INTSCACHE_BEGIN();
while ( ! finished ) {
    write a burst of CYGNUM_DEVS_FLASH_STRATA_V2_PROGRAM_BURST_SIZE
    STRATA_INTSCACHE_SUSPEND();
    STRATA_INTSCACHE_RESUME();
}
STRATA_INTSCACHE_END();
```

The default implementations of these INTSCACHE macros are as follows: `STATE` defines any local variables that may be needed, e.g. to save the current interrupt state; `BEGIN` disables interrupts, synchronizes the data caches, disables it, and invalidates the current contents; `SUSPEND` re-enables the data cache and then interrupts;

`RESUME` disables interrupts and the data cache; `END` re-enables the cache and then interrupts. The cache is only disabled when interrupts are disabled, so there is no possibility of an interrupt handler running or a context switch occurring while the cache is disabled, potentially leaving the system running very slowly. The data cache synchronization ensures that there are no dirty cache lines, so when the cache is disabled the low-level flash write code will not see stale data in memory. The invalidate ensures that at the end of the operation higher-level code will not pick up stale cache contents instead of the newly written flash data. The `SUSPEND` and `RESUME` macros only re-enable and disable the data cache. An interrupt and possibly a context switch may occur between these macros and use the cache normally. It is assumed that any code which runs at this time will not touch the memory being used by the flash operation, so as far as the low-level program code is concerned it can just continue to use the uncached memory contents as set up by the `BEGIN` macro. If any code modifies the const data currently being written to a flash block or tries to read the flash block being modified then the system's behaviour is undefined. Theoretically a more robust approach is possible, synchronizing and invalidating the cache again in every `RESUME`. However these cache operations can be expensive and `RESUME` may get invoked some thousands of times for every flash block, so this alternative approach would cripple the driver's performance.

Some implementations of the HAL cache macros may not provide the exact semantics required by the flash driver. For example `HAL_DCACHE_DISABLE` may have an unwanted side effect, or it may do more work than is needed here. The driver will check for alternative macros `HAL_STRATA_INTSCACHE_STATE`, `HAL_STRATA_INTSCACHE_BEGIN`, `HAL_STRATA_INTSCACHE_SUSPEND`, `HAL_STRATA_INTSCACHE_RESUME` and `HAL_STRATA_INTSCACHE_END`, using these instead of the defaults.

Polling Support

On some platforms it may be necessary to perform some additional action in the middle of a lengthy erase or program operation. For example, consider a platform with a watchdog device that cannot be disabled: when running in a polled environment such as RedBoot the flash operation run will run to completion, and there will be no opportunity for higher-level code to reset the watchdog; if the flash operation takes long enough the watchdog will trigger. To avoid problems in such scenarios, the platform HAL can define a macro `HAL_STRATA_POLL`. The macro is optional: if absent then the driver will automatically substitute a no-op.

Strata-Specific Functions

Name

Strata — driver-specific functions

Synopsis

```
#include <cyg/io/strata_dev.h>

void cyg_strata_read_devid_XX(struct cyg_flash_dev* device, cyg_uint32* manufacturer,
cyg_uint32* device);
int cyg_strata_unlock_all_j3_XX(struct cyg_flash_dev* device);
```

Description

The driver provides two sets of functions specific to Strata devices and not accessible via the standard eCos flash API. Both may be used safely before the flash subsystem is initialized using `cyg_flash_init`.

`cyg_strata_read_devid_XX` can be used to get the manufacturer and device codes. Typically it is called from a platform-specific driver initialization routine, allowing the platform HAL to adapt to the actual device present on the board. This may be useful if a board may get manufactured with several different and somewhat incompatible chips, although usually `cyg_strata_init_cfi` is the better approach. It may also be used during testing and porting to check that the chip is working correctly.

`cyg_strata_unlock_all_j3_XX` is only useful with 28FxxxJ3 chips and compatibles. These do not allow individual blocks to be unlocked. Hence the standard block unlock functionality is expensive: it requires checking the locked state of every block, unlocking every block, and then relocking all the blocks that should still be blocked. Worse, unlocking every block is a time-consuming operation, taking approximately a second, that needs to run with interrupts disabled. For many applications it is better to just ignore the chip's locking capabilities and run with all blocks permanently unlocked. Invoking `cyg_strata_unlock_all_j3_XX` during manufacture or when the board is commissioned achieves this.

XXXIX. Intel XScale IXDP425 Network Processor Evaluation Board Support

Overview

Name

eCos and RedBoot Support for the Intel XScale IXDP425 Network Processor Evaluation Board — Overview

Description

This document covers the configuration and usage of eCos and RedBoot on the Intel XScale IXDP425 Network Processor Evaluation Board. The IXDP425 board contains the Intel XScale IXP425 processor, 256Mbytes of SDRAM, 16MByte of parallel NOR flash memory, an I2C EEPROM, hexadecimal debug display, LEDs, and external connections for two serial channels, two NPE ethernet daughterboards and an expansion bus based on the Utopia-2 interface standard. eCos and RedBoot support for the devices and peripherals on this board is described below.

In normal operation, a RedBoot image is programmed into the flash memory, and the board will boot into this image from reset. RedBoot provides gdb stub functionality so it is then possible to download and debug stand-alone applications via the gdb debugger. RedBoot can also load and execute Linux kernels. This can happen over either a serial line or over ethernet.

This document should be read in conjunction with the *Intel XScale IXP4xx Network Processor Support* processor HAL documentation in the eCos documentation set, as well as the generic HAL documentation.

Supported Hardware

The parallel NOR flash memory supplied by default with the IXDP425 - a single Intel StrataFlash 28F128J3 - consists of 128 blocks of 128Kbytes each. In a typical setup, the first four blocks, 512 Kbytes, are reserved for the use of the RedBoot ROM image. The topmost block is used to manage the flash and hold RedBoot **fconfig** values. The remaining blocks can be used by application code. There are 123 blocks available between 0x50080000 and 0x50FE0000.

RedBoot supports the built-in high-speed and console UARTs. The default serial port settings are 115200,8,N,1.

There is an ethernet driver `CYGPKG_DEVS_ETH_INTEL_I82559` intended for use with a PCI I82559-based ethernet device to allow communication and downloads. A separate package, `CYGPKG_DEVS_ETH_ARM_IXDP425_I82559`, is responsible for configuring this generic driver to the IXDP425 hardware. This driver is also loaded automatically when configuring for the IXDP425 target.

IDE support is available to support most PCI IDE controllers. Separate support is also available to support CompactFlash cards fitted to an optional daughterboard, in True IDE mode. These features are described in the IXP4xx processor HAL documentation.

Tools

The IXDP425 support is intended to work with GNU tools configured for an arm-elf target. The original port was undertaken using arm-elf-gcc version 3.4.4, arm-elf-gdb version 6.3, and binutils version 2.15.

Setup

Name

Setup — Setting up the IXDP425 board

Overview

In a typical development environment, the IXDP425 board boots from the parallel NOR Flash and runs the RedBoot ROM monitor directly. Applications are then downloaded into RAM and run directly on the board using the command line interface, or for standalone applications, via the debugger **arm-elf-gdb**. Alternatively applications can be stored in Flash to be subsequently loaded into RAM for execution. Preparing the board therefore usually involves programming a suitable RedBoot image into flash memory.

The following RedBoot configurations are supported:

Configuration	Description	Use	File
ROM	RedBoot running from ROM	redboot_ROM.ecm	redboot_ROM.bin
RAM	RedBoot running from RAM	redboot_RAM.ecm	redboot_RAM.bin
ROMRAM	RedBoot running from RAM, but contained in the board's flash boot sector	redboot_ROMRAM.ecm	redboot_ROMRAM.bin
ROM_CFIDE	Same as ROM, but with additional CompactFlash IDE and FAT FS support	redboot_ROM_CFIDE.ecm	redboot_ROM_CFIDE.bin
ROMRAM_CFIDE	Same as ROMRAM, but with additional CompactFlash IDE and FAT FS support	redboot_ROMRAM_CFIDE.ecm	redboot_ROMRAM_CFIDE.bin
ROMLE	RedBoot running from ROM configured for little-endian operation	redboot_ROMLE.ecm	redboot_ROMLE.bin
RAMLE	RedBoot running from RAM configured for little-endian operation	redboot_RAMLE.ecm	redboot_RAMLE.bin
ROMRAMLE	RedBoot running from RAM and configured for little-endian operation, but contained in the board's flash boot sector	redboot_ROMRAMLE.ecm	redboot_ROMRAMLE.bin

For serial communications, all versions run with 8 bits, no parity, and 1 stop bit at 115200 baud. RedBoot also supports ethernet communication and flash management.

If the ROM version is to be chosen, then the RAM version is provided to allow for updating the resident RedBoot image in Flash. The ample provision of RAM memory on the board allows the ROMRAM version of RedBoot to be used instead of the standard ROM version which executes directly from Flash.

Initial Installation

Installation with a Flash programmer

This approach to initial installation may be used if a Flash device programmer is available. The IXDP425 Flash is socketed at U22. Although the supplied Flash part is an Intel StrataFlash 28F128J3, any 28FxxxJ3 part may be substituted - RedBoot will use the Common Flash Interface (CFI) to determine the Flash device geometry.

In this mode, the ROM mode RedBoot is programmed into the boot flash at offset 0x00000000.

Installation via JTAG

A JTAG device may also be used to perform initial programming. Some JTAG devices have in-built capabilities that permit programming of the Flash part. Other JTAG devices are able to load a RAM RedBoot image into SDRAM, from where a ROM RedBoot image can then in turn be loaded and then programmed.

If using a JTAG device that supports direct programming of the Flash part, the Flash is usually located at 0x50000000 in the CPU memory map, assuming the JTAG device initialisation has not remapped it elsewhere. It will usually need to first be unlocked and then erased before programming.

For other JTAG devices, to load a RAM RedBoot image into SDRAM it will first be required to initialise the memory interface, and in particular configure the SDRAM controller. Consult your JTAG device documentation on how to access IXP425 registers.

One example of a JTAG device capable of direct programming of Flash is the Abatron BDI2000, and in the following sections are the steps required to program RedBoot using it.

Preparing the Abatron BDI2000 JTAG debugger

The BDI2000 must first be configured to allow communication with your local network, and configured with the parameters for interfacing with the target board. The following steps should be followed:

1. Prepare a PC to act as a host PC and start a TFTP server on it.
2. Connect the Abatron BDI2000 JTAG debugger via both serial and ethernet to the host PC and power it on. Use the serial cable supplied with the BDI2000.
3. Install the Abatron BDI2000 bdiGDB support software on the host PC.
4. Confirm that the XScale firmware is resident in the BDI2000. For example, using the **bdisetup** utility:

```
$ bdisetup -v -s
BDI Type : BDI2000 Rev.C (SN: xxxxxxxx)
Loader   : V1.05
Firmware : V1.08 bdiGDB for XScale
Logic    : V1.03 XScale
MAC      : 00-0c-01-96-64-92
IP Addr  : 192.168.7.220
Subnet   : 255.255.255.0
Gateway  : 192.168.7.1
Host IP  : 192.168.7.9
Config   : /ixdp425.cfg
```

To upload firmware if needed, follow the procedures in the BDI2000 manual, for example using the **bdisetup** utility:

```
$ bdisetup -u -p/dev/ttyS0 -b57 -aGDB -tXSCALE
Connecting to BDI loader
```

```
Erasing CPLD
Programming firmware with ./b20xscgd.108
Erasing firmware flash ....
Erasing firmware flash passed
Programming firmware flash ....
Programming firmware flash passed
Programming CPLD with ./xscjed21.103
```

5. Locate the file `ixdp425.cfg` within the BDI2000 software installation.
6. Locate the file `regIXP425.def` within the installation of the BDI2000 bdiGDB support software.
7. Place the `ixdp425.cfg` file in a location on the PC accessible to the TFTP server. Later you will configure the BDI2000 to load this file via TFTP as its configuration file.
8. Similarly place the file `regIXP425.def` in a location accessible to the TFTP server.
9. Open `ixdp425.cfg` in an editor such as emacs or notepad and if necessary adjust the path of the `regIXP425.def` file in the [REGS] section to match its location relative to the TFTP server root. Also comment out with a ';' the IP line in the [HOST] section, or update it to refer to the development PC.
10. Install and configure the Abatron BDI2000 in line with the bdiGDB instruction manual. Configure the BDI2000 to use the `ixdp425.cfg` configuration file at the appropriate point of this process. For example, using the **bdisetup** utility:

```
$ bdssetup -c -p/dev/ttyS0 -b57 -i192.168.7.220 -h192.168.7.9 -m255.255.255.0 -g192.168.7.1 -f
Connecting to BDI loader
Writing network configuration
Configuration passed
```

The above command uses the first serial port at 57,600 baud to set the BDI2000's IP address to 192.168.7.220, its default TFTP host to 192.168.7.9, the network mask to 255.255.255.0, the default gateway to 192.168.7.1, and the configuration file to load to `/ixdp425.cfg`.

Preparing the IXDP425 board for programming

Follow the steps in this section in order to allow communication between the board and the host PC, and between the board and the JTAG device.

1. First you must connect a straight through DB9 serial cable between the high speed serial port labelled UART0 on the board and a serial port on the host computer.
2. Start a suitable terminal emulator on the host computer such as **minicom** or HyperTerminal. Set the communication parameters to 115200 baud, 8 data bits, no parity bit and 1 stop bit with no flow control.
3. If using a PCI ethernet card, connect the board to your host PC's LAN with an Ethernet cable.
4. If using a PCI ethernet card, you may need to designate the ethernet interface with a new Ethernet MAC address. The RedBoot binary image contains a default address, but each board requires its own unique address. It is advisable to mark each board with its programmed MAC address for future identification.
5. Connect the board to the BDI2000 using a 20-pin ARM/Xscale cable from the JTAG/ICE interface connector (J12) to the Target A port on the BDI2000.
6. Power up the IXDP425 board. You should see the hex display and various LEDs illuminate.

7. Connect to the BDI2000's CLI interface via TCP/IP on the standard telnet port 23. The **telnet** application is suitable for this. You should see usage information followed by the prompt:

```
Core#0>
```

8. Confirm correct connection with the BDI2000 with the **reset halt** command as follows:

```
Core#0> reset halt
- TARGET: processing reset request
- TARGET: BDI asserts RESET and TRST
- TARGET: BDI removed TRST
- TARGET: Bypass check: 0x000000001 => 0x000000001
- TARGET: JTAG exists check passed
- Core#0: ID code is 0x19274013
- Core#0: BDI sets hold_rst and halt mode
- TARGET: BDI removes RESET
- Core#0: BDI sets hold_rst and halt mode again
- Core#0: BDI loads debug handler to mini IC
- Core#0: BDI clears hold_rst
- TARGET: resetting target passed
- TARGET: processing target startup ....
- TARGET: processing target startup passed
Core#0>
```

9. Locate the `redboot_ROM.bin` image within the `loaders` subdirectory of the base of the eCos installation.
10. Copy the `redboot_ROM.bin` file into a location on the host computer accessible to its TFTP server.

Using the BDI2000 to directly program RedBoot into Flash

As previously mentioned, there are two methods of programming a RedBoot image into the parallel NOR Flash via JTAG, depending on the capabilities of the JTAG device. The BDI2000 supports direct programming of the Flash device and so that is the approach described here.

This is a three stage process. The relevant Flash blocks must first be unlocked, then erased, and finally programmed. This can be accomplished with the following steps:

1. Connect to the BDI2000 telnet port as before.
2. Use the following commands in the BDI2000 telnet session to unlock and then erase the relevant Flash blocks that will contain RedBoot.

```
Core#0>unlock 0x50000000 0x20000 4
Unlocking flash at 0x50000000
Unlocking flash at 0x50020000
Unlocking flash at 0x50040000
Unlocking flash at 0x50060000
Unlocking flash passed
Core#0>erase 0x50000000 0x20000 4
Erasing flash at 0x50000000
Erasing flash at 0x50020000
Erasing flash at 0x50040000
Erasing flash at 0x50060000
Erasing flash passed
```

3. Program the RedBoot image into Flash with the following command, replacing `/RBPATH` with the location of the `redboot_ROM.bin` file relative to the TFTP server root directory:

```
Core#0>prog 0x50000000 /RBPATH/redboot_ROM.bin bin
Programming /RBPATH/redboot_ROM.bin , please wait ....
```

```
Programming flash passed
Core#0>
```

This operation can take some time.

The RedBoot installation is now complete. This can be tested by powering off the board, disconnecting the JTAG, and then powering on the board again. The RedBoot banner should be visible on the serial port. The message

```
flash configuration checksum error or invalid key
```

does not indicate a problem at this stage of installation. It just means that RedBoot Flash configuration has yet to be performed, as described [below](#).

If it proves necessary to re-install RedBoot, this may be achieved by repeating the above process. Alternatively, a new image may be downloaded and programmed into flash more directly using RedBoot's own commands. See the RedBoot documentation for details.

RedBoot Flash configuration

The following steps describe how to initialize RedBoot's Flash configuration. This must be performed when using a RAM RedBoot to program Flash, but is also applicable to initial configuration of a ROM or ROMRAM RedBoot [loaded using JTAG](#) or with a [Flash device programmer](#).

1. Use the following command to initialize RedBoot's Flash Information System (FIS):

```
RedBoot> fis init -f
About to initialize [format] FLASH image system - continue (y/n)? y
*** Initialize FLASH Image System
... Erase from 0x50080000-0x50fdffff: .....
... Unlocking from 0x50fe0000-0x50ffffff: .
... Erase from 0x50fe0000-0x50ffffff: .
... Program from 0x0ffd0000-0x0fff0000 to 0x50fe0000: .
... Locking from 0x50fe0000-0x50ffffff: .
RedBoot>
```

2. Now configure RedBoot's Flash configuration with the command:

```
RedBoot> fconfig -i
```

If a BOOTP/DHCP server is not available, then IP configuration may be set manually. The default server IP address can be set to a PC that will act as a TFTP host for future RedBoot load operations, or may be left unset. The following gives an example configuration:

```
RedBoot> fconfig -i
Initialize non-volatile configuration - continue (y/n)? y
Run script at boot: false
Use BOOTP for network configuration: false
Gateway IP address: 192.168.7.11
Local IP address: 192.168.7.222
Local IP address mask: 255.255.255.0
Default server IP address: 192.168.7.9
Console baud rate: 115200
DNS server IP address: 192.168.7.11
GDB connection port: 9000
Force console for special debug messages: false
Network debug at boot time: false
Update RedBoot non-volatile configuration - continue (y/n)? y
```

```
... Unlocking from 0x50fe0000-0x50ffffff: .  
... Erase from 0x50fe0000-0x50ffffff: .  
... Program from 0x0ffd0000-0x0fff0000 to 0x50fe0000: .  
... Locking from 0x50fe0000-0x50ffffff: .  
RedBoot>
```

Rebuilding RedBoot

Should it prove necessary to rebuild a RedBoot binary, this is done most conveniently at the command line. The steps needed to rebuild the the ROM version of RedBoot for the IXDP425 are:

```
$ mkdir redboot_ixdp425_romram  
$ cd redboot_ixdp425_romram  
$ ecosconfig new ixdp425 redboot  
$ ecosconfig import $ECOS_REPOSITORY/hal/arm/xscale/ixdp425/VERSION/misc/redboot_ROM.ecm  
$ ecosconfig resolve  
$ ecosconfig tree  
$ make
```

At the end of the build the `install/bin` subdirectory should contain the file `redboot.bin`.

The other versions of RedBoot - RAM, ROMRAM or the little-endian variants - may be similarly built by choosing the appropriate alternative `.ecm` file.

Configuration

Name

Configuration — Platform-specific Configuration Options

Overview

The IXDP425 platform HAL package is loaded automatically when eCos is configured for the `ixdp425` target. It should never be necessary to load this package explicitly. Unloading the package should only happen as a side effect of switching target hardware.

Configuring for the `ixdp425` target also causes the IXP4xx processor HAL to be included. Many configuration options in relation to the peripheral IXP425 devices including serial UARTs, clocks, etc. are described in the IXP4xx processor HAL documentation, which should be referred to.

Startup

The platform HAL package supports three separate startup types:

RAM

This is the startup type which is normally used during application development. The board has RedBoot programmed into flash and boots into that initially. `arm-elf-gdb` is then used to load a RAM startup application into memory and debug it. It is assumed that the hardware has already been initialized by RedBoot. By default a standalone application will use the eCos virtual vectors mechanism to obtain certain services from RedBoot, including diagnostic output.

ROM

This startup type can be used for finished applications which will be programmed into flash at physical address `0x50000000`. The application will be self-contained with no dependencies on services provided by other software. eCos startup code will perform all necessary hardware initialization.

ROMRAM

This startup type can be used for finished applications which will be programmed into flash at physical location `0x50000000`. However, when it starts up, the application will first copy itself to RAM at virtual address `0x00000000` and then run from there. RAM is generally faster than flash memory, so the program will run more quickly than a ROM-startup application. The application will be self-contained with no dependencies on services provided by other software. eCos startup code will perform all necessary hardware initialization.

RedBoot and Virtual Vectors

If the application is intended to act as a ROM monitor, providing services for other applications, then the configuration option `CYGSEM_HAL_ROM_MONITOR` should be set. Typically this option is set only when building RedBoot.

If the application is supposed to make use of services provided by a ROM monitor, via the eCos virtual vector mechanism, then the configuration option `CYGSEM_HAL_USE_ROM_MONITOR` should be set. By default this op-

tion is enabled when building for a RAM startup, disabled otherwise. It can be manually disabled for a RAM startup, making the application self-contained, as a testing step before switching to ROM startup.

If the application does not rely on a ROM monitor for diagnostic services then the serial port will be claimed for HAL diagnostics.

Flash Driver

The IXDP425 is supplied by default with a 16Mbyte Intel StrataFlash 28F128J3 parallel Flash device.

The `CYGPKG_DEVS_FLASH_STRATA_V2` package contains all the code necessary to support this part and the platform HAL package contains definitions that customize the driver to the IXDP425 board. This driver is not active until the generic Flash support package, `CYGPKG_IO_FLASH`, is included in the configuration.

The device is located in a socket on a board labelled both U22 and "BOOT ROM", and can be replaced with compatible Intel StrataFlash 28FxxxJ3 parts. RedBoot will use the Common Flash Interface (CFI) to determine the Flash device geometry.

Ethernet Driver

The IXDP425 development kit includes an Intel i82559-based PCI Ethernet NIC. The `CYGPKG_DEVS_ETH_INTEL_I82559` package contains all the code necessary to support this device and the `CYGPKG_DEVS_ETH_ARM_IXDP425_I82559` package contains definitions that customize the driver to the IXDP425 board. This driver is not active until the generic Ethernet support package, `CYGPKG_IO_ETH_DRIVERS`, is included in the configuration.

The IXDP425 is also supplied with Network Processing Engine (NPE) modules, however these are not supported in this release.

CompactFlash True IDE Driver

The IXP425 variant HAL includes support for CompactFlash IDE devices accessed in True IDE mode directly on the IXP425 expansion bus. This is described further in the IXP4xx processor HAL documentation.

However note that the use of CS2 conflicts with use of the hex display, which also operates from the CS2 chip select, and so the use of the hex display by eCos/RedBoot will be disabled if CF IDE support is enabled. In addition it is expected that the hex display will show random unpredictable values during CF IDE accesses.

Other IXP425 peripherals

Details in relation to on-chip IXP425 peripherals such as PCI IDE driver, watchdog support, serial support, clocks, interrupts and so forth are described further in the IXP4xx processor HAL documentation.

Compiler Flags

The platform HAL defines the default compiler and linker flags for all packages, although it is possible to override these on a per-package basis. Most of the flags used are the same as for other architectures supported by eCos. There are just two flags specific to this port:

`-mcpu=xscale`

The arm-elf-gcc compiler supports many variants of the ARM architecture. A `-m` option should be used to select the specific variant in use, and with current tools `-mcpu=xscale` is the correct option for the XScale IXP425 CPU.

`-mbig-endian`

The arm-elf-gcc compiler will compile all code into big endian (most significant byte first) format. This is the default endianness for this port. Without this flag, arm-elf-gcc generates little endian code. You must ensure your application is built for the same endianness as RedBoot.

Although RedBoot endianness can be controlled by enabling or disabling the configuration option `CYGHWR_HAL_ARM_BIGENDIAN`, it is more convenient to use the minimal configuration files (.ecm files) as [described earlier](#).

`-mthumb`

The arm-elf-gcc compiler will compile C and C++ files into the Thumb instruction set when this option is used. The best way to build eCos in Thumb mode is to enable the configuration option `CYGHWR_THUMB`.

`-mthumb-interwork`

This option allows programs to be created that mix ARM and Thumb instruction sets. Without this option, some memory can be saved. This option should be used if `-mthumb` is used. The best way to build eCos with Thumb interworking is to enable the configuration option `CYGBLD_ARM_ENABLE_THUMB_INTERWORK`.

JTAG debugging support

Name

JTAG support — Usage

Use of JTAG for debugging

JTAG can be used to single-step and debug loaded RAM applications, or even applications resident in ROM, including RedBoot.

Debugging of ROM applications is only possible if using hardware breakpoints. The XScale only supports four such hardware breakpoints - two for instruction breakpoints and two for data breakpoints, and so they should be used sparingly. If using a GDB front-end such as Eclipse, check it has not set unnecessary extra breakpoints. Some JTAG devices give the option of whether to set hardware or software breakpoints by default. Be sure to configure your device appropriately.

Abatron BDI2000 notes

On the Abatron BDI2000, the `ixdp425.cfg` file that is included with the BDI2000 software should be used to setup and configure the hardware to an appropriate state to load programs. This includes setting up the SDRAM controller.

The `ixdp425.cfg` file also contains an option to define whether hardware or software breakpoints are used by default, using the `BREAKMODE` directive in the `[TARGET]` section. Edit this file if you wish to use software breakpoints, and remember to use the **boot** command on the BDI2000 command line interface to make the changes take effect.

On the BDI2000, debugging can be performed either via the telnet interface or using **arm-elf-gdb** and the `bdiGDB` interface. In the case of the latter, **arm-elf-gdb** needs to connect to TCP port 2001 on the BDI2000's IP address. For example:

```
(gdb) target remote 111.222.333.444:2001
```

By default when the BDI2000 is powered up, the target will always run the initialization section of the `ixdp425.cfg` file (which configures the SDRAM among other things), and halts the target. This behavior is repeated with the **reset halt** command.

If the board is reset when in '**reset halt**' mode (either with the '**reset halt**' or '**reset**' commands, or by pressing the reset button) and the '**go**' command is then given, then the board will boot as normal. If a ROMRAM RedBoot is resident in Flash, it will be run.

It is also possible for the target to always run, without initialization, after the reset button has been pressed. This mode is selected with the **reset run** command. This conveniently allows the target to be connected to the JTAG debugger, and be able to reset it with the reset button, without being required to always type '**go**' every time. Thereafter, invoking the **reset** command will repeat the previous reset style. Also in this mode, exceptions will be handled by board software, rather than causing the JTAG debugger to halt the CPU.

The HAL Port

Name

HAL Port — Implementation Details

Overview

This documentation explains how the eCos HAL specification has been mapped onto the IXDP425 hardware, and should be read in conjunction with that specification. The IXDP425 platform HAL package complements the ARM architectural HAL, the XScale variant HAL and the IXP425 processor HAL. It provides functionality which is specific to the target board.

Startup

Following a hard or soft reset, the HAL will initialize or reinitialize most of the on-chip peripherals. There is an exception for RAM startup applications which depend on a ROM monitor for certain services.

For ROM or ROMRAM startup, the HAL will perform additional initialization, setting up the external RAM and programming the various internal registers. This is all done in the `PLATFORM_SETUP1` macro in the assembler header file `hal_platform_setup.h`.

LED Codes

Unless the [Compact Flash IDE configuration option](#) is selected, RedBoot uses the 4 digit LED display to indicate status during board initialization. Possible codes are:

LED Actions

	Power-On/Reset
	Set the CPSR
	Enable coprocessor access
	Drain write and fill buffer
	Setup expansion bus chip selects
1001	Enable Icache
1002	Initialize SDRAM controller
1003	Switch flash (CS0) from 0x00000000 to 0x50000000
1004	Copy MMU table to RAM
1005	Setup TTB and domain permissions
1006	Enable MMU
1007	Enable DCache
1008	

Enable branch target buffer
1009
Drain write and fill buffer
Flush caches
100A
Start up the eCos kernel or RedBoot
0001

Linker Scripts and Memory Maps

The platform HAL package provides the memory layout information needed to generate the linker script. The key memory locations are as follows:

Flash

This is located at address 0x50000000 of the physical memory space. At initialization, the HAL uses the MMU to retain it at virtual address 0x50000000, while also providing an uncached mapping at 0xB0000000 and a data coherent mapping at 0xA0000000.

SDRAM

This is located at address 0x00000000 of the physical memory space. The HAL uses the MMU to retain this at virtual address 0x00000000, along with an alias at 0x10000000. The same memory is also accessible uncached at virtual location 0x20000000 for use by devices, and at 0x30000000 for data coherent access. The first 32 bytes are used for hardware exception vectors. The next 32 bytes are used for the VSR table and the next 256 bytes are normally used for the eCos virtual vectors, allowing RAM-based applications to use services provided by the ROM monitor. Memory is required for the MMU tables, and must be aligned on a 16Kbyte boundary. These therefore occupy memory from 0x4000 to 0x8000. For ROM/ROMRAM startup, all remaining SDRAM is available. For RAM startup, available RAM starts at virtual location 0x00080000, with the bottom 512 kilobytes reserved for use by RedBoot.

On-chip Peripheral Registers

There are several regions in the memory map devoted to on-chip peripherals or on-chip device controllers. When the MMU is enabled, all these regions are set up with a direct, uncached and unbuffered mapping so that these registers remain accessible at their physical locations.

As such, the address space for the AHB Queue Manager (AQM) resides at 0x60000000; the PCI controller resides at 0xC0000000; the expansion bus controller configuration registers reside at 0xC4000000; the SDRAM controller configuration registers reside at 0xCC000000; and all remaining IXP425 on-chip peripherals reside in the block at 0xC8000000. This latter block includes peripheral control for on-chip high-speed and console UARTs, internal bus performance monitoring unit, interrupt controller, GPIO controller, timers, WAN/Voice and Ethernet NPEs, Ethernet MACs, and the USB controller.

Off-chip Peripherals

RedBoot and eCos access the SDRAM, parallel NOR flash, and hex display on CS2 (mapped to 0x52000000). In addition a CompactFlash True IDE mode disk may be accessed via the expansion bus on CS1/CS2 (0x51000000/0x52000000), although the hex display is not usable in that case.

In addition a 64MiB PCI window is mapped to 0x48000000, for communication with devices on the PCI bus.

RedBoot and eCos do not currently make any use of any other off-chip peripherals present on the IXDP425 board.

Memory map summary

The virtual memory maps in this section use a C, B, and X column to indicate the caching policy for the region.

X	C	B	Description
-	-	-	-----
0	0	0	Uncached/Unbuffered
0	0	1	Uncached/Buffered
0	1	0	Cached/Buffered Write Through, Read Allocate
0	1	1	Cached/Buffered Write Back, Read Allocate
1	0	0	Invalid - not used
1	0	1	Uncached/Buffered No write buffer coalescing
1	1	0	Mini DCache - Policy set by Aux Ctl Register
1	1	1	Cached/Buffered Write Back, Read/Write Allocate

Virtual Address	Physical Address	XCB	Size (MB)	Description
0x00000000	0x00000000	010	256	SDRAM (cached)
0x10000000	0x00000000	010	256	SDRAM (alias)
0x20000000	0x00000000	000	256	SDRAM (uncached)
0x30000000	0x00000000	010	256	SDRAM (cached, DC)
0x48000000	0x48000000	000	64	PCI Data
0x50000000	0x50000000	010	16	Flash (CS0, cached)
0x51000000	0x51000000	000	16	CF True IDE mode chip select #0 (CS1)
0x52000000	0x52000000	000	16	Hex display/CF True IDE mode chip select #1 (CS2)
0x53000000	0x53000000	000	80	CS3 - CS7
0x60000000	0x60000000	000	64	Queue Manager
0xA0000000	0x50000000	010	16	Flash (CS0, cached, DC)
0xB0000000	0x50000000	000	16	Flash (CS0, uncached)
0xC0000000	0xC0000000	000	1	PCI Controller
0xC4000000	0xC4000000	000	1	Exp. Bus Config
0xC8000000	0xC8000000	000	1	Misc IXP425 IO
0xCC000000	0xCC000000	000	1	SDRAM Config

Other Issues

The IXDP425 platform HAL does not affect the implementation of other parts of the eCos HAL specification. The XScale variant HAL, the IXP4xx processor HAL documentation and the ARM architectural HAL documentation should be consulted for further details.

XL. eCos Support for Dynamic Memory Allocation

Memory Allocation

Name

`malloc`, `calloc`, `realloc`, `free`, `mallinfo`, `operator new`, `operator new[]`,
`operator delete`, `operator delete[]` — Access the System Heap

Synopsis

```
#include <stdlib.h>
#include <new>

void* malloc(size_t size);
void* calloc(size_t nmemb, size_t size);
void* realloc(void* ptr, size_t size);
void free(void* ptr);
struct mallinfo mallinfo(void);
void* operator new(size_t size);
void* operator new[](size_t size);
void* operator new(size_t size, const std::nothrow_t&);
void* operator new(nothrow)[](size_t size, const std::nothrow_t&);
void operator delete(void* ptr);
void operator delete[](void* ptr);
void operator delete(void* ptr, const std::nothrow_t&);
void operator delete[](void* ptr, const std::nothrow_t&);
```

Description

The dynamic memory allocation package `CYGPKG_MEMALLOC` provides support for the ISO standard C functions `malloc`, `calloc`, `realloc` and `free`. Optionally it can provide the C++ `new` and `delete` operators. There is extensive support for debugging various problems associated with dynamic memory allocation.

Some of the available target RAM will be needed for application code and static data. If the target uses RedBoot or another ROM monitor for bootstrap then that may also reserve some of the available RAM. On most targets the system heap occupies all remaining RAM, and this is used to satisfy the memory allocation requests. By default the Doug Lea memory allocator (`dlmalloc`) code is used to manage the heap. This provides a good trade off between efficient use of the memory, fast operation, and resistance to fragmentation. If the eCos configuration includes the kernel then by default the various memory allocation routines will be thread-safe.

To complement the standard APIs the memory allocation package provides support for custom memory [pools](#).

C library functions

The main dynamic memory allocation routines defined by standard C is `malloc()`: this allocates a chunk of memory from the heap at least as large as the amount requested, satisfying any alignment restrictions imposed by the architecture. The initial contents of the allocated chunk is undefined. If the heap cannot satisfy the allocation request then a null pointer will be returned.

The standard does not define what happens when `malloc()` is passed a size of 0. In eCos this is controlled by a configuration option `CYGSEM_MEMALLOC_MALLOC_ZERO_RETURNS_NULL`. By default the option is disabled and

an argument of 0 will still result in an allocation of the smallest size supported by the memory allocator. If the option is enabled then a null pointer will be returned instead.

`calloc()` tries to allocate a memory chunk of at least `nmemb*size` bytes. If the allocation succeeds then the memory will be filled with zeroes. Otherwise a null pointer is returned.

`realloc()` tries to change the size of an existing allocation while leaving the contents unchanged. This may involve resizing the chunk in situ, or it may involve a `malloc()/memcpy()/free()` sequence. If the operation succeeds a valid pointer will be returned, which may or may not be the same as the original pointer. If the operation fails then a null pointer will be returned and the original data remains intact. There are two special cases: if the `ptr` argument is a null pointer then `realloc()` will act like `malloc()`; otherwise if the `size` argument is 0 then `realloc()` will act like `free()`.

`free()` takes a pointer previously returned by `malloc()`, `calloc()` or `realloc()` and returns the memory to the heap.

`mallinfo()` is not defined by the C standard but is provided for compatibility with other systems. It returns information about the current state of the heap in the form of a `mallinfo` structure:

```
struct mallinfo {
    int arena; /* total size of memory arena */
    int ordblks; /* number of ordinary memory blocks */
    int uordblks; /* space used by ordinary memory blocks */
    int fordblks; /* space free for ordinary blocks */
    int maxfree; /* size of largest free block */
};
```

`arena` gives the total heap size. `ordblks` and `uordblks` give some information on current allocations, and `fordblks` indicates how much is left. The remaining memory may be fragmented so `maxfree` indicates the largest allocation that is currently possible. A `mallinfo` structure contains a number of other fields but those are not used by eCos and exist only for compatibility reasons.

C++ operators

C++ applications can use the standard C library routines for dynamic memory allocation, but it is more common to use the C++ `new` and `delete` operators. There are a number of different implementations of these:

1. The infrastructure package contains empty versions of the delete operators which do not interact with the system heap in any way. This is necessary because of the way the g++ compiler handles certain language constructs. Whenever there is a class with a virtual destructor the generated code always contains a reference to the `delete` operator. The linker is unable to delete this. Therefore if the application uses such a class, directly or indirectly, the final executable will contain a `delete` implementation - even if there is no dynamic allocation. The usual `delete` operator would pull in the system heap and hence the memory allocation package, significantly increasing code size for no good reason. Providing an empty `delete` avoids this.

Unfortunately this solution is imperfect. If instead the application does want to create and destroy objects on the heap, by default the empty `delete` operators will still get linked in and the memory never gets freed. It is not possible to handle both scenarios cleanly with current tools, so instead the application developer has to configure eCos appropriately. To suppress the empty delete operators the configuration option `CYGFUN_INFRA_EMPTY_DELETE_FUNCTIONS` should be disabled. If an eCos package performs dynamic memory allocation using C++ `new` and `delete` then it should automatically disable this option via a CDL **requires** property.

2. The next implementation of `new` and `delete` comes in the C++ support library `libsupc++.a`, which is normally available as part of the GNU toolchain. These versions are straightforward, simply calling `malloc()` and `free()` to access the system heap. When linking an application with an eCos linker script the C++ support library is searched automatically, so application developers only need to worry about disabling `CYGFUN_INFRA_EMPTY_DELETE_FUNCTIONS`.
3. Finally the memory allocation package can also provide implementations of the C++ operators. These access the system heap directly rather than going via `malloc()` and `free()` so can be marginally faster, but at the cost of some increased code size. There is a significant difference of the system is configured for collecting [memory debug data](#). These implementations of `new` and `delete` integrate directly with the debug data code, so more information will be collected. This is especially useful on architectures where the compiler only provides limited backtrace support.

The configuration option `CYGFUN_MEMALLOC_MALLOC_CXX_OPERATORS` controls whether or not the memory allocation package's versions of the C++ operators get built. By default this option is disabled, unless `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA` is enabled. When linking an application with an eCos linker script these operators will automatically be used in preference to the ones in `libsupc++.a`.

Debug Support

An application that uses dynamic memory allocation is often more difficult to debug than one that relies entirely on static allocation. To assist developers the memory allocation package provides a number of debugging facilities. The main one involves the collection of additional debug data for every memory allocation. This debug data can be transferred to the host and analyzed using a custom tool **ecosmdd**. Full documentation on this is provided [elsewhere](#).

This package also provides support for some simple debugging techniques which can help detect certain problems. The first is memory guards: every allocated chunk is surrounded by a number of guard bytes. When the chunk is freed, using `free()` or the appropriate C++ `delete` operator, the guards are checked and any discrepancy is treated as an assertion failure. The head guard can detect certain buffer overflows in the previously allocated chunk. If the chunk contains a thread stack and the architecture involves a descending stack then the head guard can also detect stack overflows. The tail guard can detect certain overflows in the chunk being freed and underflows in the next chunk. The guards are reset during a free operation, which can help to catch attempts to free the same chunk twice. Guard checks only happen during a free operation so a corruption may go undetected for a long time, possibly too long, but are still better to never detecting corruption.

Memory guards are controlled by the configuration option `CYGDBG_MEMALLOC_MALLOC_DEBUG_GUARDS`. By default they are enabled if system-wide debugging (`CYGPKG_INFRA_DEBUG`) is enabled, otherwise disabled.

The second debugging technique is to fill memory chunks when they are freed. This helps to catch some attempts to use a pointer which is no longer valid. Such problems are particularly common in multi-threaded applications where thread A frees a chunk that thread B is still using. When freed chunks are filled thread B will suddenly see spurious data, often resulting in bus errors or other exceptions. The relevant configuration option is `CYGDBG_MEMALLOC_MALLOC_DEBUG_FILL_FREE`, which by default is also enabled if `CYGPKG_INFRA_DEBUG` is enabled. The option's value determines what the freed chunk gets filled with, usually `0xff`.

Memory Pool Functions

Name

`cyg_mempool_fix_*()`, `cyg_mempool_var_*()` — Additional Memory Pools

Synopsis

```
#include <cyg/kernel/kapi.h>

void cyg_mempool_fix_create(void* base, cyg_int32 size, cyg_int32 blocksize,
cyg_handle_t* handle, cyg_mempool_fix* fix);
void cyg_mempool_fix_delete(cyg_handle_t fixpool);
void* cyg_mempool_fix_alloc(cyg_handle_t fixpool);
void* cyg_mempool_fix_timed_alloc(cyg_handle_t fixpool, cyg_tick_count_t abstime);
void* cyg_mempool_fix_try_alloc(cyg_handle_t fixpool);
void cyg_mempool_fix_free(cyg_handle_t fixpool, void* ptr);
cyg_bool_t cyg_mempool_fix_waiting(cyg_handle_t fixpool);
void cyg_mempool_fix_get_info(cyg_handle_t fixpool, cyg_mempool_info* info);
void cyg_mempool_var_create(void* base, cyg_int32 size, cyg_handle_t* handle,
cyg_mempool_var* var);
void cyg_mempool_var_delete(cyg_handle_t varpool);
void* cyg_mempool_var_alloc(cyg_handle_t varpool, size_t size);
void* cyg_mempool_var_timed_alloc(cyg_handle_t varpool, size_t size, cyg_tick_count_t
abstime);
void* cyg_mempool_var_try_alloc(cyg_handle_t varpool, size_t size);
void cyg_mempool_var_free(cyg_handle_t varpool, void* ptr);
cyg_bool_t cyg_mempool_var_waiting(cyg_handle_t varpool);
void cyg_mempool_var_get_info(cyg_handle_t varpool, cyg_mempool_info* info);
```

Description

The memory allocation package provides support for additional memory pools, to complement the system heap. These pools are not created automatically by the system, they have to be created by application code or by other packages. There are exported APIs for two types of pool: fixed and variable.

Allocating memory from a fixed memory pool is very fast and, more importantly, deterministic. However the size of each allocation is fixed at the time the pool is created. This is not a problem if the required allocations are all the same size, or nearly so, but otherwise the memory will be used inefficiently. The pool cannot become fragmented.

Variable memory pools provide essentially the same functionality as the system heap, so are rarely used. However on some targets not all free memory is assigned automatically to the system heap. For example there may be a small area of fast on-chip memory as well as the slower external memory. The system heap will only use the latter. A variable memory pool can be created for the former, allowing application code to dynamically allocate fast memory where appropriate.

If the eCos configuration includes the kernel then by default the memory pool functions will be thread-safe. The pool functions do not implement the `malloc()` guard and free-fill debug facilities, nor the debug data support.

Fixed Memory Pools

A fixed memory pool must be created explicitly, for example:

```
#define BLOCK_SIZE      1024
#define BLOCK_COUNT     64

static cyg_uint32      pool_memory[((BLOCK_COUNT * BLOCK_SIZE)+3) / 4];
static cyg_handle_t    pool_handle;
static cyg_mempool_fix pool_data;

...

cyg_mempool_fix_create((void*) pool_memory,
                      BLOCK_COUNT * BLOCK_SIZE,
                      BLOCK_SIZE,
                      &pool_handle, &pool_data);
```

This creates a pool of 63 1K blocks. *pool_memory* is normally allocated statically, but could also be a pointer to a special area of memory such as on-chip RAM, or it could even be dynamically allocated using `malloc()`. The pointer should be suitably aligned for the target architecture, usually to either a 32 or a 64 bit boundary. *pool_handle* can be used for subsequent pool operations. *pool_data* is a small data structure providing the space needed to administer the pool.

The above pool only provides 63 blocks, not 64. The administration overhead depends on the number of blocks so cannot all be allowed for in the *pool_data* structure. A small amount of the pool memory is consumed as well, effectively using up all of the first block. To eliminate this inefficiency:

```
#define BLOCK_SIZE      1024
#define BLOCK_COUNT     64
#define OVERHEAD        (((BLOCK_COUNT + 31) / 32) * sizeof(cyg_uint32))
#define ACTUAL_SIZE      ((BLOCK_SIZE * BLOCK_COUNT) + OVERHEAD)

static cyg_uint32      pool_memory[(ACTUAL_SIZE + 3) / 4];
static cyg_handle_t    pool_handle;
static cyg_mempool_fix pool_data;

...

cyg_mempool_fix_create(pool_memory,
                      ACTUAL_SIZE,
                      BLOCK_SIZE,
                      &pool_handle, &pool_data);
```

There are three functions for allocating memory. `cyg_mempool_fix_try_alloc()` is analogous to `malloc()`; it attempts to allocate a block from the pool, returning a null pointer if all blocks are currently in use. There is no need to specify the allocation size because all blocks are the same size. The other two functions are only available in configurations containing the eCos kernel. `cyg_mempool_fix_alloc()` will allocate a free block if there is one available, otherwise the current thread will be suspended until a block becomes available. A null pointer will only be returned if the thread is woken up again via `cyg_thread_release()`. `cyg_mempool_fix_timed_alloc()` may also suspend the current thread, but only for a number of clock ticks. If no block becomes free before the specified time is reached then a null pointer will be returned. The *abstime* argument is an absolute time, typically calculated by adding a `cyg_tick_count_t` timeout to the result of `cyg_current_time()`. In other words the pool API works in exactly the same way as kernel functions such

as `cyg_semaphore_timed_wait()`. `cyg_mempool_fix_waiting()` can be used to check whether any threads are currently suspended waiting for a free block.

A block can be released using `cyg_mempool_fix_free()`. If a pool is no longer required it can be destroyed by a call to `cyg_mempool_fix_delete()`. Information about the current state of a pool can be obtained with `cyg_mempool_fix_get_info()`, in the form of a `cyg_mempool_info` structure:

```
typedef struct {
    cyg_int32 totalmem;
    cyg_int32 freemem;
    void*     base;
    cyg_int32 size;
    cyg_int32 blocksize;
    cyg_int32 maxfree;           // The largest free block
} cyg_mempool_info;
```

Variable Memory Pools

The variable memory pool API is very similar to the fixed pool API. The key differences are:

1. `cyg_mempool_var_create()` does not take a block size parameter since the pool supports allocations of any size.
2. There is no special need to worry about overheads when creating the pool. The overheads will be shared between the allocations so spread throughout the pool
3. The block size is no longer implicit, so the three allocation routines need an explicit *size* argument.
4. Allocation operations are not deterministic and may take significantly longer than a fixed pool allocation. A variable pool is also vulnerable to memory fragmentation.

Memory Debug Data

Name

`mdd_dump`, `ecosmdd` — Analyze Memory Usage

Synopsis

`mdd_dump`

`mdd_dumpnow`

`mdd_reset`

`ecosmdd stats` *mddout.0*

`ecosmdd dump` [options] [*exe*] *mddout.0*

`ecosmdd history` [options] [*exe*] *mddout.0* [*mddout.1...*]

`ecosmdd diff` [options] [*exe*] *mddout.0* *mddout.1*

Description

Generally it is more difficult to debug an application that allocates memory dynamically than one that relies entirely on static allocation. Some problems such as buffer overflows can affect both. However the locations of static variables are readily determined from the linker map and debug information, so it is much easier to figure out which static buffer overflowed and then find the offending code. With dynamic allocation buffer overflows can still be [detected](#), but it is much harder to figure out what each buffer is used for.

Another problem is excessive memory usage. A typical embedded system is designed with the smallest amount of memory that should suffice for the application. Often the application uses more memory than expected, and it is necessary to find out exactly where it is all going and where savings could be made. The alternative is a hardware redesign, associated delays, and increased manufacturing costs. A linker map gives details of the static data but not of dynamic allocations.

A third problem is memory leaks. If an application allocates memory that does not get freed then the heap will eventually run out. Usually this causes a system failure and means a reboot. It may take hours, days or even weeks, but any system failure is at best undesirable and at worst totally unacceptable.

The memory allocation package provides a debug data facility to assist developers faced with these problems. This involves storing additional metadata on the target for each allocated memory chunk, for example the function where the allocation occurred and the time that it happened. Configuration options control exactly what metadata gets collected. The debug data can be transferred from the target to the host in a gdb session, and then analyzed using the **`ecosmdd`** program. This provides a number of sub-commands: **`stats`**, **`dump`**, **`history`** and **`diff`**. It also provides various options for filtering, sorting and formatting the debug data.

Configuration Options

Memory debug data is not free. Collecting the debug data on the target requires extra memory and cpu cycles. To be useful the debug data has to be transferred to the host, and this can be time-consuming. If the application developer is tracking down problems with running out of memory then the debug data exacerbates the situation. Hence by default memory debug data is disabled, and there are configuration options to control exactly what gets enabled.

The first option to consider is `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA`. This has to be explicitly enabled by the developer. If it is left disabled then no debug data functionality is available.

Once the main debug data option has been enabled the memory allocation code will collect information about all current allocations. The minimum information needed is a pointer to the allocated data, the number of bytes involved, a 32-bit sequence number to allow the host-side to identify and sort the allocations, plus another pointer for linked list management. This gives a minimum overhead of 16 bytes per allocated chunk (assuming a typical 32-bit processor). However this allows for only limited analysis. Additional fields are controlled by separate configuration options:

`CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_ACTUAL_SIZE`

When the application requests say 12 bytes of data the memory allocation code will actually allocate more than this. There is some unavoidable overhead to keep track of the various allocations. There may be alignment restrictions. Optional [Debug guards](#) add to the overhead. If `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_ACTUAL_SIZE` is enabled then the debug data will include the actual size of each allocation, not just the requested size. By default this option is enabled. The cost is an extra `size_t`, usually four bytes, in each allocation record.

`CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_TIMESTAMP`

Every allocation record in the debug data contains a unique sequence number, a simple 32-bit counter. Amongst other uses this allows host-side tools to sort allocation events in time-order. However a sequence number does not give any information about the time elapsed between allocations. More detailed time information can be very useful, for example to associate allocations with external events. This takes the form of a `cyg_tick_count_t` as returned by the kernel function `cyg_current_time()`. The typical cost is an extra eight bytes in each allocation record.

`CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_TIMESTAMP` is enabled by default if the eCos kernel `CYGPKG_KERNEL` is present. It cannot be enabled if the configuration does not include the kernel.

`CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD`

In multi-threaded applications it can be useful to know which thread allocated which chunk of memory. For example if the application is structured as a set of mostly independent subsystems operating in a separate threads then each subsystem's memory usage can be analyzed separately. Optionally the debug data can include thread information, consisting of a unique numerical thread id, the `cyg_handle_t` identifying the thread, and the thread name as passed to `cyg_thread_create()`. The overhead is a 32-bit integer in each allocation record, plus a small amount of extra memory to keep track of the threads that have performed memory allocations.

`CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD` is enabled by default if the eCos kernel `CYGPKG_KERNEL` is present. It cannot be enabled if the configuration does not include the kernel.

CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_BACKTRACE

Arguably the most useful information about each memory allocation is a partial backtrace, identifying the code responsible for each allocation. On the target side this is implemented using the support function `__builtin_return_address()` provided by the `gcc` compiler. On the host-side the executable can be disassembled to map a return address onto the calling function. If the executable contains `-g` debug information then it may also be possible to work out the corresponding source file name and line number, and hence the exact line of code that performed the allocation.

CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_BACKTRACE is enabled by default, with a value of 1. This means the debug data will contain a single level of backtrace, e.g. the function that called `malloc()`. The backtrace level can be increased up to a maximum of 8, giving more detailed information about each allocation. This is especially useful when allocations occur inside library code since it gives a closer association between application actions and memory allocations. Higher levels do involve extra memory overhead, a 32-bit integer per level per allocation record, and extra cpu cycles.

Important: On many architectures the GNU tools only provided limited backtrace functionality. Often only a single level of backtrace is available. If CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_BACKTRACE is set to a value greater than 1 the compiler will issue warnings when building the memory allocation package, and the extra debug data backtrace slots will just be filled with zeroes.

Even if backtrace information is available it is not always as useful as might be thought. Because of compiler optimizations the relation between the generated code and the original source is not always obvious, so when the host-side tools convert a return address to a source file and line number the results may not be exactly correct. For backtrace levels greater than 1 the results may even be completely wrong. The details will vary from architecture to architecture. When the code involves C++ template instantiation the compiler may not provide enough debug information to allow the backtrace pointers to be analyzed fully.

Depending on which options and how many backtrace levels are enabled, each allocation record will take up between 16 and 64 bytes of data on a 32-bit processor, and somewhat more on a 64-bit processor.

By default memory debug data is collected only for current allocations. This is sufficient for many debug purposes. For example if the problem is a buffer overflow then looking at the current allocations usually allows the developer to determine what the buffer and the surrounding allocations are used for. A complete dump of all current allocations can be used to figure out what all the memory is being used for. Examining two dumps separated in time can be used to track down memory leaks. However sometimes it is necessary to know about free operations as well as current allocations. A good example is identifying which thread freed a chunk that other threads still believe to be usable. To support this it is possible to collect historical debug data as well as the details of all current allocations.

There is a major problem with historical debug data. The number of current allocations is limited by the memory available on the target, so typically will be somewhere between 100 and 10000. The corresponding debug data will occupy between 2K and 640K of the available target-side memory, and there is an implicit upper bound. Historical data does not have an upper bound: an application may make millions of `malloc()` and `free()` calls yet never have more than a 100 allocations at any one time. Those millions of history records would occupy many megabytes of target-side memory. Typical targets do not have such amounts of spare memory, and even if they do transferring the history to the host for analysis would be very time-consuming. Therefore it is not practical to keep a full history. Instead the history debug data goes into a circular buffer, so only the last `n` records are kept. Overflows are detected and the application developer can take action, if desired.

By default history is disabled, controlled by the configuration option CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_HISTORY. If enabled the number of entries in the

history circular buffer is controlled by `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_HISTORY_RECORDS`, with a default value of 2048. Each history record stores both allocation and free debug data, so is approximately twice the size of an allocation record. With default settings the history circular buffer will occupy approximately 100K of target-side memory.

Enabling memory debug data does not affect the memory allocation APIs: applications just call `malloc()` and `free()` as usual. Similarly C++ applications can use the `new` and `delete` operators, but to get the maximum benefits of the backtrace info it is desirable to enable `CYGFUN_MEMALLOC_MALLOC_CXX_OPERATORS`.

Dumping the Debug Data with GDB

When an application is linked with a suitable eCos configuration, the memory debug data will be collected automatically on the target-side. This debug data needs to be transferred to the host, and a number of gdb macros are provided for this purpose. The application is debugged in a gdb session as usual. At an appropriate time the target is halted and the appropriate gdb macro is invoked. This will transfer the current debug data to the host, generating a file `mddout.0` which can then be fed into the **ecosmdd** analysis program.

The gdb macros can be found in the file `mdd.gdb` in the memory allocation packages' `host` subdirectory. Typically this gdb script will be **source'd** by the user's own `.gdbinit` gdb initialization script, so that the macros are always available. Alternatively the macros can be copied directly into that file, albeit at the risk of complications if the macros get updated in a future version of this package. The `host` subdirectory also contains a program **ecosmdd** (actually a portable Tcl script). This must be installed in an appropriate location that is on the user's PATH. The gdb macros rely on being able to execute this program.

The main macro is **mdd_dump**. It does not take any arguments. Usually it will just transfer the memory debug data to the host. However there is a problem if the target-side code was in the middle of updating the debug data: that data may not be in an entirely consistent state. To avoid problems the **mdd_dump** will check a target-side busy flag. If appropriate it will report that a dump may currently be unsafe, instead of proceeding with the dump anyway. The function `cyg_memalloc_dd_done` will be called once the debug data has been updated, so an application developer can set a temporary breakpoint on that function and let the application continue briefly. Alternatively there is a separate macro **mdd_dumpnow**. This will ignore the busy flag and proceed with the dump, irrespective of what the target happened to be doing when it was halted. There is a very small possibility that the resulting dump file will have problems.

Note: The memory allocation code treats the actual allocation and the updating of the debug info as separate steps. Hence it is possible that a chunk of memory has just been allocated or freed, but the `mddout.0` dump file will not yet show this. Usually this temporary discrepancy is not important: it can only matter if the application developer is analysing the debug data and the target-side state concurrently. However application developers should be aware of the possibility. An alternative implementation involving more locking would be possible, but at the cost of potentially significant changes in the application's behaviour.

The time taken to generate a dump file will depend both on how much debug data is collected and on the debug communication channel. It can take anywhere from several seconds to many minutes. Enabling the history circular support can significantly increase the time needed.

Sometimes it is desirable to generate more than one `mddout` dump file in a single debug session. For example the user may want to halt the application at two specific points in the run and find out what allocations have occurred between these points. The first invocation of **mdd_dump** or **mdd_dumpnow** will produce a dump file `mddout.0`. Subsequent invocations will produce dump files `mddout.1`, `mddout.2`, and so on. If desired the numbering can be reset using the **mdd_reset** macro. The next debug session will again produce files `mddout.0`, `mddout.1` and so on, overwriting the previous run's results. The macro scripting facilities in gdb are rather limited, so the file naming is actually handled by invoking the **ecosmdd** program.

If the debug data includes the history circular buffer there is special support for handling overflows. This makes it possible to collect complete history information, spread over a number of mddout dump files, which can then be analyzed together. When an overflow occurs the target-side will call the function `cyg_memalloc_dd_history_overflow()`. Application developers can set a breakpoint on this function, and use **mdd_dump** whenever the breakpoint is hit to generate another dump file with a whole buffer's worth of history records. **mdd_dump** will automatically reset the circular buffer. `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_HISTORY_RECORDS` can be increased to reduce the number of dump files that are needed, at the cost of target-side memory.

A similar technique can be used for other purposes. For example the application developer may want to know the state of the heap once it has reached approximately 80% full. One way of achieving this is to have a separate high-priority thread which calls `mallinfo` at regular intervals. When it detects the desired condition it calls a special function. The developer sets a breakpoint on that function and can then take appropriate action when the condition is satisfied.

Extracting Statistics

The **ecosmdd stats** command is the simplest of the available analysis tools. It just takes a single argument, an mddout dump file:

```
$ ecosmdd stats mddout.0
mddout.0: statistics
Heap      : 0x00097d68 to 0x01ffffff, size 32160K (32932504 bytes)
History   : 132773 memory allocations, 130257 frees
Current   : 1268K (1298850 bytes) used in 2516 allocations
Actual    : approximately 1508K (1544784 bytes)
Overhead  : approximately 240K (245934 bytes), 15%
Debugdata : approximately 107K (110280 bytes) static, 92K (94628 bytes) dynamic
           : (debug data is in addition to other overheads)
Allocators:
           malloc() 1009
           new(nothrow) 788
           new(nothrow)[] 451
           calloc() 251
           realloc() 17
Threads   :
           1 : handle 0x00075670, Idle Thread
           2 : handle 0x00093af8, main
           3 : handle 0x000739b0, thread_0
           4 : handle 0x00073a50, thread_1
           5 : handle 0x00073af0, thread_2
           6 : handle 0x00073b90, thread_3
Options   : actual_size enabled, time stamps enabled, thread info enabled
           : backtrace enabled, 1 levels
           : history enabled, 2048 records max
```

The fields in the output are as follows:

1. The start and end address of the heap and its size. This example is for a development board with a generous 32MB. Approximately 600K is used for application code and static data and for RedBoot, leaving most of the memory available for dynamic memory allocation.
2. Total numbers of past allocations and frees, with the difference corresponding to the number of current allocations. Note that the total size of past allocations is not recorded because of the likelihood of an overflow and hence misleading data.

3. Totals for the current allocations, giving the size as requested by application code.
4. The actual amount of memory used for these allocations, allowing for overhead. This information is only available if `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_ACTUAL_SIZE` is enabled. Note that the numbers are approximate: they only count per-allocation overhead; there may be additional costs for pool data structures and the like which are not included; usually these are sufficiently small that they can be ignored.
5. The difference between the above two fields. For this example the overhead is comparatively high. The configuration included support for debug guards which adds an extra 12 bytes to each allocation plus whatever was needed by the allocation code itself. Most of the allocations were small, so the guards have a disproportionate effect.
6. Additional memory needed for the debug data, both static and dynamic. The configuration included a history circular buffer with default settings, accounting for most of the static cost. The debug data for 2516 current allocations account for most of the dynamic costs, and is not included in the earlier figures. The results of `mallinfo()` will include the dynamic debug data.
7. Counts for the various types of dynamic memory allocation.
8. A list of the various threads: unique id, a `cyg_handle_t` handle, and the name passed to `cyg_thread_create`. This information is only available if `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD` is enabled. The ids can be used in a filter to show only allocations performed by the specified thread. The code only keeps track of threads involved with dynamic memory allocation, not every thread in the system. It is actually unlikely that the idle thread allocated any memory. Instead allocations during system initialization, before the scheduler was started, will usually be ascribed to the idle thread.
9. Details of the relevant configuration options. This can be useful when figuring out what filters, sort keys, or format specifiers are permitted, as an alternative to checking the configuration options.

Dumping Current Allocations

The **ecosmdd dump** can be used to analyze an **mddout** dump file and report on all current allocations.

```
$ ecosmdd dump consume mddout.0
0x00097d78 : malloc() 256 bytes, actual size 272 (+16), seqno 0, time 0
  By thread 1, 0x00075670 Idle Thread
    1) backtrace 0x0004da74 function Cyg_StdioStreamBuffer::set_buffer(unsigned, unsigned char*)
      /opt/ecos/packages/language/c/libc/stdio/current/src/common/streambuf.cxx:96
      "      malloced_buf = (cyg_uint8 * )malloc( size );"
0x000c0f50 : malloc() 13 bytes, actual size 32 (+19), seqno 229605, time 3960
  By thread 3, 0x000739b0 thread_0
    1) backtrace 0x00040ed8 function worker2()
      /tmp/mdd/consume.cxx:393
      "      allocs[index].data.c      = malloc(size);"
0x000c0f70 : new(nothrow) 1024 bytes, actual size 1040 (+16), seqno 251083, time 4329
  By thread 5, 0x00073af0 thread_2
    1) backtrace 0x00040c48 function worker1(int)
      /tmp/mdd/consume.cxx:315
      "      allocs[index].data.large   = new(std::nothrow) Large;"
...
```

`consume` is the executable. This output shows the first three allocation records, sorted in address order. The fields are as follows:

1. The address of the allocated chunk. This is the pointer that would be returned by e.g. `malloc()`. The memory allocation code may store some header information before this address, but that is transparent to the application. There is a big gap between the first and second records because the application freed a large buffer just before the dump file was generated.
2. The memory allocation function that was called to get this chunk. This may be a standard C library function or a C++ operator.
3. The allocation size requested by the application.
4. The actual allocation size and, in brackets, the overhead. This is provided only if `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_ACTUAL_SIZE` is enabled.
5. A sequence number. The first record shows the very first dynamic memory allocation in this test run, performed by the standard I/O initialization code. Sequence numbers are generated using a simple incrementing counter and are unique within a test run. The counter can overflow, but that is only likely to happen if an application makes very intensive use of `malloc()` and runs for several days.
6. A timestamp. This is a kernel `cyg_tick_count_t` as returned by the kernel function `cyg_current_time()`. Usually it corresponds to a counter running at 100Hz, so the second record is for a `malloc()` that occurred about 40 seconds into the run. Timestamps are only listed if `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_TIMESTAMP` is enabled.
7. A line of thread information showing the thread id, handle and name. This requires `CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD`.
8. The level 1 backtrace. The first line gives the return address and the calling function. The second line gives a source code file name and line number. The third line shows the actual source line. In the third record the source code shows a C++ Large object being created. If enabled, additional levels of backtrace will follow.

The function name is only available if the executable is specified on the command line. The file name and line number are only available if the executable contains `-g` debug information for the specified function. Usually this will be true for the application code itself and for eCos code, but not for other libraries supplied in binary format. The source line is only available if the file name and line number are known and the relevant file can be found on the current system. Again this may not be true for libraries supplied in binary format.

The executable does not have to be specified on the command line. Disassembling it can take considerable time, and serves only to provide more detailed backtrace information. Typical output without an executable would look like:

```
$ ecosmdd dump mddout.0 | more
0x00097d78 : malloc() 256 bytes, actual size 272 (+16), seqno 0, time 0
  By thread 1, 0x00075670 Idle Thread
    1) backtrace return address 0x0004da74
...
```

The **dump** subcommand accepts the standard options for [architecture](#), [ignoring](#) certain files, [sorting](#) the output, applying [filters](#), and [formatting](#) each record. For example to show only partial information for the allocations performed by thread 4 between approximately 40 and 42 seconds into the run, sorted by size with largest first, then by allocation time earliest first, the following can be used:

```
$ ecosmdd dump -Fthread=4 -Ftime_min=4000 -Ftime_max=4200 -SNS \
-f '%p %a %n @ %T' mddout.0
0x002a43e8 malloc() 1553 @ 4079
0x000f9308 malloc() 1139 @ 4149
```

```

0x000c2a80 new(nothrow) 1024 @ 4104
0x00292428 new(nothrow)[] 388 @ 4194
0x000e0998 malloc() 240 @ 4147
0x00275678 new(nothrow) 128 @ 4013
0x00238c40 new(nothrow) 128 @ 4104
0x0023f7a8 new(nothrow) 128 @ 4194
0x000e1048 malloc() 18 @ 4014
0x0032cfe8 new(nothrow) 16 @ 4106
0x00131fa0 malloc() 8 @ 4107
0x0015d1a8 malloc() 8 @ 4125
0x002162d8 malloc() 7 @ 4129
0x001217c0 malloc() 7 @ 4190

```

The options should immediately follow the **dump** subcommand, before the executable or mddout file.

Showing the History

```

$ ecosmdd history consume mddout.0
Caution: history is incomplete.

```

```

malloc() 256 bytes: 0x00097d78 , actual size 272 (+16), seqno 0, time 0
  By thread 1, 0x00075670 Idle Thread
  1) backtrace 0x0004da74 function Cyg_StdioStreamBuffer::set_buffer(unsigned, unsigned char*)
    /opt/ecos/packages/language/c/libc/stdio/current/src/common/streambuf.cxx:96
    "      malloced_buf = (cyg_uint8 * )malloc( size );"
malloc() 131072 bytes: 0x00097e88 (freed) , actual size 131088 (+16), seqno 1, time 0
  By thread 2, 0x00093af8 main
  1) backtrace 0x000415b4 function main
    /tmp/mdd/consume.cxx:575
    "      spare      = malloc(128 * 1024);"
new(nothrow) 16 bytes: 0x00319270 (freed) , actual size 32 (+16), seqno 223425, time 3851
  By thread 3, 0x000739b0 thread_0
  1) backtrace 0x00040f4c function worker2()
    /tmp//consume.cxx:409
    "      allocs[index].data.small      = new(std::nothrow) Small;"
...
delete 16 bytes: 0x00156218 , actual size 40 (+24), seqno 258950, time 4461
  By thread 5, 0x000739b0 thread_0
  1) backtrace 0x00040cb8 function worker1(int)
    /tmp/mdd/consume.cxx:251
    "      break;"
free() 347 bytes: 0x001e6b08 , actual size 368 (+21), seqno 258951, time 4461
  By thread 6, 0x000739b0 thread_0
  1) backtrace 0x000409a4 function worker1(int)
    /tmp/mdd/consume.cxx:216
    "      free(allocs[index].data.c);"
...

```

Here **ecosmdd** has processed the executable and read in both the history data and the current allocation records from `mddout.0`. The file does not contain complete history information: there have been at least 258951 allocation and free operations, and the history buffer only stores the last 2048 frees. Each record is output in a similar format to **ecosmdd dump**. However history analysis is based around the order of events rather than the current state of the heap so the allocation function is shown before the heap.

The first record shows the first allocation in the system, and it is still allocated. Next comes the second allocation, which has been freed. This information will have come from the history circular buffer, implying that the

buffer was freed in one of the last 2048 free operations. The third record shows another buffer that has been freed recently. There are no records between sequence numbers 1 and 223425, so all memory that has been allocated in the interval has already been freed and the relevant records are no longer in the history buffer.

The next two records show `delete` and `free()` operations. The format is essentially the same. The sequence number, timestamp, thread and backtrace information correspond to the free operation, not the allocation. Note that for the delete operation **ecosmdd** failed to get the source line number right: the `delete` invocation actually occurred a couple of lines earlier. Unfortunately the debug information in the executable was not sufficiently precise.

By default the history records will be shown earliest first. This order can be reversed with a `-r` option. **ecosmdd history** also accepts the standard options for [architecture](#), [ignoring](#) certain files, applying [filters](#), and [formatting](#) each record. The standard sort option is not supported because history implies sorting in time order. For example:

```
$ ecosmdd history -r -f '%a %p, %n bytes, seqno %s' consume mddout.0
Caution: history is incomplete.
```

```
free() 0x00097e88, 131072 bytes, seqno 263029
free() 0x00302490, 11 bytes, seqno 263028
new(nothrow) 0x00182cc0, 128 bytes, seqno 263027
...
```

If the desired history information is spread over more than one `mddout` file then they can all be passed to **ecosmdd history**. For example:

```
$ ecosmdd history -r consume mddout.0 mddout.1 mddout.2 mddout3
...
```

Options and the executable are handled as before. The `mddout` files should be listed in order of creation, and should correspond to a single test run. **ecosmdd** will extract both the history circular buffer and the current allocation data for the last file, but only the history buffers for the earlier ones - details of their current allocations can be found in later files. Obviously if eCos has been configured with `CYDBG_MEMALLOC_DEBUG_DEBUGDATA_HISTORY` disabled then only the last file will contain useful information.

Comparing Two mddout Files

Sometimes, especially when tracking down a memory leak, it is useful to compare two dump files taken at different times and see what has changed. This functionality is provided by **ecosmdd diff**:

```
$ ecosmdd diff consume mddout.1 mddout.2
File mddout.1 : 1496K (1532048 bytes) used in 2543 allocations.
File mddout.2 : 1488K (1523769 bytes) used in 2483 allocations.
1331 new allocations in mddout.2 but not in mddout.1
1391 allocations in mddout.1 but freed in mddout.2

New allocations in mddout.2 but not in mddout.1
0x000ba8a8 : new(nothrow)[] 228 bytes, actual size 256 (+28), seqno 11001, time 214
  By thread 3, 0x000739b0 thread_0
    1) backtrace 0x00040fc0 function worker2()
      /tmp/mdd/consume.cxx:417
      "          allocs[index].data.smallv  = new(std::nothrow) Small[count];"
0x000ba9a8 : new(nothrow) 128 bytes, actual size 144 (+16), seqno 11528, time 222
  By thread 5, 0x00073af0 thread_2
    1) backtrace 0x00040b78 function worker1(int)
      /tmp/mdd/consume.cxx:296
```

```

"          allocs[index].data.medium    = new(std::nothrow) Medium;"
...
Allocations in mddout.1 but freed in mddout.2
0x000ba9a8 : new(nothrow) 128 bytes, actual size 144 (+16), seqno 8213, time 162
  By thread 5, 0x00073af0 thread_2
  1) backtrace 0x00040b78 function worker1(int)
    /tmp/mdd/consume.cxx:296
    "          allocs[index].data.medium    = new(std::nothrow) Medium;"
0x000baa68 : new(nothrow) 128 bytes, actual size 144 (+16), seqno 9539, time 185
  By thread 6, 0x00073b90 thread_3
  1) backtrace 0x00041028 function worker2()
    /tmp/mdd/consume.cxx:424
    "          allocs[index].data.medium    = new(std::nothrow) Medium;"
...

```

The output begins with some statistics about the two dump files. Next comes a list of all memory chunks allocated in the second file but not in the first, and of all chunks allocated in the first but not the second. The diff uses the unique sequence number so will not be fooled if a chunk is freed and then allocated again.

ecosmdd diff accepts the standard options for [architecture](#), [ignoring](#) certain files, [sorting](#) the output, applying [filters](#), and [formatting](#) each record. Optionally these options can be followed by the executable, to get extended backtrace information. Finally there should be two mddout files:

```

$ ecosmdd diff -Fsize_min=10240 -f '%n bytes at %p by %f1' -SN \
  consume mddout.1 mddout.2
File mddout.1 : 1496K (1532048 bytes) used in 2543 allocations.
File mddout.2 : 1488K (1523769 bytes) used in 2483 allocations.
1331 new allocations in mddout.2 but not in mddout.1
1391 allocations in mddout.1 but freed in mddout.2

New allocations in mddout.2 but not in mddout.1
19691 bytes at 0x0025d498 by worker1(int)
19233 bytes at 0x00273758 by worker2()
...

Allocations in mddout.1 but freed in mddout.2
19858 bytes at 0x0025d498 by worker2()
18085 bytes at 0x001a2bf8 by worker2()
...

```

Standard Options

The various **ecosmdd** subcommands accept a number of standard options for specifying the architecture, ignoring certain source files, sorting and filtering the output, and formatting each record.

Specifying the Architecture

To provide extended backtrace information **ecosmdd** needs to disassemble the supplied executable. This involves running the appropriate **objdump** command, for example **arm-elf-objdump** or **m68k-elf-objdump**. **ecosmdd** reads in the executable's ELF header and uses this to work out the architecture. If it fails the architecture must instead be specified on the command line, for example:

```
$ ecosmdd dump -Adeepthought-elf ...
```

ecosmdd will now try to run **deephthought-elf-objdump** to disassemble the executable.

Ignoring Selected Source Files

When the application involves extended use of header files with inline functions, the backtrace information can get even more confused than usual. Consider a function `tom()` which invokes an inline function `dick()` in a header file `<harry.h`, and `dick()` makes a memory allocation call. At run-time, because of the inlining the return address will be inside function `tom()`. However the debug information for the return address will usually specify the header file, not the source file containing `tom()`. This can make it much more difficult to interpret the backtrace.

There is no perfect solution to this problem, but **ecosmdd** contains an attempt at a partial solution. When disassembling an executable by default it will ignore any debug info where the file name matches the glob pattern `*/include/*`, if more accurate information for the current function is already available. This should catch inline functions in eCos, gcc and libstdc++ headers, and hence the backtrace output should more closely match what is actually happening in the application.

The default behaviour can be suppressed using the `-n` option, for example:

```
$ ecosmdd dump -n consume mddout.0
...
```

Alternatively a different glob pattern can be specified with the `-I` option (taking care to stop the shell from expanding the glob pattern prematurely):

```
$ ecosmdd dump -I\*.h consume mddout.0
```

Sorting the Output

By default the **dump** and **diff** will output their results sorted by increasing address. A different sort can be specified using the `-S` option, for example:

```
$ ecosmdd dump -SNs consume mddout.0
```

The `-S` should be followed by one or more sort keys. In the above example the primary sort key is `N`, specifying sort by decreasing allocation size so the largest allocations come first. When two allocations are the same size the secondary sort key (if specified) comes into play. Here the secondary key is `s`, meaning by increasing sequence number, so two allocations of the same size will be shown in history order. Any number of sort keys can be specified but it does not make sense to repeat a sort key or its inverse. Sequence numbers are unique so it also does not make sense to specify another sort key after `s` or `S`. If two allocations remain unsorted after all the specified sort keys have been processed then the output order is undefined. The available sort keys are:

<code>p</code>	Sort by increasing address, so the lowest address comes first.
<code>P</code>	Sort by decreasing address, so the highest address comes first.
<code>n</code>	Sort by increasing allocation size, so the smallest allocations come first.
<code>N</code>	Sort by decreasing allocation size, so the largest allocations come first.

s	Sort by increasing sequence numbers, so oldest allocations come first.
S	Sort by decreasing sequence number, so newest allocations come first.
a	Sort by memory allocation function, so for example all <code>realloc()</code> allocations will be grouped together.
t	Sort by increasing thread id. ecosmdd stats can be used to get details of the various threads. This sort key is only available if <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD</code> is enabled.
T	Sort by decreasing thread id. ecosmdd stats can be used to get details of the various threads. This sort key is only available if <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD</code> is enabled.

Filtering out Unwanted Data

Non-trivial applications can result in very large amounts of memory debug data. **ecosmdd** provides a number of filters to eliminate unwanted data. For example, to show only allocations of 1K or larger:

```
$ ecosmdd dump -Fsize_min=1024 consume mddout.0
...
```

A filter takes the form `-F<key>=<value>`. The supported keys are:

thread=<id>	Only show allocations performed by the specified thread. This filter can only be used if <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD</code> is enabled.
size_min=<size>	Ignore any allocations smaller than the specified size.
size_max=<size>	Ignore any allocations larger than the specified size.
seqno_min=<start>	Only show the event identified by the sequence number and subsequent ones.
seqno_max=<end>	Only show events up to and including the one identified by the sequence number.
time_min=<start>	Discard any records prior to the specified time.
time_max=<end>	Discard any records after the specified time.
ptr_min=<base>	Filter out allocations before the specified address.
ptr_max=<limit>	Filter out allocations after the specified address.

Multiple filters can be specified. For example to show only allocations performed by thread 6 which are larger than 4K and which occurred in a certain time interval:

```
$ ecosmdd dump -Fthread=6 -Fsize_min=4096 -Ftime_min=4000 -Ftime_max=5000 \
    consume mddout.0
```

Formatting the Output

By default **ecosmdd** outputs all available information for each record. Sometimes it is better to see only some of the fields. At other times a different format may be preferred, for example to feed the **ecosmdd** output into some other tool. Hence it is possible to specify a custom format string, along similar lines to the C `strftime` and `printf` functions:

```
$ ecosmdd dump -f '%a for %n bytes -> %p'
malloc() for 256 bytes -> 0x00097d78
malloc() for 131072 bytes -> 0x00097e88
malloc() for 4 bytes -> 0x000b7e98
calloc() for 3724 bytes -> 0x000b7eb0
...
```

A `%` character introduces a conversion sequence. Other characters are just passed straight through. The supported conversion sequences are:

<code>%%</code>	A single <code>%</code> character.
<code>%p</code>	The address of the allocated chunk.
<code>%n</code>	The requested allocation size.
<code>%m</code>	The actual allocation size. This requires <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_ACTUAL_SIZE</code> .
<code>%o</code>	The allocation overhead for this chunk. This requires <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_ACTUAL_SIZE</code> .
<code>%s</code>	The sequence number.
<code>%a</code>	The allocating function, for example <code>malloc()</code>
<code>%T</code>	A timestamp for the event. This requires <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_TIMESTAMP</code>
<code>%t</code>	The thread identifier. This requires <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD</code>
<code>%h</code>	The thread handle. This requires <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD</code>
<code>%N</code>	The thread name. This requires <code>CYGDBG_MEMALLOC_DEBUG_DEBUGDATA_THREAD</code>
<code>%b1 to %b8</code>	The backtrace return address for the appropriate level. It is an error to specify a level greater than what is actually present in the <code>mddout</code> file.
<code>%f1 to %f8</code>	The backtrace function name for the appropriate level. This can only be used if the executable has been specified on the command line.
<code>%w1 to %w8</code>	The backtrace location for the appropriate level, in the form <code>filename:linenumber</code> . This can only be used if the executable has been specified on the command line, and even then the information is not always available.

%l1 to %l8

The backtrace source line for the appropriate level. This can only be used if the executable has been specified on the command line, and even then the information is not always available.

The usual format string for a dump operation, assuming default configuration settings, is: '%p : %a %n bytes, %m (+%o), seqno %s, time %T\n By thread %t, %h %N\n 1) backtrace %b1 function %f1\n %w1\n \"%l1\"'

XLI. MMC and SD Media Card Disk Driver

Device Driver for MMC and SD media Cards

Name

CYGPKG_DEVS_DISK_MMC — eCos Support for MMC and SD media Cards

Description

This package provides a disk device driver for two commercial flash memory card standards: MultiMedia Cards (MMC), and Secure Digital (SD) cards, including the high-capacity SDHC variant. The MMC card implementation is intended to allow operation with memory cards compliant with the MultiMediaCard Standard version 2, as published by the MultiMediaCard Association (<http://www.mmca.org>). The SD implementation is intended to allow operation with cards compliant with the SD Physical Layer Specification version 2, as published by the SD Card Association (<http://www.sdcard.org/>).

This package evolved from an MMC-only implementation and as such the naming of certain aspects such as the CDL package name reflects that heritage. Any identifiers which reference MMC usually refer to either MMC or SD cards unless otherwise noted.

An MMC/SD card provides non-volatile storage in a small footprint (24mm * 32mm * 1.4mm), and weighing less than 2 grams. Typical card sizes are 128MB to 2GB, with an upper limit of 4GB for MMC and SDv1; and 32GB for SDHC cards in SDv2. It should be noted that these sizes are measured in millions of bytes, not 2²⁰. This driver provides support for 4GB MMC and SDv1 cards, although in practice, the FAT16 filesystem layout on such cards is unusual and may not be supported by a filesystem implementation using this driver. This problem should not occur with cards of size 2GB and less, or with SDHC cards.

At the hardware level there are two ways of accessing an MMC card. The first is to use a custom interface frequently known as either an MCI (Multimedia Card Interface, although this allows support for SD as well) or an MMC/SD bus. The second interface is via connection to an SPI bus. A card will detect the interface in use at run-time. The custom MCI interface allows for better performance but requires additional hardware. SPI peripheral support is more readily available on many existing CPUs. At this time, the SPI bus mode of interface does not support SD cards in this driver.

Theoretically an MMC/SD card can be used with any file system. In practice all cards are formatted for PC compatibility, with a partition table in the first block and a single FAT file system on the rest of the card. The SPI mode driver always checks the format of the MMC card and will only allow access to a card if it is formatted this way. The MCI card bus driver can adapt to a card with no partition table as long as it contains a FAT filesystem starting from the first block. This non-standard format can sometimes be created by Windows when reformatting a corrupted card. This ability is controlled by the CYGSEM_IO_DISK_DETECT_FAT_BOOT CDL configuration option in the generic disk device driver package CYGPKG_IO_DISK.

Card Insertion and Removal

An MMC or SD socket allows cards to be removed and inserted at any time. It is a common feature for such sockets to contain a contact allowing the presence of cards to be detected. On some hardware that signal is routed to the processor allowing it to be sampled, usually connected as a GPIO signal or to an interrupt line (or to a GPIO interrupt if available).

In such cases, the MMC/SD bus driver layer in this package is able to be informed by the hardware MMC/SD bus driver of whether cards are present or not, and if possible, can be informed by an event callback that a card has just been inserted or removed. The SPI mode driver in this package does not yet support this feature.

If using the MMC/SD bus driver with appropriate hardware and driver support, the MMC/SD bus driver layer in this package can plug into the removable media support offered by the generic disk driver layer (CYGPKG_IO_DISK) if the configuration option `CYGFUN_DEVS_DISK_MMCSDBUS_REMOVABLE_MEDIA_SUPPORT` is enabled. This option may only be enabled if a hardware driver indicates that support is available. This facility allows for event notification when a card is inserted or removed from the socket. This information can be used directly by the application using the disk package APIs (see that package's documentation), or to allow use of, for example, the automounter support provided in the File I/O package (CYGPKG_IO_FILEIO).

If card detection by an interrupt is not possible, or if using the SPI bus driver, then the only time the device driver will detect removal events is when the next I/O operation happens. At that point, the operation will fail, typically with an error code such as `ENODEV`, `ETIMEDOUT` or possible `EIO`. It is left to higher-level code to recover from this error - the MMC/SD driver is unable to do anything since the card has gone. In the case of the eCosPro implementation of the FAT filesystem, it has been made robust to such events such that it will always be able to force an unmount using the `umount_force` function instead of the standard `umount` function.

Without card detection by interrupt, use of the automounter is not possible, therefore expected usage is that application code will explicitly `mount` the card before attempting any file I/O.

Irrespective of card detection abilities, it is expected that the application will `umount` the card before it is removed. Until unmounted, the system is likely to keep some disk blocks cached, for performance reasons. If the card is removed before the `umount` then it may end up with a corrupted file system. Application design to inform users of when it is safe to remove card media, and regular uses of the standard `sync` function will reduce the risk of file system corruption.

If card detection support is available, but is only pollable, rather than being connected to an interrupt, then this has limited benefits other than to accelerate the process of determining whether a card has been removed, which otherwise necessitate attempting operations and waiting for potential timeouts. In a future revision of this driver it may become possible to use a polling thread to check periodically for whether cards have been inserted or removed.

Write Protection and Security

The MMC and SD specifications allow cards to be write-protected in software. The current device driver does not yet make it possible to mark a card as write-protected, however it does respect the setting, and on mounting such a card will mark it internally as read-only. Any attempt to write to the card will fail with the error `EROFS`.

SD cards additionally feature a write-protect or 'lock' switch to indicate that cards must not be written to. This is not a physical protection however - instead it is expected that the lock switch position is detected by a contact in the socket, and it is for software to sample the state of that contact to determine whether the card is write-protected. Therefore the lock switch may not be respected if either the hardware or hardware driver does not support sampling the lock switch position from the socket. If sampling is supported however, the MMC/SD bus driver will respect that and mark the card internally as read-only.

SD (and to a lesser extent MMC) support other security features such as password protection and encryption. This driver does not yet support these features.

Configuration Options

`CYGPKG_DEVS_DISK_MMC` is a hardware package which should get loaded automatically when you configure for a suitable eCos target platform. In this case suitable means that the hardware either:

- a. has an MMC/SD socket connected to an SPI bus, that an SPI bus driver package exists and is also automatically loaded, and that the platform HAL provides [information](#) on how the card is connected to the SPI

bus; or

- b. has an MMC/SD socket connected to a custom MCI interface's card bus and a driver package for the MCI exists and is also automatically loaded, or exists in the HAL.

The package depends on support from the generic disk package `CYGPKG_IO_DISK`. That will not be loaded automatically; the presence of an MMC/SD socket on the board does not mean that the application has any need for a file system. Hence by default `CYGPKG_DEVS_DISK_MMC` will be inactive and will not contribute any code or data to the application's memory footprint. To activate the driver it will be necessary to add one or more packages to the configuration using **ecosconfig add** or the graphical configuration tool: the generic disk support `CYGPKG_IO_DISK`; usually a file system, `CYGPKG_FS_FAT`; support for the file I/O API `CYGPKG_IO_FILEIO`; and possibly additional support packages that may be needed by the file system, for example `CYGPKG_LINUX_COMPAT` for FAT. Depending on the template used to create the initial configuration some of these may be loaded already.

SPI mode operation configuration

The package provides two main configuration options when using the SPI mode of operation. `CYGDAT_DEVS_DISK_MMC_SPI_DISK0_NAME` specifies the name of the raw disk device, for example `/dev/mmcdisk0`. Allowing for partition tables that makes `/dev/mmcdisk0/1` the first argument that should be passed to a `mount` call. If the hardware has multiple disk devices then each one will need a unique name. `CYGIMP_DEVS_DISK_MMC_SPI_POLLED` controls whether the SPI bus will be accessed in interrupt-driven or polled mode. It will default to interrupt-driven if the application is multi-threaded, which is assumed to be the case if the kernel is present. If the kernel is absent, for example in a RedBoot configuration, then the driver will default to polled mode. With some hardware polled mode may significantly increase disk throughput even in a multi-threaded application, but will consume CPU cycles that could be used by other threads.

MMC/SD card bus mode operation configuration

When using an MMC/SD card bus, there are a number of CDL configuration settings to be aware of within this driver.

Number of sockets on the MMC/SD bus (`CYGINT_DEVS_DISK_MMCSDBUS_CONNECTORS`)

This CDL interface indicates the number of sockets capable of being supported by the MMC/SD card bus driver. It is usually implemented by either a hardware device driver or the platform HAL. At the present time there can only be 1 socket supported. This limitation is intended to be lifted in the future.

SD card support (`CYGFUN_DEVS_DISK_MMCSDBUS_SD`)

This option is present to allow SD card support to be disabled. SD card support is considered a superset of MMC support, and therefore it is not possible to disable MMC card support. If SD cards are not to be used, this option can be disabled to reduce code and memory footprints, along with slightly faster execution.

Device name for the MMC/SD disk 0 device (`CYGDAT_DEVS_DISK_MMCSDBUS_DISK0_NAME`)

This is the name of the raw disk device. It provides the prefix used for the separate disk device strings which are passed to the `mount` call. For example, a setting of `/dev/mmcsd0/` would allow the first partition on the card to be accessed as `/dev/mmcsd0/1`, the second as `/dev/mmcsd0/2`, etc. `/dev/mmcsd0/0` is a special device name used to access the entire device (including the partition table if present). Furthermore, the `/dev/mmcsd0` device can be used for registering disk insertion/removal events with the disk layer.

Consult the disk package documentation for details. The setting of this configuration option must end with a slash character ('/').

Hardware drivers support card detection (`CYGINT_DEVS_DISK_MMCSDBUS_CARDDETECTION`)

This CDL interface is implemented by a hardware device driver or platform HAL to indicate that it is able to report the presence or absence of cards.

Removable MMC/SD media support (`CYGFUN_DEVS_DISK_MMCSDBUS_REMOVABLEMEDIASUPPORT`)

This option is used to determine whether the MMC/SD bus layer will plug into the generic disk package's removable media support, i.e. allowing notification of insertion or removal of cards. There is no point enabling this option without hardware and driver support, so it is not possible to enable it if `CYGINT_DEVS_DISK_MMCSDBUS_CARDDETECTION` has not been implemented. Some code can be saved if this option is disabled.

MMC/SD debug output (`CYGDBG_DEVS_DISK_MMCSDBUS_DEBUG`)

Detailed debugging output is possible via the diagnostic console. By default there is no debugging output, but setting this option to 1 or 2 will provide increased verbosity of debugging output.

Additional SPI Mode Functionality

When using the SPI mode to access MMC cards, the disk driver package exports a variable `cyg_mmc_spi_polled`. This defaults to true or false depending on the configuration option `CYGIMP_DEVS_DISK_MMC_SPI_POLLED`. If the default mode is interrupt-driven then file I/O, including mount operations, are only allowed when the scheduler has started and interrupts have been enabled. Any attempts at file I/O earlier during system initialization, for example inside a C++ static constructor, will lock up. If it is necessary to perform file I/O at this time then the driver can be temporarily switched to polling mode before the I/O operation by setting `cyg_mmc_spi_polled`, and clearing it again after the I/O. Alternatively the default mode can be changed to polling by editing the configuration, and then the `main()` thread can change the mode to interrupt-driven once the scheduler has started.

Porting to New Hardware

SPI mode

Assuming that the MMC connector is hooked up to a standard SPI bus and that there is already an eCos SPI bus driver, porting the MMC disk driver package should be straightforward. Some other package, usually the platform HAL, should provide a `cyg_spi_device` structure `cyg_spi_mmc_dev0`. That structure contains the information needed by this package to interact with the MMC card via the usual SPI interface, for example how to activate the appropriate chip select. The platform HAL should also implement the CDL interface `CYGINT_DEVS_DISK_MMC_SPI_CONNECTORS`.

When defining `cyg_spi_mmc_dev0` special care must be taken with the chip select. The MMC protocol is transaction-oriented. For example a read operation involves an initial command sent to the card, then a reply, then the actual data, and finally a checksum. The card's chip select must be kept asserted for the entire operation, and there can be no interactions with other devices on the same SPI bus during this time.

Optionally the platform HAL may define a macro `HAL_MMC_SPI_INIT` which will be invoked during a mount operation. This can take any hardware-specific actions that may be necessary, for example manipulating GPIO pins. Usually no such macro is needed because the hardware is set up during platform initialization.

On some targets there may be additional hardware to detect events such as card insertion or removal, but there is no support for exploiting such hardware at present.

Only a single MMC socket is supported. Given the nature of SPI buses there is a problem if the MMC socket is hooked up via an expansion connector rather than being attached to the main board. The platform HAL would not know about the socket so would not implement the CDL interface `CYGINT_DEVS_DISK_MMC_SPI_CONNECTORS`, and the `ecos.db` target entry would not include `CYGPKG_DEVS_DISK_MMC`. Because this is a hardware package it cannot easily be added by hand. Instead this scenario would require some editing of the existing platform HAL and target entry.

Card bus mode

Creating a hardware driver for accessing a card connected via a card bus requires a large amount of detailed description closely related to the specific code definitions. Therefore comprehensive descriptions of functionality has been provided in the `mmc_sd_bus.h` header file in the `include` directory of this package. Drivers should include this file, although before doing so they must define the C preprocessor macro `__MMCSD_DRIVER_PRIVATE` in order to obtain definitions private to card bus drivers.

It is appropriate to provide a high-level overview of the porting process however. A driver package must implement the CDL interface `CYGINT_DEVS_DISK_MMCSD_BUS_CONNECTORS` to indicate the presence of a socket driven as a card bus. It may also implement `CYGINT_DEVS_DISK_MMCSD_BUS_CARD_DETECTION` if appropriate.

The driver in this package accesses the hardware driver through the abstraction of the card bus. This is done by instantiating a bus object using the `CYG_MMCSD_BUS` macro. This takes as arguments an opaque word of private data which may be useful to the hardware driver for identifying this bus or for any relevant bus state, and it also takes a function callback list. The `CYG_MMCSD_BUS` instantiation must exist in a module which is always included in the program image. This is usually performed when building the package by including it in the `libextras.a` library (which is converted to `extras.o` in the eCos build process and forcibly included in the program image that way).

This function callback list must be instantiated using the `CYG_MMCSD_BUS_FUNS` macro. This provides a table identifying driver functions to: initialise the bus at system startup time; (re-)initialise the socket when attempting to access a card in it for the first time; shutting down a socket to conserve power; doing specialised configuration options; preparing to select a card in a socket; sending a command to a card; and transferring data blocks to or from a card. At this point the byte and stream operations may be left as `NULL` and are only present for potential future expansion. Details on the purpose and arguments to these functions can be found in `mmc_sd_bus.h`.

If the hardware and driver is capable of reporting card insertion/removal events, then notification of insertion or removal can be performed by calling the `MMCSD_CARD_DETECT_EVENT()` macro to register this with the MMC/SD layer, which will perform any further processing required. It must be called in DSR or thread context, not ISR context.

