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. Similary 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 μITRON. 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 μITRON 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 reenable 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 9.

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 18.

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_t 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,
                      static_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_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_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_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.

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);
void 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`.

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`,

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 previous 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_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_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.

`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 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 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 scenarioes 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 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.

`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. 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. 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. `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 a waiting thread to be woken up, if its condition is now satisfied.

`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 thead 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;
}
```

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 one of `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 has been fully handled and no further effort is required.

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 `CYG_ISR_CALL_DSR`, the system will call the deferred service routine or 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 reenable 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 know 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.

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. RedBoot™ User's Guide

Chapter 1. Getting Started with RedBoot

RedBoot™ is an acronym for "Red Hat Embedded Debug and Bootstrap", and is the standard embedded system debug/bootstrap environment from Red Hat, replacing the previous generation of debug firmware: CygMon and GDB stubs. It provides a complete bootstrap environment for a range of embedded operating systems, such as embedded Linux™ and eCos™, and includes facilities such as network downloading and debugging. It also provides a simple flash file system for boot images.

RedBoot provides a wide set of tools for downloading and executing programs on embedded target systems, as well as tools for manipulating the target system's environment. It can be used for both product development (debug support) and for end product deployment (flash and network booting).

Here are some highlights of RedBoot's capabilities:

- Boot scripting support
- Simple command line interface for RedBoot configuration and management, accessible via serial (terminal) or Ethernet (telnet)
- Integrated GDB stubs for connection to a host-based debugger via serial or ethernet. (Ethernet connectivity is limited to local network only)
- Attribute Configuration - user control of aspects such as system time and date (if applicable), default Flash image to boot from, default failsafe image, static IP address, etc.
- Configurable and extensible, specifically adapted to the target environment
- Network bootstrap support including setup and download, via BOOTP, DHCP and TFTP
- X/YModem support for image download via serial
- Power On Self Test

Although RedBoot is derived from eCos, it may be used as a generalized system debug and bootstrap control software for any embedded system and any operating system. For example, with appropriate additions, RedBoot could replace the commonly used BIOS of PC (and certain other) architectures. Red Hat is currently installing RedBoot on all embedded platforms as a standard practice, and RedBoot is now generally included as part of all Red Hat Embedded Linux and eCos ports. Users who specifically wish to use RedBoot with the eCos operating system should refer to the *Getting Started with eCos* document, which provides information about the portability and extendability of RedBoot in an eCos environment.

More information about RedBoot on the web

The RedBoot Net Distribution web site (http://sources.redhat.com/redboot/) contains downloadable sources and documentation for all publically released targets, including the latest features and updates.

Installing RedBoot

To install the RedBoot package, follow the procedures detailed in the accompanying README.

Although there are other possible configurations, RedBoot is usually run from the target platform's flash boot sector or boot ROM, and is designed to run when your system is initially powered on. The method used to install the RedBoot image into non-volatile storage varies from platform to platform. In general, it requires that the image be programmed into flash in situ or programmed into the flash or ROM using a device programmer. In some cases this will be done at manufacturing time; the platform being delivered with RedBoot already in place. In other cases, you will have to program RedBoot into the appropriate device(s) yourself. Installing to flash in situ may require special cabling or interface devices and software provided by the board manufacturer. The details of this installation process for a given platform will be found in Installation and Testing. Once installed, user-specific configuration options may be applied, using the **fconfig** command, providing that persistent data storage in flash is present in the relevant RedBoot version. See the Section called *Configuring the RedBoot Environment* for details.

User Interface

RedBoot provides a command line user interface (CLI). At the minimum, this interface is normally available on a serial port on the platform. If more than one serial interface is available, RedBoot is normally configured to try to use any one of the ports for the CLI. Once command input has been received on one port, that port is used exclusively until the board is reset or the channel is manually changed by the user. If the platform has networking capabilities, the RedBoot CLI is also accessible using the `telnet` access protocol. By default, RedBoot runs `telnet` on port TCP/9000, but this is configurable and/or settable by the user.

RedBoot also contains a set of GDB "stubs", consisting of code which supports the GDB remote protocol. GDB stub mode is automatically invoked when the '$' character appears anywhere on a command line unless escaped using the '\' character. The platform will remain in GDB stub mode until explicitly disconnected (via the GDB protocol). The GDB stub mode is available regardless of the connection method; either serial or network. Note that if a GDB connection is made via the network, then special care must be taken to preserve that connection when running user code. eCos contains special network sharing code to allow for this situation, and can be used as a model if this methodology is required in other OS environments.

RedBoot Editing Commands

RedBoot uses the following line editing commands.

> **NOTE:** In this description, ^A means the character formed by typing the letter “A” while holding down the control key.

- Delete (0x7F) or Backspace (0x08) erases the character to the left of the cursor.
- ^A moves the cursor (insertion point) to the beginning of the line.
- ^K erases all characters on the line from the cursor to the end.
- ^E positions the cursor to the end of the line.
- ^D erases the character under the cursor.
- ^F moves the cursor one character to the right.
- ^B moves the cursor one character to the left.

- ^P replaces the current line by a previous line from the history buffer. A small number of lines can be kept as history. Using ^P (and ^N), the current line can be replaced by any one of the previously typed lines.
- ^N replaces the current line by the next line from the history buffer.

In the case of the **fconfig** command, additional editing commands are possible. As data are entered for this command, the current/previous value will be displayed and the cursor placed at the end of that data. The user may use the editing keys (above) to move around in the data to modify it as appropriate. Additionally, when certain characters are entered at the end of the current value, i.e. entered separately, certain behavior is elicited.

- ^ (caret) switch to editing the previous item in the **fconfig** list. If fconfig edits item A, followed by item B, pressing ^ when changing item B, allows you to change item A. This is similar to the up arrow. Note: ^P and ^N do not have the same meaning while editing **fconfig** data and should not be used.
- . (period) stop editing any further items. This does not change the current item.
- Return leaves the value for this item unchanged. Currently it is not possible to step through the value for the start-up script; it must always be retyped.

RedBoot Startup Mode

RedBoot can normally be configured to run in a number of startup modes (or just "modes" for short), determining its location of residence and execution:

ROM mode

In this mode, RedBoot both resides and executes from ROM memory (flash or EPROM). This mode is used when there are limited RAM resources. The flash commands cannot update the region of flash where the RedBoot image resides. In order to update the RedBoot image in flash, it is necessary to run a RAM mode instance of RedBoot.

ROMRAM mode

In this mode, RedBoot resides in ROM memory (flash or EPROM), but is copied to RAM memory before it starts executing. The RAM footprint is larger than for ROM mode, but there are two advantages to make up for this: it normally runs faster (relevant only on slower boards) and it is able to update the flash region where the image resides.

RAM mode

In this mode, RedBoot both resides and executes from RAM memory. This is used for updating a primary ROM mode image in situ and sometimes as part of the RedBoot installation on the board when there’s already an existing (non-RedBoot) boot monitor available.

You can only use ROM and ROMRAM mode images for booting a board - a RAM mode image cannot run unless loaded by another ROM monitor. There is no need for this startup mode if a RedBoot ROMRAM mode image is the primary boot monitor. When this startup mode is programmed into flash (as a convenience as it’s fast to load from flash) it will generally be named as "RedBoot[RAM]" in the FIS directory.

The chosen mode has influence on flash and RAM resource usage (see the Section called *RedBoot Resource Usage*) and the procedure of an in situ update of RedBoot in flash (see Chapter 4).

The startup mode is controlled by the option CYG_HAL_STARTUP which resides in the platform HAL. Some platforms provide only some of the RAM, ROM, and ROMRAM modes, others provide additional modes.

To see mode of a currently executing RedBoot, issue the **version** command, which prints the RedBoot banner, including the startup mode (here ROM):

```
RedBoot>version

RedBoot(tm) bootstrap and debug environment [ROM]
Non-certified release, version UNKNOWN - built 13:31:57, May 17 2002
```

RedBoot Resource Usage

RedBoot takes up both flash and RAM resources depending on its startup mode and number of enabled features. There are also other resources used by RedBoot, such as timers. Platform-specific resources used by RedBoot are listed in the platform specific parts of this manual.

Both flash and RAM resources used by RedBoot depend to some degree on the features enabled in the RedBoot configuration. It is possible to reduce in particular the RAM resources used by RedBoot by removing features that are not needed. Flash resources can also be reduced, but due to the granularity of the flash (the block sizes), reductions in feature size do not always result in flash resource savings.

Flash Resources

On many platforms, a ROM mode RedBoot image resides in the first flash sectors, working as the board's primary boot monitor. On these platforms, it is also normal to reserve a similar amount of flash for a secondary RAM mode image, which is used when updating the primary ROM mode image.

On other platforms, a ROMRAM mode RedBoot image is used as the primary boot monitor. On these platforms there is not normally reserved space for a RAM mode RedBoot image, since the ROMRAM mode RedBoot is capable of updating the primary boot monitor image.

Most platforms also contain a FIS directory (keeping track of available flash space) and a RedBoot config block (containing RedBoot board configuration data).

To see the amount of reserved flash memory, run the **fis list** command:

```
RedBoot> fis list
Name              FLASH addr  Mem addr    Length      Entry point
RedBoot           0x00000000  0x00000000  0x00020000  0x00000000
RedBoot[RAM]      0x00020000  0x06020000  0x00020000  0x060213C0
RedBoot config    0x0007F000  0x0007F000  0x00001000  0x00000000
FIS directory     0x00070000  0x00070000  0x0000F000  0x00000000
```

To save flash resources, use a ROMRAM mode RedBoot, or if using a ROM mode RedBoot, avoid reserving space for the RedBoot[RAM] image (this is done by changing the RedBoot configuration) and download the RAM mode RedBoot whenever it is needed. If the RedBoot image takes up a fraction of an extra flash block, it may be possible to reduce the image size enough to free this block by removing some features.

RAM Resources

RedBoot reserves RAM space for its run-time data, and such things as CPU exception/interrupt tables. It normally does so at the bottom of the memory map. It may also reserve space at the top of the memory map for configurable RedBoot features such as the net stack and zlib decompression support.

To see the actual amount of reserved space, issue the **version** command, which prints the RedBoot banner, including the RAM usage:

```
RedBoot> version

RedBoot(tm) bootstrap and debug environment [ROM]
Non-certified release, version UNKNOWN - built 13:31:57, May 17 2002

Platform: FooBar (SH 7615)
Copyright (C) 2000, 2001, 2002, Red Hat, Inc.

RAM: 0x06000000-0x06080000, 0x06012498-0x06061000 available
FLASH: 0x00000000 - 0x00080000, 8 blocks of 0x00010000 bytes each.
```

To simplify operations that temporarily need data in free memory, the limits of free RAM are also available as aliases (aligned to the nearest kilo-byte limit). These are named FREEMEMLO and FREEMEMHI, and can be used in commands like any user defined alias:

```
RedBoot> load -r -b %{FREEMEMLO} file
Raw file loaded 0x06012800-0x06013e53, assumed entry at 0x06012800

RedBoot> x -b %{FREEMEMHI}
06061000: 86 F5 EB D8 3D 11 51 F2  96 F4 B2 DC 76 76 8F 77  |....=.Q.....vv.w|
06061010: E6 55 DD DB F3 75 5D 15  E0 F3 FC D9 C8 73 1D DA  |.U...u]......s..|
```

To reduce RedBoot's RAM resource usage, use a ROM mode RedBoot. The RedBoot features that use most RAM are the net stack, the flash support and the gunzip support. These, and other features, can be disabled to reduce the RAM footprint, but obviously at the cost of lost functionality.

Configuring the RedBoot Environment

Once installed, RedBoot will operate fairly generically. However, there are some features that can be configured for a particular installation. These depend primarily on whether flash and/or networking support are available. The remainder of this discussion assumes that support for both of these options is included in RedBoot.

Target Network Configuration

Each node in a networked system needs to have a unique address. Since the network support in RedBoot is based on TCP/IP, this address is an IP (Internet Protocol) address. There are two ways for a system to “know” its IP address. First, it can be stored locally on the platform. This is known as having a static IP address. Second, the system can use the network itself to discover its IP address. This is known as a dynamic IP address. RedBoot supports this dynamic IP address mode by use of the BOOTP (a subset of DHCP) protocol. In this case, RedBoot will ask the network (actually some generic server on the network) for the IP address to use.

> **NOTE:** Currently, RedBoot only supports BOOTP. In future releases, DHCP may also be supported, but such support will be limited to additional data items, not lease-based address allocation.

The choice of IP address type is made via the **fconfig** command. Once a selection is made, it will be stored in flash memory. RedBoot only queries the flash configuration information at reset, so any changes will require restarting the platform.

Here is an example of the RedBoot **fconfig** command, showing network addressing:

```
RedBoot> fconfig -l
Run script at boot: false
Use BOOTP for network configuration: false
Local IP address: 192.168.1.29
Default server IP address: 192.168.1.101
DNS server IP address: 192.168.1.1
GDB connection port: 9000
Network debug at boot time: false
```

In this case, the board has been configured with a static IP address listed as the Local IP address. The default server IP address specifies which network node to communicate with for TFTP service. This address can be overridden directly in the TFTP commands.

The `DNS server IP address` option controls where RedBoot should make DNS lookups. A setting of 0.0.0.0 will disable DNS lookups. The DNS server IP address can also be set at runtime.

If the selection for `Use BOOTP for network configuration` had been `true`, these IP addresses would be determined at boot time, via the BOOTP protocol. The final number which needs to be configured, regardless of IP address selection mode, is the `GDB connection port`. RedBoot allows for incoming commands on either the available serial ports or via the network. This port number is the TCP port that RedBoot will use to accept incoming connections.

These connections can be used for GDB sessions, but they can also be used for generic RedBoot commands. In particular, it is possible to communicate with RedBoot via the telnet protocol. For example, on Linux®:

```
% telnet redboot_board 9000
Connected to redboot_board
Escape character is ‘^]’.
RedBoot>
```

Host Network Configuration

RedBoot may require three different classes of service from a network host:

- dynamic IP address allocation, using BOOTP
- TFTP service for file downloading
- DNS server for hostname lookups

Depending on the host system, these services may or may not be available or enabled by default. See your system documentation for more details.

In particular, on Red Hat Linux, neither of these services will be configured out of the box. The following will provide a limited explanation of how to set them up. These configuration setups must be done as `root` on the host or server machine.

Enable TFTP on Red Hat Linux 6.2

1. Ensure that you have the tftp-server RPM package installed. By default, this installs the TFTP server in a disabled state. These steps will enable it:
2. Make sure that the following line is uncommented in the control file `/etc/inetd.conf`

```
tftp dgram   udp     wait    root    /usr/sbin/tcpd      /usr/sbin/in.tftpd
```

3. If it was necessary to change the line in Step 2, then the inetd server must be restarted, which can be done via the command:

```
# service inet reload
```

Enable TFTP on Red Hat Linux 7 (or newer)

1. Ensure that the xinetd RPM is installed.
2. Ensure that the tftp-server RPM is installed.
3. Enable TFTP by means of the following:

```
/sbin/chkconfig tftp on
```

   Reload the xinetd configuration using the command:

```
 /sbin/service xinetd reload
```

   Create the directory /tftpboot using the command

```
mkdir /tftpboot
```

NOTE: Under Red Hat 7 you must address files by absolute pathnames, for example: `/tftpboot/boot.img` not `/boot.img`, as you may have done with other implementations. On systems newer than Red Hat 7 (7.1 and beyond), filenames are once again relative to the `/tftpboot` directory.

Enable BOOTP/DHCP server on Red Hat Linux

First, ensure that you have the proper package, `dhcp` (not `dhcpd`) installed. The DHCP server provides Dynamic Host Configuration, that is, IP address and other data to hosts on a network. It does this in different ways. Next, there can be a fixed relationship between a certain node and the data, based on that node's unique Ethernet Station Address (ESA, sometimes called a MAC address). The other possibility is simply to assign addresses that are free. The sample DHCP configuration file shown does both. Refer to the DHCP documentation for more details.

Example 1-1. Sample DHCP configuration file

```
--------------- /etc/dhcpd.conf -----------------------------
default-lease-time 600;
max-lease-time 7200;
option subnet-mask 255.255.255.0;
option broadcast-address 192.168.1.255;
option domain-name-servers 198.41.0.4, 128.9.0.107;
option domain-name “bogus.com”;
allow bootp;
shared-network BOGUS {
subnet 192.168.1.0 netmask 255.255.255.0 {
         option routers 192.168.1.101;
         range 192.168.1.1 192.168.1.254;
}
 }
host mbx {
         hardware ethernet 08:00:3E:28:79:B8;
         fixed-address 192.168.1.20;
         filename “/tftpboot/192.168.1.21/zImage”;
         default-lease-time -1;
         server-name “srvr.bugus.com”;
         server-identifier 192.168.1.101;
         option host-name “mbx”;
}
```

Once the DHCP package has been installed and the configuration file set up, type:

```
# service dhcpd start
```

Enable DNS server on Red Hat Linux

First, ensure that you have the proper RPM package, `caching-nameserver` installed. Then change the configuration (in `/etc/named.conf`) so that the `forwarders` point to the primary nameservers for your machine, normally using the nameservers listed in `/etc/resolv.conf`.

Example 1-2. Sample `/etc/named.conf` for Red Hat Linux 7.x

```
--------------- /etc/named.conf -----------------------------
// generated by named-bootconf.pl

options {
        directory "/var/named";
```

```
        /*
         * If there is a firewall between you and nameservers you want
         * to talk to, you might need to uncomment the query-source
         * directive below.  Previous versions of BIND always asked
         * questions using port 53, but BIND 8.1 uses an unprivileged
         * port by default.
         */
        // query-source address * port 53;


        forward first;
        forwarders {
                212.242.40.3;
                212.242.40.51;
        };
};

//
// a caching only nameserver config
//
// Uncomment the following for Red Hat Linux 7.2 or above:
// controls {
//         inet 127.0.0.1 allow { localhost; } keys { rndckey; };
// };
// include "/etc/rndc.key";
zone "." IN {
        type hint;
        file "named.ca";
};

zone "localhost" IN {
        type master;
        file "localhost.zone";
        allow-update { none; };
};

zone "0.0.127.in-addr.arpa" IN {
        type master;
        file "named.local";
        allow-update { none; };
};
```

Make sure the server is started with the command:

```
# service named start
```

and is started on next reboot with the command

```
# chkconfig named on
```

Finally, you may wish to change `/etc/resolv.conf` to use `127.0.0.1` as the nameserver for your local machine.

RedBoot network gateway

RedBoot cannot communicate with machines on different subnets because it does not support routing. It always assumes that it can get to an address directly, therefore it always tries to ARP and then send packets directly to that unit. This means that whatever it talks to must be on the same subnet. If you need to talk to a host on a different subnet (even if it's on the same 'wire'), you need to go through an ARP proxy, providing that there is a Linux box connected to the network which is able to route to the TFTP server. For example: `/proc/sys/net/ipv4/conf/<interface>/proxy_arp` where <*interface*>should be replaced with whichever network interface is directly connected to the board.

Verification

Once your network setup has been configured, perform simple verification tests as follows:

- Reboot your system, to enable the setup, and then try to 'ping' the target board from a host.
- Once communication has been established, try to ping a host using the RedBoot ping command - both by IP address and hostname.
- Try using the RedBoot load command to download a file from a host.

Chapter 2. RedBoot Commands and Examples

Introduction

RedBoot provides three basic classes of commands:

- Program loading and execution
- Flash image and configuration management
- Miscellaneous commands

Given the extensible and configurable nature of eCos and RedBoot, there may be extended or enhanced sets of commands available.

The basic format for commands is:

```
RedBoot> COMMAND [-S]... [-s val]... operand
```

Commands may require additional information beyond the basic command name. In most cases this additional information is optional, with suitable default values provided if they are not present.

Format	Description	Example
-S	A boolean switch; the behavior of the command will differ, depending on the presence of the switch. In this example, the **-f** switch indicates that a complete initialization of the FIS data should be performed. There may be many such switches available for any given command and any or all of them may be present, in any order.	`RedBoot>` **`fis init -f`**
-s *val*	A qualified value; the letter "s" introduces the value, qualifying it's meaning. In the example, **-b 0x100000** specifies where the memory dump should begin. There may be many such switches available for any given command and any or all of them may be present, in any order.	`RedBoot>` **`dump -b 0x100000 -l 0x20`**

Format	Description	Example
operand	A simple value; some commands require a single parameter for which an additional **-X** switch would be redundant. In the example, **JFFS2** is the name of a flash image. The image name is always required, thus is no need to qualify it with a switch. Note that any un-qualified operand must always appear at the end of the command.	`RedBoot> fis delete JFFS2`

The list of available commands, and their syntax, can be obtained by typing **help** at the command line:

```
RedBoot> help
Manage aliases kept in FLASH memory
      alias name [value]
Set/Query the system console baud rate
      baudrate [-b <rate>]
Manage machine caches
      cache [ON | OFF]
Display/switch console channel
      channel [-1|<channel number>]
Display disk partitions
      disks
Display (hex dump) a range of memory
      dump -b <location> [-l <length>] [-s]
Manage flash images
      fis {cmds}
Manage configuration kept in FLASH memory
      fconfig [-i] [-l] [-n] [-f] [-d] | [-d] nickname [value]
Execute code at a location
      go [-w <timeout>] [entry]
Help about help?
      help [<topic>]
Set/change IP addresses
      ip_address [-l <local_ip_address>] [-h <server_address>]
Load a file
      load [-r] [-v] [-d] [-c <channel>] [-h <host>] [-m {TFTP | HTTP | {x|y}MODEM | disk}]
      [-b <base_address>] <file_name>
Network connectivity test
      ping [-v] [-n <count>] [-t <timeout>] [-i <IP_addr]
      -h <host>
Reset the system
      reset
Display RedBoot version information
      version
Display (hex dump) a range of memory
      x -b <location> [-l <length>] [-s]
```

Commands can be abbreviated to their shortest unique string. Thus in the list above, **d,du,dum** and dump are all valid for the **dump** command. The **fconfig** command can be abbreviated **fc**, but **f** would be ambiguous with **fis**.

There is one additional, special command. When RedBoot detects '$' or '+' (unless escaped via '\') in a command, it switches to GDB protocol mode. At this point, the eCos GDB stubs take over, allowing connections from a GDB host. The only way to get back to RedBoot from GDB mode is to restart the platform.

> **NOTE:** Multiple commands may be entered on a single line, separated by the semi-colon “;” character.

The standard RedBoot command set is structured around the bootstrap environment. These commands are designed to be simple to use and remember, while still providing sufficient power and flexibility to be useful. No attempt has been made to render RedBoot as the end-all product. As such, things such as the debug environment are left to other modules, such as GDB stubs, which are typically included in RedBoot.

The command set may be also be extended on a platform basis.

Common Commands

alias

Name

`alias` — Manipulate command line aliases

Synopsis

alias { *name*}[*value*]

Arguments

Name	**Type**	**Description**	**Default**
name	Name	The name for this alias.	*none*
value	String	Replacement value for the alias.	*none*

Description

The **alias** command is used to maintain simple command line aliases. These aliases are shorthand for longer expressions. When the pattern %{name} appears in a command line, including in a script, the corresponding value will be substituted. Aliases may be nested.

If no value is provided, then the current value of the alias is displayed.

If the system supports non-volatile configuration data via the **fconfig** command (see the Section called *Persistent State Flash-based Configuration and Control* in Chapter 2), then the value will be saved and used when the system is reset.

Examples

Set an alias.

```
RedBoot> alias joe "This is Joe"
Update RedBoot non-volatile configuration - continue (y/n)? n
```

Display an alias.

```
RedBoot> alias joe
'joe' = 'This is Joe'
```

Use an alias. Note: the "=" command simply echoes the command to to console.

```
RedBoot> = %{joe}
This is Joe
```

Aliases can be nested.

```
RedBoot> alias frank "Who are you? %{joe}"
Update RedBoot non-volatile configuration - continue (y/n)? n
RedBoot> = %{frank}
Who are you? This is Joe
```

Notice how the value of %{frank} changes when %{joe} is changed since the value of %{joe} is not evaluated until %{frank} is evaluated.

```
RedBoot> alias joe "This is now Josephine"
Update RedBoot non-volatile configuration - continue (y/n)? n
RedBoot> = %{frank}
Who are you? This is now Josephine
```

baudrate

Name

`baudrate` — Set the baud rate for the system serial console

Synopsis

baudrate [-b *`rate`*]

Arguments

Name	Type	Description	Default
-b *`rate`*	Number	The baud rate to use for the serial console.	*none*

Description

The **baudrate** command sets the baud rate for the system serial console.

If no value is provided, then the current value of the console baud rate is displayed.

If the system supports non-volatile configuration data via the **fconfig** command (see the Section called *Persistent State Flash-based Configuration and Control* in Chapter 2), then the value will be saved and used when the system is reset.

Examples

Show the current baud rate.

```
RedBoot> baudrate
Baud rate = 38400
```

Change the console baud rate. In order to make this operation safer, there will be a slight pause after the first message to give you time to change to the new baud rate. If it doesn't work, or a less than affirmative answer is given to the "continue" prompt, then the baud rate will revert to the current value. Only after the baud rate has been firmly established will *RedBoot* give you an opportunity to save the value in persistent storage.

```
RedBoot> baudrate -b 57600
Baud rate will be changed to 57600 - update your settings
Device baud rate changed at this point
Baud rate changed to 57600 - continue (y/n)? y
```

baudrate

```
Update RedBoot non-volatile configuration - continue (y/n)? n
```

cache

Name

`cache` — Control hardware caches

Synopsis

cache [on | off]

Arguments

Name	Type	Description	Default
on		Turn the caches on	*none*
off		Turn the caches off	*none*

Description

The **cache** command is used to manipulate the caches on the processor.

With no options, this command specifies the state of the system caches.

When an option is given, the caches are turned off or on appropriately.

Examples

Show the current cache state.

```
RedBoot> cache
Data cache: On, Instruction cache: On
```

Disable the caches.

```
RedBoot> cache off
RedBoot> cache
Data cache: Off, Instruction cache: Off
```

Enable the caches.

```
RedBoot> cache on
```

cache

```
RedBoot> cache
Data cache: On, Instruction cache: On
```

channel

Name

`channel` — Select the system console channel

Synopsis

channel [-1 | *channel_number*]

Arguments

Name	Type	Description	Default
-1		Reset the console channel	*none*
channel_number	Number	Select a channel	*none*

Description

With no arguments, the **channel** command displays the current console channel number.

When passed an argument of 0 upward, this command switches the console channel to that channel number. The mapping between channel numbers and physical channels is platform specific but will typically be something like channel 0 is the first serial port, channel 1 is the second, etc.

When passed an argument of -1, this command reverts RedBoot to responding to whatever channel receives input first, as happens when RedBoot initially starts execution.

Examples

Show the current channel.

```
RedBoot> channel
Current console channel id: 0
```

Change to an invalid channel.

```
RedBoot> channel 99
**Error: bad channel number ’99’
```

Revert to the default channel setting (any console mode).

```
RedBoot> channel -1
```

cksum

Name

`cksum` — Compute POSIX checksums

Synopsis

cksum {-b *location*} {-l *length*}

Arguments

Name	Type	Description	Default
-b *location*	Memory address	Location in memory for stat of data.	*none*
-l *length*	Number	Length of data	*none*

Description

Computes the POSIX checksum on a range of memory (either RAM or FLASH). The values printed (decimal cksum, decimal length, hexadecimal cksum, hexadecimal length) can be compared with the output from the Linux program 'cksum'.

Examples

Checksum a buffer.

```
RedBoot> cksum -b 0x100000 -l 0x100
POSIX cksum = 3286483632 256 (0xc3e3c2b0 0x00000100)
```

Checksum an area of memory after loading a file. Note that the base address and length parameters are provided by the preceding load command.

```
RedBoot> load -r -b %{FREEMEMLO} redboot.bin
Raw file loaded 0x06012800-0x0602f0a8
RedBoot> cksum
Computing cksum for area 0x06012800-0x0602f0a8
POSIX cksum = 2092197813 116904 (0x7cb467b5 0x0001c8a8)
```

disks

Name

`disks` — List available disk partitions.

Synopsis

disks

Arguments

None.

Description

The **disks** command is used to list disk partitions recognized by RedBoot.

Examples

Show what disk partitions are available.

```
RedBoot> disks
hda1     Linux Swap
hda2     Linux
00100000: 00 3E 00 06 00 06 00 06  00 00 00 00 00 00 00 00  |.>..............|
00100010: 00 00 00 78 00 70 00 60  00 60 00 60 00 60 00 60  |...x.p.‘.‘.‘.‘.‘|
```

dump

Name

`dump` — Display memory.

Synopsis

dump {-b *`location`*} [-l *`length`*] [-s] [-1 | -2 | -4]

Arguments

Name	Type	Description	Default
-b *`location`*	Memory address	Location in memory for start of data.	*none*
-l *`length`*	Number	Length of data	32
-s	Boolean	Format data using Motorola S-records.	
-1		Access one byte (8 bits) at a time. Only the least significant 8 bits of the pattern will be used.	-1
-2		Access two bytes (16 bits) at a time. Only the least significant 16 bits of the pattern will be used.	-1
-4		Access one word (32 bits) at a time.	-1

Description

Display a range of memory on the system console.

The **x** is a synonym for **dump**.

Note that this command could be detrimental if used on memory mapped hardware registers.

The memory is displayed at most sixteen bytes per line, first as the raw hex value, followed by an ASCII interpretation of the data.

Examples

Display a buffer, one byte at a time.

```
RedBoot> mfill -b 0x100000 -l 0x20 -p 0xDEADFACE
RedBoot> x -b 0x100000
00100000: CE FA AD DE CE FA AD DE  CE FA AD DE CE FA AD DE  |................|
00100010: CE FA AD DE CE FA AD DE  CE FA AD DE CE FA AD DE  |................|
```

Display a buffer, one short (16 bit) word at a time. Note in this case that the ASCII interpretation is suppressed.

```
RedBoot> dump -b 0x100000 -2
00100000: FACE DEAD FACE DEAD  FACE DEAD FACE DEAD
00100010: FACE DEAD FACE DEAD  FACE DEAD FACE DEAD
```

Display a buffer, one word (32 bit) word at a time. Note in this case that the ASCII interpretation is suppressed.

```
RedBoot> dump -b 0x100000 -4
00100000: DEADFACE DEADFACE DEADFACE DEADFACE
00100010: DEADFACE DEADFACE DEADFACE DEADFACE
```

Display the same buffer, using Motorola S-record format.

```
RedBoot> dump -b 0x100000 -s
S31500100000CEFAADDECEFAADDECEFAADDECEFAADDE8E
S31500100010CEFAADDECEFAADDECEFAADDECEFAADDE7E
```

Display a buffer, with visible ASCII strings.

```
RedBoot> d -b 0xfe00b000 -l 0x80
0xFE00B000: 20 25 70 0A 00 00 00 00  41 74 74 65 6D 70 74 20 | %p.....Attempt |
0xFE00B010: 74 6F 20 6C 6F 61 64 20  53 2D 72 65 63 6F 72 64 |to load S-record|
0xFE00B020: 20 64 61 74 61 20 74 6F  20 61 64 64 72 65 73 73 | data to address|
0xFE00B030: 3A 20 25 70 20 5B 6E 6F  74 20 69 6E 20 52 41 4D |: %p [not in RAM|
0xFE00B040: 5D 0A 00 00 2A 2A 2A 20  57 61 72 6E 69 6E 67 21 |]...*** Warning!|
0xFE00B050: 20 43 68 65 63 6B 73 75  6D 20 66 61 69 6C 75 72 | Checksum failur|
0xFE00B060: 65 20 2D 20 41 64 64 72  3A 20 25 6C 78 2C 20 25 |e - Addr: %lx, %|
0xFE00B070: 30 32 6C 58 20 3C 3E 20  25 30 32 6C 58 0A 00 00 |02lX <> %02lX...|
0xFE00B080: 45 6E 74 72 79 20 70 6F  69 6E 74 3A 20 25 70 2C |Entry point: %p,|
```

help

Name

`help` — Display help on available commands

Synopsis

help [*topic*]

Arguments

Name	Type	Description	Default
topic	String	Which command to provide help for.	All commands

Description

The **help** command displays information about the available RedBoot commands. If a *topic* is given, then the display is restricted to information about that specific command.

If the command has sub-commands, e.g. **fis**, then the topic specific display will print additional information about the available sub-commands. special (ICMP) packets to a specific host. These packets should be automatically returned by that host. The command will indicate how many of these round-trips were successfully completed.

Examples

Show generic help. Note that the contents of this display will depend on the various configuration options for RedBoot when it was built.

```
RedBoot> help
Manage aliases kept in FLASH memory
   alias name [value]
Manage machine caches
   cache [ON | OFF]
Display/switch console channel
   channel [-1|<channel number>]
Compute a 32bit checksum [POSIX algorithm] for a range of memory
   cksum -b <location> -l <length>
Display (hex dump) a range of memory
   dump -b <location> [-l <length>] [-s] [-1|2|4]
Manage FLASH images
   fis {cmds}
Manage configuration kept in FLASH memory
   fconfig [-i] [-l] [-n] [-f] [-d] | [-d] nickname [value]
```

```
Execute code at a location
   go [-w <timeout>] [entry]
Help about help?
   help [<topic>]
Set/change IP addresses
   ip_address [-l <local_ip_address>] [-h <server_address>]
Load a file
   load [-r] [-v] [-d] [-h <host>] [-m {TFTP | HTTP | {x|y}MODEM -c <channel_number>}]
        [-b <base_address>] <file_name>
Compare two blocks of memory
   mcmp -s <location> -d <location> -l <length> [-1|-2|-4]
Fill a block of memory with a pattern
   mfill -b <location> -l <length> -p <pattern> [-1|-2|-4]
Network connectivity test
   ping [-v] [-n <count>] [-l <length>] [-t <timeout>] [-r <rate>]
        [-i <IP_addr>] -h <IP_addr>
Reset the system
   reset
Display RedBoot version information
   version
Display (hex dump) a range of memory
   x -b <location> [-l <length>] [-s] [-1|2|4]
```

Help about a command with sub-commands.

```
RedBoot> help fis
Manage FLASH images
   fis {cmds}
Create an image
  fis create -b <mem_base> -l <image_length> [-s <data_length>]
      [-f <flash_addr>] [-e <entry_point>] [-r <ram_addr>] [-n] <name>
Display an image from FLASH Image System [FIS]
  fis delete name
Erase FLASH contents
  fis erase -f <flash_addr> -l <length>
Display free [available] locations within FLASH Image System [FIS]
  fis free
Initialize FLASH Image System [FIS]
  fis init [-f]
Display contents of FLASH Image System [FIS]
  fis list [-c] [-d]
Load image from FLASH Image System [FIS] into RAM
  fis load [-d] [-b <memory_load_address>] [-c] name
Write raw data directly to FLASH
  fis write -f <flash_addr> -b <mem_base> -l <image_length>
```

ip_address

Name

`ip_address` — Set IP addresses

Synopsis

ip_address [-l *local_IP_address*] [-h *server_IP_address*] [-d *DNS_server_IP_address*]

Arguments

Name	Type	Description	Default
-l *local_IP_address*	Numeric IP or DNS name	The IP address RedBoot should use.	*none*
-h *server_IP_address*	Numeric IP or DNS name	The IP address of the default server. Use of this address is implied by other commands, such as **load**.	*none*
-d *DNS_server_IP_address*	Numeric IP or DNS name	The IP address of the DNS server.	*none*

Description

The **ip_address** command is used to show and/or change the basic IP addresses used by RedBoot. IP addresses may be given as numeric values, e.g. 192.168.1.67, or as symbolic names such as www.redhat.com if DNS support is enabled.

The `-l` option is used to set the IP address used by the target device.

The `-h` option is used to set the default server address, such as is used by the **load** command.

The `-d` option is used to set the default DNS server address which is used for resolving symbolic network addresses. Note that an address of 0.0.0.0 will disable DNS lookups.

Examples

Display the current network settings.

```
RedBoot> ip_address
IP: 192.168.1.31, Default server: 192.168.1.101, DNS server IP: 0.0.0.0
```

Change the DNS server address.

```
RedBoot> ip_address -d 192.168.1.101
IP: 192.168.1.31, Default server: 192.168.1.101, DNS server IP: 192.168.1.101
```

Change the default server address.

```
RedBoot> ip_address -h 192.168.1.104
IP: 192.168.1.31, Default server: 192.168.1.104, DNS server IP: 192.168.1.101
```

load

Name

`load` — Download programs or data to the RedBoot platform

Synopsis

load [-v] [-d] [-r] [-m [[xmodem | ymodem] | tftp | disk]] [-h *server_IP_address*] [-b *location*] [-c *channel*] [*file_name*]

Arguments

Name	Type	Description	Default
-v	Boolean	Display a small spinner (indicator) while the download is in progress. This is just for feedback, especially during long loads. Note that the option has no effect when using a serial download method since it would interfere with the protocol.	*quiet*
-d	Boolean	Decompress data stream (gzip data)	*non-compressed data*
-r	Boolean	Raw (or binary) data	*formatted (S-records, ELF image, etc)*
-m tftp		Transfer data via the network using TFTP protocol.	TFTP
-m http		Transfer data via the network using HTTP protocol.	TFTP
-m xmodem		Transfer data using *X-modem* protocol.	TFTP
-m ymodem		Transfer data using *Y-modem* protocol.	TFTP
-m disk		Transfer data from a local disk.	TFTP
-h *server_IP_address*	Numeric IP or DNS name	The IP address of the TFTP or HTTP server.	Value set by **ip_address**

Name	Type	Description	Default
-b *location*	Number	Address in memory to load the data. Formatted data streams will have an implied load address which this option may override.	*Depends on data format*
-c *channel*	Number	Specify which I/O channel to use for download. This option is only supported when using either xmodem or ymodem protocol.	*Depends on data format*
file_name	String	The name of the file on the TFTP or HTTP server or the local disk. Details of how this is specified for TFTP are host-specific. For local disk files, the name must be in *disk*: *filename* format. The disk portion must match one of the disk names listed by the **disks** command.	*None*

Description

The **load** command is used to download data into the target system. Data can be loaded via a network connection, using either the TFTP or HTTP protocols, or the console serial connection using the X/Y modem protocol. Files may also be loaded directly from local filesystems on disk. Files to be downloaded may either be executable images in ELF executable program format, Motorola S-record (SREC) format or raw data.

Examples

Download a Motorola S-record (or ELF) image, using TFTP, specifying the base memory address.

```
RedBoot> load redboot.ROM -b 0x8c400000
Address offset = 0x0c400000
Entry point: 0x80000000, address range: 0x80000000-0x8000fe80
```

Download a Motorola S-record (or ELF) image, using HTTP, specifying the host [server] address.

```
RedBoot> load /redboot.ROM -m HTTP -h 192.168.1.104
Address offset = 0x0c400000
Entry point: 0x80000000, address range: 0x80000000-0x8000fe80
```

Load an ELF file from /dev/hda1 which should be an EXT2 partition:

```
RedBoot> load -mode disk hda1:hello.elf
Entry point: 0x00020000, address range: 0x00020000-0x0002fd70
```

load

mcmp

Name

`mcmp` — Compare two segments of memory

Synopsis

mcmp {-s *location1*} {-d *location1*} {-l *length*} [-1 | -2 | -4]

Arguments

Name	Type	Description	Default
-s *location1*	Memory address	Location for start of data.	*none*
-d *location2*	Memory address	Location for start of data.	*none*
-l *length*	Number	Length of data	*none*
-1		Access one byte (8 bits) at a time. Only the least significant 8 bits of the pattern will be used.	-4
-2		Access two bytes (16 bits) at a time. Only the least significant 16 bits of the pattern will be used.	-4
-4		Access one word (32 bits) at a time.	-4

Description

Compares the contents of two ranges of memory (RAM, ROM, FLASH, etc).

Examples

Compare two buffers which match (result is *quiet*).

```
RedBoot> mfill -b 0x100000 -l 0x20 -p 0xDEADFACE
RedBoot> mfill -b 0x200000 -l 0x20 -p 0xDEADFACE
RedBoot> mcmp -s 0x100000 -d 0x200000 -l 0x20
```

Compare two buffers which don't match. Only the first non-matching element is displayed.

```
RedBoot> mcmp -s 0x100000 -d 0x200000 -l 0x30 -2
Buffers don’t match - 0x00100020=0x6000, 0x00200020=0x0000
```

mfill

Name

`mfill` — Fill RAM with a specified pattern

Synopsis

mfill {-b *location*} {-l *length*} {-p *value*} [-1 | -2 | -4]

Arguments

Name	Type	Description	Default
-b *location*	Memory address	Location in memory for start of data.	*none*
-l *length*	Number	Length of data	*none*
-p *pattern*	Number	Data value to fill with	0
-1		Access one byte (8 bits) at a time. Only the least significant 8 bits of the pattern will be used.	-4
-2		Access two bytes (16 bits) at a time. Only the least significant 16 bits of the pattern will be used.	-4
-4		Access one word (32 bits) at a time.	-4

Description

Fills a range of memory with the given pattern.

Examples

Fill a buffer with zeros.

```
RedBoot> x -b 0x100000 -l 0x20
00100000: 00 3E 00 06 00 06 00 06  00 00 00 00 00 00 00 00  |.>..............|
00100010: 00 00 00 78 00 70 00 60  00 60 00 60 00 60 00 60  |...x.p.‘.‘.‘.‘.‘|
RedBoot> mfill -b 0x100000 -l 0x20
RedBoot> x -b 0x100000 -l 0x20
00100000: 00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
```

```
00100010: 00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
```

Fill a buffer with a pattern.

```
RedBoot> mfill -b 0x100000 -l 0x20 -p 0xDEADFACE
RedBoot> x -b 0x100000 -l 0x20
00100000: CE FA AD DE CE FA AD DE  CE FA AD DE CE FA AD DE  |................|
00100010: CE FA AD DE CE FA AD DE  CE FA AD DE CE FA AD DE  |................|
```

ping

Name

`ping` — Verify network connectivity

Synopsis

ping [-v] [-i *local_IP_address*] [-l *length*] [-n *count*] [-t *timeout*] [-r *rate*] {-h *server_IP_address*}

Arguments

Name	Type	Description	Default
-v	Boolean	Be verbose, displaying information about each packet sent.	*quiet*
-n *local_IP_address*	Number	Controls the number of packets to be sent.	10
-i *local_IP_address*	Numeric IP or DNS name	The IP address RedBoot should use.	Value set by **ip_address**
-h *server_IP_address*	Numeric IP or DNS name	The IP address of the host to contact.	*none*
-l *length*	Number	The length of the ICMP data payload.	64
-r *length*	Number	How fast to deliver packets, i.e. time between successive sends. A value of 0 sends packets as quickly as possible.	1000ms (1 second)
-t *length*	Number	How long to wait for the round-trip to complete, specified in milliseconds.	1000ms (1 second)

Description

The **ping** command checks the connectivity of the local network by sending special (ICMP) packets to a specific host. These packets should be automatically returned by that host. The command will indicate how many of these round-trips were successfully completed.

Examples

Test connectivity to host 192.168.1.101.

```
RedBoot> ping -h 192.168.1.101
Network PING - from 192.168.1.31 to 192.168.1.101
PING - received 10 of 10 expected
```

Test connectivity to host 192.168.1.101, with verbose reporting.

```
RedBoot> ping -h 192.168.1.101 -v -n 4
Network PING - from 192.168.1.31 to 192.168.1.101
 seq: 1, time: 1 (ticks)
 seq: 2, time: 1 (ticks)
 seq: 3, time: 1 (ticks)
 seq: 4, time: 1 (ticks)
PING - received 10 of 10 expected
```

```
Test connectivity to a non-existent host (192.168.1.109).
RedBoot> ping -h 192.168.1.109 -v -n 4
PING: Cannot reach server ’192.168.1.109’ (192.168.1.109)
```

reset

Name

`reset` — Reset the device

Synopsis

reset

Arguments

None

Description

The **reset** command causes the target platform to be reset. Where possible (hardware support permitting), this will be equivalent to a power-on reset condition.

Examples

Reset the platform.

```
RedBoot> reset
... Resetting.+... Waiting for network card: .
Socket Communications, Inc: Low Power Ethernet CF Revision C 5V/3.3V 08/27/98
Ethernet eth0: MAC address 00:c0:1b:00:ba:28
IP: 192.168.1.29, Default server: 192.168.1.101

RedBoot(tm) bootstrap and debug environment [ROM]
Non-certified release, version UNKNOWN - built 10:41:41, May 14 2002

Platform: Compaq iPAQ Pocket PC (StrongARM 1110)
Copyright (C) 2000, 2001, 2002, Red Hat, Inc.

RAM: 0x00000000-0x01fc0000, 0x00014748-0x01f71000 available
FLASH: 0x50000000 - 0x51000000, 64 blocks of 0x00040000 bytes each.
RedBoot>
```

version

Name

`version` — Display RedBoot version information

Synopsis

version

Arguments

None

Description

The **version** command simply displays version information about RedBoot.

Examples

Display RedBoot's version.

```
RedBoot> version
RedBoot(tm) debug environment - built 09:12:03, Feb 12 2001
Platform: XYZ (PowerPC 860)
Copyright (C) 2000, 2001, Red Hat, Inc.
RAM: 0x00000000-0x00400000
```

version

Flash Image System (FIS)

If the platform has flash memory, RedBoot can use this for image storage. Executable images, as well as data, can be stored in flash in a simple file store. The **fis** command (fis is short for Flash Image System) is used to manipulate and maintain flash images.

fis init

Name

`fis init` — Initialize Flash Image System (FIS)

Synopsis

fis init [-*f*]

Arguments

Name	Type	Description	Default
-f		All blocks of flash memory (except for the boot blocks) will be erased as part of the initialization procedure.	

Description

This command is used to initialize the Flash Image System (FIS). It should normally only be executed once, when RedBoot is first installed on the hardware. If the reserved images or their sizes in the FIS change, due to a different configuration of RedBoot being used, it may be necessary to issue the command again though.

Note: Subsequent executions will cause loss of previously stored information in the FIS.

Examples

Initialize the FIS directory.

```
RedBoot> fis init
About to initialize [format] flash image system - continue (y/n)? y
```

```
*** Initialize FLASH Image System
    Warning: device contents not erased, some blocks may not be usable
... Erase from 0x00070000-0x00080000: .
... Program from 0x0606f000-0x0607f000 at 0x00070000: .
```

Initialize the FIS directory and all of flash memory, except for first blocks of the flash where the boot monitor resides.

```
RedBoot> fis init -f
About to initialize [format] flash image system - continue (y/n)? y
*** Initialize FLASH Image System
... Erase from 0x00020000-0x00070000: .....
... Erase from 0x00080000-0x00080000:
... Erase from 0x00070000-0x00080000: .
... Program from 0x0606f000-0x0607f000 at 0x00070000: .
```

fis list

Name

`fis list` — List Flash Image System directory

Synopsis

fis list [-*f*]

Arguments

Name	Type	Description	Default
-c		Show image checksum instead of memory address (column `Mem addr` is replaced by `Checksum`).	
-d		Show image data length instead of amount of flash occupied by image (column `Length` is replaced by `Datalen`).	

Description

This command lists the images currently available in the FIS. Certain images used by RedBoot have fixed names and have reserved slots in the FIS (these can be seen after using the **fis init** command). Other images can be manipulated by the user.

Note: The images are listed in the order they appear in the FIS directory, not by name or creation time.

Examples

List the FIS directory.

```
RedBoot> fis list
Name              FLASH addr  Mem addr    Length      Entry point
RedBoot           0x00000000  0x00000000  0x00020000  0x00000000
RedBoot config    0x0007F000  0x0007F000  0x00001000  0x00000000
FIS directory     0x00070000  0x00070000  0x0000F000  0x00000000
```

List the FIS directory, with image checksums substituted for memory addresses.

```
RedBoot> fis list -c
Name              FLASH addr  Checksum    Length      Entry point
RedBoot           0x00000000  0x00000000  0x00020000  0x00000000
RedBoot config    0x0007F000  0x00000000  0x00001000  0x00000000
FIS directory     0x00070000  0x00000000  0x0000F000  0x00000000
```

List the FIS directory with image data lengths substituted for flash block reservation lengths.

```
RedBoot> fis list
Name              FLASH addr  Mem addr    Datalen     Entry point
RedBoot           0x00000000  0x00000000  0x00000000  0x00000000
RedBoot config    0x0007F000  0x0007F000  0x00000000  0x00000000
FIS directory     0x00070000  0x00070000  0x00000000  0x00000000
```

fis free

Name

`fis free` — Free flash image

Synopsis

fis free

Description

This command shows which areas of the flash memory are currently not in use. When a block contains non-erased contents it is considered in use. Since it is possible to force an image to be loaded at a particular flash location, this command can be used to check whether that location is in use by any other image.

> **Note:** There is currently no cross-checking between actual flash contents and the FIS directory, which mans that there could be a segment of flash which is not erased that does not correspond to a named image, or vice-versa.

Examples

Show free flash areas.

```
RedBoot> fis free
        0xA0040000 .. 0xA07C0000
        0xA0840000 .. 0xA0FC0000
```

fis free

fis create

Name

`fis create` — Create flash image

Synopsis

fis create {-b *`data address`*} {-l *`length`*} [-f *`flash address`*] [-e *`entry`*] [-r *`relocation address`*] [-s *`data length`*] [-n] [*`name`*]

Arguments

Name	Type	Description	Default
-b	Number	Address of data to be written to the flash.	Address of last loaded file. If not set in a load operation, it must be specified.
-l	Number	Length of flash area to occopy. If specified, and the named image already exists, the length must match the value in the FIS directory.	Length of area reserved in FIS directory if the image already exists, or the length of the last loaded file. If neither are set, it must be specified.
-f	Number	Address of flash area to occopy.	The address of an area reserved in the FIS directory for extant images. Otherwise the first free block which is large enough will be used.
-e	Number	Entry address for an executable image, used by the **fis load** command.	The entry address of last loaded file.
-r	Number	Address where the image should be relocated to by the **fis load** command. This is only relevant for images that will be loaded with the **fis load** command.	The load address of the last loaded file.

Name	Type	Description	Default
-s	Number	Actual length of data written to image. This is used to control the range over which the checksum is made.	It defaults to the length of the last loaded file.
-n		When set, no image data will be written to the flash. Only the FIS directory will be updated.	
name	String	Name of flash image.	

Description

This command creates an image in the FIS directory. The data for the image must exist in RAM memory before the copy. Typically, you would use the RedBoot **load** command to load file into RAM and then the **fis create** command to write it to a flash image.

Examples

Trying to create an extant image, will require the action to be verified.

```
RedBoot> fis create RedBoot -f 0xa0000000 -b 0x8c400000 -l 0x20000
An image named ‘RedBoot’ exists - continue (y/n)? n
```

Create a new test image, let the command find a suitable place.

```
RedBoot> fis create junk -b 0x8c400000 -l 0x20000
... Erase from 0xa0040000-0xa0060000: .
... Program from 0x8c400000-0x8c420000 at 0xa0040000: .
... Erase from 0xa0fe0000-0xa1000000: .
... Program from 0x8c7d0000-0x8c7f0000 at 0xa0fe0000: .
```

Update the RedBoot[RAM] image.

```
RedBoot> load redboot_RAM.img
Entry point: 0x060213c0, address range: 0x06020000-0x06036cc0
RedBoot> fis create RedBoot[RAM]
No memory address set.
An image named ’RedBoot[RAM]’ exists - continue (y/n)? y
* CAUTION * about to program ’RedBoot[RAM]’
            at 0x00020000..0x00036cbf from 0x06020000 - continue (y/n)? y
... Erase from 0x00020000-0x00040000: ..
... Program from 0x06020000-0x06036cc0 at 0x00020000: ..
... Erase from 0x00070000-0x00080000: .
... Program from 0x0606f000-0x0607f000 at 0x00070000: .
```

fis load

Name

`fis load` — Load flash image

Synopsis

fis load [-b *load address*] [-c] [-d] [*name*]

Arguments

Name	Type	Description	Default
-b	Number	Address the image should be loaded to. Executable images normally load at the location to which the file was linked. This option allows the image to be loaded to a specific memory location, possibly overriding any assumed location.	If not specified, the address associated with the image in the FIS directory will be used.
-c		Compute and print the checksum of the image data after it has been loaded into memory.	
-d		Decompress gzipped image while copying it from flash to RAM.	
name	String	The name of the file, as shown in the FIS directory.	

Description

This command is used to transfer an image from flash memory to RAM.

Once the image has been loaded, it may be executed using the **go** command.

Examples

Load and run RedBoot[RAM] image.

```
RedBoot> fis load RedBoot[RAM]
RedBoot> go
```

fis delete

Name

`fis delete` — Delete flash image

Synopsis

fis delete {*name*}

Arguments

Name	Type	Description	Default
name	Number	Name of image that should be deleted.	

Description

This command removes an image from the FIS. The flash memory will be erased as part of the execution of this command, as well as removal of the name from the FIS directory.

> **Note:** Certain images are reserved by RedBoot and cannot be deleted. RedBoot will issue a warning if this is attempted.

Examples

```
RedBoot> fis list
Name              flash addr   Mem addr    Length    Entry point
RedBoot          0xA0000000   0xA0000000  0x020000  0x80000000
RedBoot config   0xA0FC0000   0xA0FC0000  0x020000  0x00000000
FIS directory    0xA0FE0000   0xA0FE0000  0x020000  0x00000000
junk             0xA0040000   0x8C400000  0x020000  0x80000000
RedBoot> fis delete junk
Delete image ‘junk’ - continue (y/n)? y
... Erase from 0xa0040000-0xa0060000: .
... Erase from 0xa0fe0000-0xa1000000: .
... Program from 0x8c7d0000-0x8c7f0000 at 0xa0fe0000: .
```

fis lock

Name

`fis lock` — Lock flash area

Synopsis

fis lock {-f *flash_address*} {-l *length*}

Arguments

Name	Type	Description	Default
flash_address	Number	Address of area to be locked.	
length	Number	Length of area to be locked.	

Description

This command is used to write-protect (lock) a portion of flash memory, to prevent accidental overwriting of images. In order to make make any modifications to the flash, a matching **fis unlock** command must be issued. This command is optional and will only be provided on hardware which can support write-protection of the flash space.

> **Note:** Depending on the system, attempting to write to write-protected flash may generate errors or warnings, or be benignly quiet.

Examples

Lock an area of the flash

```
RedBoot> fis lock -f 0xa0040000 -l 0x20000
... Lock from 0xa0040000-0xa0060000: .
```

fis unlock

Name

`fis unlock` — Unlock flash area

Synopsis

fis unlock {-f *flash_address*} {-l *length*}

Arguments

Name	Type	Description	Default
flash_address	Number	Address of area to be unlocked.	
length	Number	Length of area to be unlocked.	

Description

This command is used to unlock a portion of flash memory forcibly, allowing it to be updated. It must be issued for regions which have been locked before the FIS can reuse those portions of flash.

> **Note:** Some flash devices power up in locked state and always need to be manually unlocked before they can be written to.

Examples

Unlock an area of the flash

```
RedBoot> fis unlock -f 0xa0040000 -l 0x20000
... Unlock from 0xa0040000-0xa0060000: .
```

fis erase

Name

`fis erase` — Erase flash area

Synopsis

fis erase {-f *flash_address*} {-l *length*}

Arguments

Name	Type	Description	Default
flash_address	Number	Address of area to be erased.	
length	Number	Length of area to be erased.	

Description

This command is used to erase a portion of flash memory forcibly. There is no cross-checking to ensure that the area being erased does not correspond to an existing image.

Examples

Erase an area of the flash

```
RedBoot> fis erase -f 0xa0040000 -l 0x20000
... Erase from 0xa0040000-0xa0060000: .
```

fis erase

fis write

Name

`fis write` — Write flash area

Synopsis

fis write {-b *mem_address*} {-l *length*} {-f *flash_address*}

Arguments

Name	Type	Description	Default
mem_address	Number	Address of data to be written to flash.	
length	Number	Length of data to be writtem.	
flash_address	Number	Address of flash to write to.	

Description

This command is used to write data from memory to flash. There is no cross-checking to ensure that the area being written to does not correspond to an existing image.

Examples

Write an area of data to the flash

```
RedBoot> fis write -b 0x0606f000 -l 0x1000 -f 0x00020000
* CAUTION * about to program FLASH
            at 0x00020000..0x0002ffff from 0x0606f000 - continue (y/n)? y
... Erase from 0x00020000-0x00030000: .
... Program from 0x0606f000-0x0607f000 at 0x00020000: .
```

fis write

Persistent State Flash-based Configuration and Control

RedBoot provides flash management support for storage in the flash memory of multiple executable images and of non-volatile information such as IP addresses and other network information.

RedBoot on platforms that support flash based configuration information will report the following message the first time that RedBoot is booted on the target:

```
flash configuration checksum error or invalid key
```

This error can be ignored if no flash based configuration is desired, or can be silenced by running the **fconfig** command as described below. At this point you may also wish to run the **fis init** command. See other fis commands in the Section called *Flash Image System (FIS)*.

Certain control and configuration information used by RedBoot can be stored in flash.

The details of what information is maintained in flash differ, based on the platform and the configuration. However, the basic operation used to maintain this information is the same. Using the **fconfig -l** command, the information may be displayed and/or changed.

If the optional flag `-i` is specified, then the configuration database will be reset to its default state. This is also needed the first time RedBoot is installed on the target, or when updating to a newer RedBoot with different configuration keys.

If the optional flag `-l` is specified, the configuration data is simply listed. Otherwise, each configuration parameter will be displayed and you are given a chance to change it. The entire value must be typed - typing just carriage return will leave a value unchanged. Boolean values may be entered using the first letter (`t` for true, `f` for false). At any time the editing process may be stopped simply by entering a period (.) on the line. Entering the caret (^) moves the editing back to the previous item. See “RedBoot Editing Commands”, the Section called *RedBoot Editing Commands* in Chapter 1.

If any changes are made in the configuration, then the updated data will be written back to flash after getting acknowledgment from the user.

If the optional flag `-n` is specified (with or without `-l`) then “nicknames” of the entries are used. These are shorter and less descriptive than “full” names. The full name may also be displayed by adding the `-f` flag.

The reason for telling you nicknames is that a quick way to set a single entry is provided, using the format

```
RedBoot> fconfig nickname value
```

If no value is supplied, the command will list and prompt for only that entry. If a value is supplied, then the entry will be set to that value. You will be prompted whether to write the new information into flash if any change was made. For example

```
RedBoot> fconfig -l -n
boot_script: false
bootp: false
bootp_my_ip: 10.16.19.176
bootp_server_ip: 10.16.19.66
dns_ip: 10.16.19.1
gdb_port: 9000
net_debug: false
RedBoot> fconfig bootp_my_ip 10.16.19.177
bootp_my_ip: 10.16.19.176 Setting to 10.16.19.177
Update RedBoot non-volatile configuration - continue (y/n)? y
```

```
  ... Unlock from 0x507c0000-0x507e0000: .
  ... Erase from 0x507c0000-0x507e0000: .
  ... Program from 0x0000a8d0-0x0000acd0 at 0x507c0000: .
  ... Lock from 0x507c0000-0x507e0000: .
  RedBoot>
```

Additionally, nicknames can be used like aliases via the format %{nickname}. This allows the values stored by **`fconfig`** to be used directly by scripts and commands.

Depending on how your terminal program is connected and its capabilities, you might find that you are unable to use line-editing to delete the ‘old’ value when using the default behaviour of **fconfig** ***`nickname`*** or just plain **fconfig**, as shown in this example:

```
RedBoot> fco bootp
bootp: false_
```

The user deletes the word “false;” and enters “true” so the display looks like this:

```
RedBoot> fco bootp
bootp: true
Update RedBoot non-volatile configuration - continue (y/n)? y
... Unlock from ...
RedBoot> _
```

To edit when you cannot backspace, use the optional flag `-d` (for “dumb terminal”) to provide a simpler interface thus:

```
RedBoot> fco -d bootp
bootp: false ? _
```

and you enter the value in the obvious manner thus:

```
RedBoot> fco -d bootp
bootp: false ? true
Update RedBoot non-volatile configuration - continue (y/n)? y
... Unlock from ...
RedBoot> _
```

One item which is always present in the configuration data is the ability to execute a script at boot time. A sequence of RedBoot commands can be entered which will be executed when the system starts up. Optionally, a time-out period can be provided which allows the user to abort the startup script and proceed with normal command processing from the console.

```
RedBoot> fconfig -l
Run script at boot: false
Use BOOTP for network configuration: false
Local IP address: 192.168.1.29
Default server IP address: 192.168.1.101
DNS server IP address: 192.168.1.1
```

```
GDB connection port: 9000
Network debug at boot time: false
```

The following example sets a boot script and then shows it running.

```
RedBoot> fconfig
Run script at boot: false t
      Boot script:
Enter script, terminate with empty line
>> fi li
    Boot script timeout: 0 10
Use BOOTP for network configuration: false .
Update RedBoot non-volatile configuration - continue (y/n)? y
... Erase from 0xa0fc0000-0xa0fe0000: .
... Program from 0x8c021f60-0x8c022360 at 0xa0fc0000: .
RedBoot>
RedBoot(tm) debug environment - built 08:22:24, Aug 23 2000
Copyright (C) 2000, Red Hat, Inc.


RAM: 0x8c000000-0x8c800000
flash: 0xa0000000 - 0xa1000000, 128 blocks of 0x00020000 bytes ea.
Socket Communications, Inc: Low Power Ethernet CF Revision C \
5V/3.3V 08/27/98 IP: 192.168.1.29, Default server: 192.168.1.101 \
== Executing boot script in 10 seconds - enter ^C to abort
RedBoot> fi li
Name              flash addr   Mem addr    Length    Entry point
RedBoot          0xA0000000   0xA0000000  0x020000  0x80000000
RedBoot config   0xA0FC0000   0xA0FC0000  0x020000  0x00000000
FIS directory    0xA0FE0000   0xA0FE0000  0x020000  0x00000000
RedBoot>
```

NOTE: The bold characters above indicate where something was entered on the console. As you can see, the **fi li** command at the end came from the script, not the console. Once the script is executed, command processing reverts to the console.

NOTE: RedBoot supports the notion of a boot script timeout, i.e. a period of time that RedBoot waits before executing the boot time script. This period is primarily to allow the possibility of canceling the script. Since a timeout value of zero (0) seconds would never allow the script to be aborted or canceled, this value is not allowed. If the timeout value is zero, then RedBoot will abort the script execution immediately.

On many targets, RedBoot may be configured to run from ROM or it may be configured to run from RAM. Other configurations are also possible. All RedBoot configurations will execute the boot script, but in certain cases it may be desirable to limit the execution of certain script commands to one RedBoot configuration or the other. This can be accomplished by prepending `{<startup type>}` to the commands which should be executed only by the RedBoot configured for the specified startup type. The following boot script illustrates this concept by having the ROM based RedBoot load and run the RAM based RedBoot. The RAM based RedBoot will then list flash images.

```
RedBoot> fco
Run script at boot: false t
Boot script:
Enter script, terminate with empty line
>> {ROM}fis load RedBoot[RAM]
>> {ROM}go
>> {RAM}fis li
>>
Boot script timeout (1000ms resolution): 2
Use BOOTP for network configuration: false
 ...
Update RedBoot non-volatile configuration - continue (y/n)? y
... Unlock from 0x007c0000-0x007e0000: .
... Erase from 0x007c0000-0x007e0000: .
... Program from 0xa0015030-0xa0016030 at 0x007df000: .
... Lock from 0x007c0000-0x007e0000: .
RedBoot> reset
... Resetting.
+Ethernet eth0: MAC address 00:80:4d:46:01:05
IP: 192.168.1.153, Default server: 192.168.1.10

RedBoot(tm) bootstrap and debug environment [ROM]
Red Hat certified release, version R1.xx - built 17:37:36, Aug 14 2001

Platform: IQ80310 (XScale)
Copyright (C) 2000, 2001, Red Hat, Inc.

RAM: 0xa0000000-0xa2000000, 0xa001b088-0xa1fdf000 available
FLASH: 0x00000000 - 0x00800000, 64 blocks of 0x00020000 bytes each.
== Executing boot script in 2.000 seconds - enter ^C to abort
RedBoot> fis load RedBoot[RAM]
RedBoot> go
+Ethernet eth0: MAC address 00:80:4d:46:01:05
IP: 192.168.1.153, Default server: 192.168.1.10

RedBoot(tm) bootstrap and debug environment [RAM]
Red Hat certified release, version R1.xx - built 13:03:47, Aug 14 2001

Platform: IQ80310 (XScale)
Copyright (C) 2000, 2001, Red Hat, Inc.

RAM: 0xa0000000-0xa2000000, 0xa0057fe8-0xa1fdf000 available
FLASH: 0x00000000 - 0x00800000, 64 blocks of 0x00020000 bytes each.
== Executing boot script in 2.000 seconds - enter ^C to abort
RedBoot> fis li
Name              FLASH addr  Mem addr    Length      Entry point
RedBoot           0x00000000  0x00000000  0x00040000  0x00002000
RedBoot config    0x007DF000  0x007DF000  0x00001000  0x00000000
FIS directory     0x007E0000  0x007E0000  0x00020000  0x00000000
RedBoot>
```

Executing Programs from RedBoot

Once an image has been loaded into memory, either via the **load** command or the **fis load** command, execution may be transfered to that image.

> **NOTE:** The image is assumed to be a stand-alone entity, as RedBoot gives the entire platform over to it. Typical examples would be an eCos application or a Linux kernel.

go

Name

`go` — Execute a program

Synopsis

go [-w *`timeout`*][*`start_address`*]

Arguments

Name	Type	Description	Default
-w *`timeout`*	Number	How long to wait before starting execution.	0
`start_address`	Number	Address in memory to begin execution.	Value set by last **load** or **fis load** command.

Description

The **go** command causes RedBoot to give control of the target platform to another program. This program must execute stand alone, e.g. an eCos application or a Linux kernel.

If the -w option is used, RedBoot will print a message and then wait for a period of time before starting the execution. This is most useful in a script, giving the user a chance to abort executing a program and move on in the script.

Examples

Execute a program - *no explicit output from RedBoot*.

```
RedBoot> go 0x40040
```

Execute a program with a timeout.

```
RedBoot> go -w 10
About to start execution at 0x00000000 - abort with ^C within 10 seconds
^C
RedBoot>
```

Note that the starting address was implied (0x00000000 in this example). The user is prompted that execution will commence in 10 seconds. At anytime within that 10 seconds the user may type Ctrl+C on the console and RedBoot will abort execution and return for the next command, either from a script or the console.

exec

Name

`exec` — Execute a Linux kernel

Synopsis

exec [-w *timeout*] [-r *ramdisk_address*] [-s *ramdisk_length*] [-b *load_address* {-l *load_length*}] [-c *kernel_command_line*] [*entry_point*]

Arguments

Name	Type	Description	Default
-w *timeout*	Number	Time to wait before starting execution.	0
-r *ramdisk_address*	Number	Address in memory of "initrd"-style ramdisk - passed to Linux kernel.	*None*
-s *ramdisk_length*	Number	Length of ramdisk image - passed to Linux kernel.	*None*
-b *load_address*	Number	Address in memory of the Linux kernel image.	Value set by **load** or **fis load**
-l *load_length*	Number	Length of Linux kernel image.	*none*
-c *ker-nel_command_line*	String	Command line to pass to the Linux kernel.	*None*
entry_address	Number	Starting address for Linux kernel execution	Implied by architecture

Description

The **exec** command is used to execute a non-eCos application, typically a Linux kernel. Additional information may be passed to the kernel at startup time. This command is quite special (and unique from the **go** command) in that the program being executed may expect certain environmental setups, for example that the MMU is turned off, etc.

The Linux kernel expects to have been loaded to a particular memory location which is architecture dependent(0xC0008000 in the case of the SA1110). Since this memory is used by RedBoot internally, it is not possible to load the kernel to that location directly. Thus the requirement for the "-b" option which tells the command where the kernel has been loaded. When the **exec** command runs, the image will be relocated to the appropriate location before being started. The "-r" and "-s" options are used to pass information to the kernel about where a statically loaded ramdisk (initrd) is located.

The "-c" option can be used to pass textual "command line" information to the kernel. If the command line data contains any punctuation (spaces, etc), then it must be quoted using the double-quote character ’"’. If the quote character is required, it should be written as ’\"’.

Examples

Execute a Linux kernel, passing a command line, which needs relocation. The result from RedBoot is normally quiet, with the target platform being passed over to Linux immediately.

```
RedBoot> exec -b 0x100000 -l 0x80000 -c "noinitrd root=/dev/mtdblock3 console=ttySA0"
```

Execute a Linux kernel, default entry address and no relocation required, with a timeout. The *emphasized lines* are output from the loaded kernel.

```
RedBoot> exec -c "console=ttyS0,38400 ip=dhcp nfsroot=/export/elfs-sh" -w 5
Now booting linux kernel:
Base address 0x8c001000 Entry 0x8c210000
Cmdline : console=ttyS0,38400 ip=dhcp nfsroot=/export/elfs-sh
About to start execution at 0x8x210000 - abort with ^C within 5 seconds
Linux version 2.4.10-pre6 (...) (gcc version 3.1-stdsh-010931) #3 Thu Sep 27 11:04:23 BST 2001
```

Chapter 3. Rebuilding RedBoot

Introduction

RedBoot is built as an application on top of eCos. The makefile rules for building RedBoot are part of the eCos CDL package, so it's possible to build eCos from the Configuration Tool, as well as from the command line using ecosconfig.

Building RedBoot requires only a few steps: selecting the platform and the RedBoot template, importing a platform specific configuration file, and finally starting the build.

The platform specific configuration file makes sure the settings are correct for building RedBoot on the given platform. Each platform should provide at least two of these configuration files: `redboot_RAM.ecm` for a RAM mode RedBoot configuration and `redboot_ROM.ecm` or `redboot_ROMRAM.ecm` for a ROM or ROMRAM mode RedBoot configuration. There may be additional configuration files according to the requirements of the particular platform.

The RedBoot build process results in a number of files in the install `bin` directory. The ELF file `redboot.elf` is the pricipal result. Depending on the platform CDL, there will also be generated versions of RedBoot in other file formats, such as `redboot.bin` (binary format, good when doing an update of a primary RedBoot image, see the Section called *Update the primary RedBoot flash image* in Chapter 4), `redboot.srec` (Motorola S-record format, good when downloading a RAM mode image for execution), and `redboot.img` (stripped ELF format, good when downloading a RAM mode image for execution, smaller than the .srec file). Some platforms may provide additional file formats and also relocate some of these files to a particular address making them more suitable for downloading using a different boot monitor or flash programming tools.

The platform specific information in Chapter 5 should be consulted, as there may be other special instructions required to build RedBoot for particular platforms.

Rebuilding RedBoot using ecosconfig

To rebuild RedBoot using the ecosconfig tool, create a temporary directory for building RedBoot, name it according to the desired configuration of RedBoot, here RAM:

```
$ mkdir /tmp/redboot_RAM
$ cd /tmp/redboot_RAM
```

Create the build tree according to the chosen platform, here using the Hitachi Solution Engine 7751 board as an example:

> **Note:** It is assumed that the environment variable ECOS_REPOSITORY points to the eCos/RedBoot source tree.

```
$ ecosconfig new se7751 redboot
U CYGPKG_HAL_SH_7750, new inferred value 0
U CYGPKG_HAL_SH_7751, new inferred value 1
U CYGHWR_HAL_SH_IRQ_USE_IRQLVL, new inferred value 1
U CYGSEM_HAL_USE_ROM_MONITOR, new inferred value 0
```

```
U CYGDBG_HAL_COMMON_CONTEXT_SAVE_MINIMUM, new inferred value 0
U CYGDBG_HAL_DEBUG_GDB_INCLUDE_STUBS, new inferred value 1
U CYGFUN_LIBC_STRING_BSD_FUNCS, new inferred value 0
U CYGPKG_NS_DNS_BUILD, new inferred value 0
```

Replace the platform name ("se7751") with the appropriate name for the chosen platform.

Then import the appropriate platform RedBoot configuration file, here for RAM configuration:

```
$ ecosconfig import ${ECOS_REPOSITORY}/hal/sh/se7751/VERSION/misc/redboot_RAM.ecm
$ ecosconfig tree
```

Replace architecture ("sh"), platform ("se7751") and version ("*VERSION*") with those appropriate for the chosen platform and the version number of its HAL package. Also replace the configuration name ("redboot_RAM.ecm") with that of the appropriate configuration file.

RedBoot can now be built:

```
$ make
```

The resulting RedBoot files will be in the associated install directory, in this example, `./install/bin`.

In Chapter 5 each platform's details are described in the form of shell variables. Using those, the steps to build RedBoot are:

```
export REDBOOT_CFG=redboot_ROM
export VERSION=VERSION
mkdir /tmp/${REDBOOT_CFG}
cd /tmp/${REDBOOT_CFG}
ecosconfig new ${TARGET} redboot
ecosconfig import ${ECOS_REPOSITORY}/hal/${ARCH_DIR}/${PLATFORM_DIR}/${VERSION}/misc/${REDBOOT_CFG
ecosconfig tree
make
```

To build for another configuration, simply change the *`REDBOOT_CFG`* definition accordingly. Also make sure the *`VERSION`* variable matches the version of the platform package.

Rebuilding RedBoot from the Configuration Tool

To rebuild RedBoot from the Configuration Tool, open the template window (Build->Templates) and select the appropriate Hardware target and in Packages select "redboot". Then press OK. Depending on the platform, a number of conflicts may need to be resolved before the build can be started; select "Continue".

Import the desired RedBoot configuration file from the platform HAL (File->Import...). Depending on the platform, a number of conflicts may need to be resolved before the build can be started; select "Continue". For example, if the platform selected is Hitachi SE7751 board and the RAM configuration RedBoot should be built, import the file `hal/sh/se7751/VERSION/misc/redboot_RAM.ecm`.

Save the configuration somewhere suitable with enough disk space for building RedBoot (File->Save...). Choose the name according to the RedBoot configuration, for example `redboot_RAM.ecc`.

Then start the build (Build->Library) and wait for it to complete. The resulting RedBoot files will be in the associated install directory, for the example this would be `redboot_RAM_install/bin`.

As noted above, each platform's details are described in Chapter 5. Use the information provided in the shell variables to find the configuration file - the path to it is `${ECOS_REPOSITORY}/hal/${ARCH_DIR}/${PLATFORM_DIR}/${VERSION}/misc/${REDBOOT_CFG}.ecm`, where *`ECOS_REPOSITORY`* points to the eCos/RedBoot sources, *`VERSION`* is the version of the package (usually "current") and *`REDBOOT_CFG`* is the desired configuration, e.g. redboot_RAM.

Chapter 4. Updating RedBoot

Introduction

RedBoot normally resides in an EPROM or, more common these days, a flash on the board. In the former case, updating RedBoot necessitates physically removing the part and reprogramming a new RedBoot image into it using prommer hardware. In the latter case, it is often possible to update RedBoot in situ using Redboot's flash management commands.

The process of updating RedBoot in situ is documented in this section. For this process, it is assumed that the target is connected to a host system and that there is a serial connection giving access to the RedBoot CLI. For platforms with a ROMRAM mode RedBoot, skip to the Section called *Update the primary RedBoot flash image*.

> **Note:** The addresses and sizes included in the below are examples only, and will differ from those you will see. This is normal and should not cause concern.

Load and start a RedBoot RAM instance

There are a number of choices here. The basic case is where a RAM mode image has been stored in the FIS (flash Image System). To load and execute this image, use the commands:

```
RedBoot> fis load RedBoot[RAM]
RedBoot> go
```

If this image is not available, or does not work, then an alternate RAM mode image must be loaded:

```
RedBoot> load redboot_RAM.img
Entry point: 0x060213c0, address range: 0x06020000-0x060369c8
RedBoot> go
```

> **Note:** This command loads the RedBoot image using the TFTP protocol via a network connection. Other methods of loading are available, refer to the **load** command for more details.

> **Note:** If you expect to be doing this more than once, it is a good idea to program the RAM mode image into the flash. You do this using the **fis create** command after having downloaded the RAM mode image, but before you start it.
>
> Some platforms support locking (write protecting) certain regions of the flash, while others do not. If your platform does not support locking, simply ignore the **fis unlock** and **fis lock** steps (the commands will not be recognized by RedBoot).
>
> ```
> RedBoot> fis unlock RedBoot[RAM]
>   ... Unlock from 0x00000000-0x00020000: ..
> ```

```
RedBoot> fis create RedBoot[RAM]
An image named 'RedBoot[RAM]' exists - continue (y/n)? y
* CAUTION * about to program 'RedBoot[RAM]'
            at 0x00020000..0x000369c7 from 0x06020000 - continue (y/n)?y
... Erase from 0x00020000-0x00040000: ..
... Program from 0x06020000-0x060369c8 at 0x00020000: ..
... Erase from 0x00070000-0x00080000: .
... Program from 0x0606f000-0x0607f000 at 0x00070000: .
RedBoot> fis lock RedBoot[RAM]
  ... Lock from 0x00000000-0x00020000: ..
```

Update the primary RedBoot flash image

An instance of RedBoot should now be running on the target from RAM. This can be verified by looking for the mode identifier in the banner. It should be either [RAM] or [ROMRAM].

If this is the first time RedBoot is running on the board or if the flash contents has been damaged, initialize the FIS directory:

```
RedBoot> fis init -f
About to initialize [format] FLASH image system - continue (y/n)? y
*** Initialize FLASH Image System
... Erase from 0x00020000-0x00070000: .....
... Erase from 0x00080000-0x00080000:
... Erase from 0x00070000-0x00080000: .
... Program from 0x0606f000-0x0607f000 at 0x00070000: .
```

It is important to understand that the presence of a correctly initialized FIS directory allows RedBoot to automatically determine the flash parameters. Additionally, executing the steps below as stated without loading other data or using other flash commands (than possibly **fis list**) allows RedBoot to automatically determine the image location and size parameters. This greatly reduces the risk of potential critical mistakes due to typographical errors. It is still always possible to explicitly specify parameters, and indeed override these, but it is not advised.

> **Note:** If the new RedBoot image has grown beyond the slot in flash reserved for it, it is necessary to change the RedBoot configuration option CYGBLD_REDBOOT_MIN_IMAGE_SIZE so the FIS is created with adequate space reserved for RedBoot images. In this case, it is necessary to re-initialize the FIS directory as described above, using a RAM mode RedBoot compiled with the updated configuration.

Using the **load** command, download the new flash based image from the host, relocating the image to RAM::

```
RedBoot> load -r -b %{FREEMEMLO} redboot_ROM.bin
Raw file loaded 0x06046800-0x06062fe8, assumed entry at 0x06046800
```

Note: This command loads the RedBoot image using the TFTP protocol via a network connection. Other methods of loading are available, refer to the load command for more details.

Note: Note that the binary version of the image is being downloaded. This is to ensure that the memory after the image is loaded should match the contents of the file on the host. Loading SREC or ELF versions of the image does not guarantee this since these formats may contain holes, leaving bytes in these holes in an unknown state after the load, and thus causing a likely cksum difference. It is possible to use these, but then the step verifying the cksum below may fail.

Once the image is loaded into RAM, it should be checksummed, thus verifying that the image on the target is indeed the image intended to be loaded, and that no corruption of the image has happened. This is done using the cksum command:

```
RedBoot> cksum
Computing cksum for area 0x06046800-0x06062fe8
POSIX cksum = 2535322412 116712 (0x971df32c 0x0001c7e8)
```

Compare the numbers with those for the binary version of the image on the host. If they do not match, try downloading the image again.

Assuming the cksum matches, the next step is programming the image into flash using the FIS commands.

Some platforms support locking (write protecting) certain regions of the flash, while others do not. If your platform does not support locking, simply ignore the **fis unlock** and **fis lock** steps (the commands will not be recognized by RedBoot).

```
RedBoot> fis unlock RedBoot
  ... Unlock from 0x00000000-0x00020000: ..
RedBoot> fis create RedBoot
An image named 'RedBoot' exists - continue (y/n)? y
* CAUTION * about to program 'RedBoot'
            at 0x00000000..0x0001c7e7 from 0x06046800 - continue (y/n)? y
... Erase from 0x00000000-0x00020000: ..
... Program from 0x06046800-0x06062fe8 at 0x00000000: ..
... Erase from 0x00070000-0x00080000: .
... Program from 0x0606f000-0x0607f000 at 0x00070000: .
RedBoot> fis lock RedBoot
  ... Lock from 0x00000000-0x00020000: ..
```

Reboot; run the new RedBoot image

Once the image has been successfully written into the flash, simply reset the target and the new version of RedBoot should be running.

When installing RedBoot for the first time, or after updating to a newer RedBoot with different configuration keys, it is necessary to update the configuration directory in the flash using the **fconfig** command. See the Section called *Persistent State Flash-based Configuration and Control* in Chapter 2.

Chapter 5. Installation and Testing

AM3x/MN103E010 Matsushita MN103E010 (AM33/2.0) ASB2305 Board

Overview

RedBoot supports the debug serial port and the built in ethernet port for communication and downloads. The default serial port settings are 115200,8,N,1 with RTS/CTS flow control. RedBoot can run from either flash, and can support flash management for either the boot PROM or the system flash regions.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
PROM	[ROM]	RedBoot running from the boot PROM and able to access the system flash.	redboot_ROM.ecm
FLASH	[ROM]	RedBoot running from the system flash and able to access the boot PROM.	redboot_FLASH.ecm
RAM	[RAM]	RedBoot running from RAM and able to access the boot PROM.	redboot_RAM.ecm

Initial Installation

Unless a pre-programmed system flash module is available to be plugged into a new board, RedBoot must be installed with the aid of a JTAG interface unit. To achieve this, the RAM mode RedBoot must be loaded directly into RAM by JTAG and started, and then *that* must be used to store the ROM mode RedBoot into the boot PROM.

These instructions assume that you have binary images of the RAM-based and boot PROM-based RedBoot images available.

Preparing to program the board

If the board is to be programmed, whether via JTAG or RedBoot, some hardware settings need to be changed:

- Jumper across ST18 on the board to allow write access to the boot PROM.
- Set DIP switch S1-3 to OFF to allow RedBoot to write to the system flash.
- Set the switch S5 (on the front of the board) to boot from whichever flash is *not* being programmed. Note that the RedBoot image cannot access the flash from which it is currently executing (it can only access the other flash).

The RedBoot binary image files should also be copied to the TFTP pickup area on the host providing TFTP services if that is how RedBoot should pick up the images it is going to program into the flash. Alternatively, the images can be passed by YMODEM over the serial link.

Preparing to use the JTAG debugger

The JTAG debugger will also need setting up:

1. Install the JTAG debugger software (WICE103E) on a PC running Windows (WinNT is probably the best choice for this) in “C:/PanaX”.
2. Install the Matsushita provided “project” into the “C:/Panax/wice103e/prj” directory.
3. Install the RedBoot image files into the “C:/Panax/wice103e/prj” directory under the names redboot.ram and redboot.prom.
4. Make sure the PC’s BIOS has the parallel port set to full bidirectional mode.
5. Connect the JTAG debugger to the PC’s parallel port.
6. Connect the JTAG debugger to the board.
7. Set the switch on the front of the board to boot from “boot PROM”.
8. Power up the JTAG debugger and then power up the board.
9. Connect the board’s Debug Serial port to a computer by a null modem cable.
10. Start minicom or some other serial communication software and set for 115200 baud, 1-N-8 with hardware (RTS/CTS) flow control.

Loading the RAM-based RedBoot via JTAG

To perform the first half of the operation, the following steps should be followed:

1. Start the JTAG debugger software.
2. Run the following commands at the JTAG debugger’s prompt to set up the MMU registers on the CPU.

```
ed 0xc0002000, 0x12000580

ed 0xd8c00100, 0x8000fe01
ed 0xd8c00200, 0x21111000
ed 0xd8c00204, 0x00100200
ed 0xd8c00208, 0x00000004

ed 0xd8c00110, 0x8400fe01
ed 0xd8c00210, 0x21111000
ed 0xd8c00214, 0x00100200
ed 0xd8c00218, 0x00000004

ed 0xd8c00120, 0x8600ff81
ed 0xd8c00220, 0x21111000
ed 0xd8c00224, 0x00100200
ed 0xd8c00228, 0x00000004
```

```
ed 0xd8c00130, 0x8680ff81
ed 0xd8c00230, 0x21111000
ed 0xd8c00234, 0x00100200
ed 0xd8c00238, 0x00000004

ed 0xd8c00140, 0x9800f801
ed 0xd8c00240, 0x00140000
ed 0xd8c00244, 0x11011100
ed 0xd8c00248, 0x01000001

ed 0xda000000, 0x55561645
ed 0xda000004, 0x000003c0
ed 0xda000008, 0x9000fe01
ed 0xda00000c, 0x9200fe01
ed 0xda000000, 0xa89b0654
```

3. Run the following commands at the JTAG debugger's prompt to tell it what regions of the CPU's address space it can access:

```
ex 0x80000000,0x81ffffff,/mexram
ex 0x84000000,0x85ffffff,/mexram
ex 0x86000000,0x867fffff,/mexram
ex 0x86800000,0x87ffffff,/mexram
ex 0x8c000000,0x8cffffff,/mexram
ex 0x90000000,0x93ffffff,/mexram
```

4. Instruct the debugger to load the RAM RedBoot image into RAM:

```
_pc=90000000
u_pc
rd redboot.ram,90000000
```

5. Load the boot PROM RedBoot into RAM:

```
rd redboot.prom,91020000
```

6. Start RedBoot in RAM:

```
g
```

   Note that RedBoot may take some time to start up, as it will attempt to query a BOOTP or DHCP server to try and automatically get an IP address for the board. Note, however, that it should send a plus over the serial port immediately, and the 7-segment LEDs should display "rh 8".

Loading the boot PROM-based RedBoot via the RAM mode RedBoot

Once the RAM mode RedBoot is up and running, it can be communicated with by way of the serial port. Commands can now be entered directly to RedBoot for flashing the boot PROM.

1. Instruct RedBoot to initialise the boot PROM:

```
RedBoot> fi init
```

2. Write the previously loaded redboot.prom image into the boot PROM:

```
RedBoot> fi write -f 0x80000000 -b 0x91020000 -l 0x00020000
```

3. Check that RedBoot has written the image:

```
RedBoot> dump -b 0x91020000
RedBoot> dump -b 0x80000000
```

   Barring the difference in address, the two dumps should be the same.

4. Close the JTAG software and power-cycle the board. The RedBoot banners should be displayed again over the serial port, followed by the RedBoot prompt. The boot PROM-based RedBoot will now be running.
5. Power off the board and unjumper ST18 to write-protect the contents of the boot PROM. Then power the board back up.
6. Run the following command to initialise the system flash:

```
RedBoot> fi init
```

   Then program the system flash based RedBoot into the system flash:

```
RedBoot> load -r -b %{FREEMEMLO} redboot_FLASH.bin
RedBoot> fi write -f 0x84000000 -b %{FREEMEMLO} -l 0x00020000
```

   NOTE: RedBoot arranges the flashes on booting such that they always appear at the same addresses, no matter which one was booted from.

7. A similar sequence of commands can be used to program the boot PROM when RedBoot has been booted from an image stored in the system flash.

```
RedBoot> load -r -b %{FREEMEMLO} /tftpboot/redboot_ROM.bin
RedBoot> fi write -f 0x80000000 -b %{FREEMEMLO} -l 0x00020000
```

   See the Section called *Persistent State Flash-based Configuration and Control* in Chapter 2 for details on configuring the RedBoot in general, and also the Section called *Flash Image System (FIS)* in Chapter 2 for more details on programming the system flash.

Additional Commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this architecture (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for ASB2305 board are:

-w <*time*>

Wait time in seconds before starting kernel

-c *"params"*

Parameters passed to kernel

<*addr*>

Kernel entry point, defaulting to the entry point of the last image loaded

The parameter string is stored in the on-chip memory at location 0x8C001000, and is prefixed by “cmdline:” if it was supplied.

Memory Maps

RedBoot sets up the following memory map on the ASB2305 board.

> **NOTE:** The regions mapped between 0x80000000-0x9FFFFFFF are cached by the CPU. However, all those regions can be accessed uncached by adding 0x20000000 to the address.

```
Physical Address Range   Description
-----------------------  -----------
0x80000000 - 0x9FFFFFFF  Cached Region
0x80000000 - 0x81FFFFFF  Boot PROM
0x84000000 - 0x85FFFFFF  System Flash
0x86000000 - 0x86007FFF  64Kbit Sys Config EEPROM
0x86F90000 - 0x86F90003  4x 7-segment LEDs
0x86FA0000 - 0x86FA0003  Software DIP Switches
0x86FB0000 - 0x86FB001F  PC16550 Debug Serial Port
0x8C000000 - 0x8FFFFFFF  On-Chip Memory (repeated 16Kb SRAM)
0x90000000 - 0x93FFFFFF  SDRAM
0x98000000 - 0x9BFFFFFF  Paged PCI Memory Space (64Mb)
0x9C000000 - 0x9DFFFFFF  PCI Local SRAM (32Mb)
0x9E000000 - 0x9E03FFFF  PCI I/O Space
0x9E040000 - 0x9E0400FF  AM33-PCI Bridge Registers
0x9FFFFFF4 - 0x9FFFFFF7  PCI Memory Page Register
0x9FFFFFF8 - 0x9FFFFFFF  PCI Config Registers
0xA0000000 - 0xBFFFFFFF  Uncached Mirror Region
0xC0000000 - 0xDFFFFFFF  CPU Control Registers
```

The ASB2305 HAL makes use of the on-chip memory in the following way:

```
0x8C000000 - 0x8C0000FF  hal_vsr_table
0x8C000100 - 0x8C0001FF  hal_virtual_vector_table
0x8C001000 -             Linux command line (RedBoot exec command)
           - 0x8C003FFF  Emergency DoubleFault Exception Stack
```

Currently the CPU’s interrupt table lies at the beginning of the RedBoot image, which must therefore be aligned to a 0xFF000000 mask.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=asb2305
export ARCH_DIR=mn10300
export PLATFORM_DIR=asb2305
```

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM7 ARM Evaluator7T

Overview

RedBoot supports both serial ports for communication and downloads. The default serial port settings are 38400,8,N,1.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from flash address 0x20000, with ARM Boot Monitor in flash boot sector.	redboot_ROMA.ecm

Initial Installation

RedBoot is installed using the on-board boot environment. See the user manual for full details.

Quick download instructions

Here are quick start instructions for downloading the prebuilt Redboot image:

- Boot the board and press ENTER:

```
ARM Evaluator7T Boot Monitor PreRelease 1.00
Press ENTER within 2 seconds to stop autoboot
Boot:
```

- Erase the part of the flash where RedBoot will get programmed:

```
Boot: flasherase 01820000 10000
```

- Prepare to download the UU-encoded version of the RedBoot image:

```
Boot: download 10000
Ready to download. Use ’transmit’ option on terminal emulator to download file.
```

- Either use ASCII transmit option in the terminal emulator, or on Linux, simply cat the file to the serial port:

```
$ cat redboot.UU > /dev/ttyS0
```

  When complete, you should see:

```
Loaded file redboot.bin at address 000100000, size = 41960
Boot:
```

- Program the flash:

```
Boot: flashwrite 01820000 10000 10000
```

- And verify that the module is available:

```
Boot: rommodules
Header   Base     Limit
018057c8 01800000 018059e7 BootStrapLoader v1.0 Apr 27 2000 10:33:58
01828f24 01820000 0182a3e8 RedBoot              Apr  5 2001
```

- Reboot the board and you should see the RedBoot banner.

Special RedBoot Commands

None.

Memory Maps

RedBoot sets up the following memory map on the E7T board.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range  C B  Description
----------------------- - -  -----------
0x00000000 - 0x0007ffff Y N  SDRAM
0x03ff0000 - 0x03ffffff N N  Microcontroller registers
0x01820000 - 0x0187ffff N N  System flash (mirrored)
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=e7t
export ARCH_DIR=arm
export PLATFORM_DIR=e7t
```

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM7+ARM9 ARM Integrator

Overview

RedBoot supports both serial ports for communication and downloads. The default serial port settings are 38400,8,N,1.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector.	redboot_ROMRAM.ecm

Initial Installation

RedBoot is installed using the on-board bootPROM environment. See the user manual for full details.

Quick download instructions

Here are quick start instructions for downloading the prebuilt Redboot image:

- Set DIP switch S1[1] to the ON position and reset or power the board up. You will see the bootPROM startup message on serial port A (J14):

  ```
  Initialising...
  ```

```
ARM bootPROM [Version 1.3] Rebuilt on Jun 26 2001 at 22:04:10
Running on a Integrator Evaluation Board
Board Revision V1.0, ARM966E-S Processor
Memory Size is 16MBytes, Flash Size is 32MBytes
Copyright (c) ARM Limited 1999 - 2001. All rights reserved.
Board designed by ARM Limited
Hardware support provided at http://www.arm.com/
For help on the available commands type ? or h
boot Monitor >
```

- Issue the FLASH ROM load command:

  ```
  boot Monitor > L
  Load Motorola S-Records into flash

  Deleting Image 0

  The S-Record loader only accepts input on the serial port.
  Type Ctrl/C to exit loader.
  ```

- Either use the ASCII transmit option in the terminal emulator, or on Linux, simply cat the file to the serial port:

  ```
  $ cat redboot.srec > /dev/ttyS0
  ```

  When complete, type Ctrl-C and you should see something similar to:

  ```
  ................................
  ................................
  ....................
  Downloaded 5,394 records in 81 seconds.

  Overwritten block/s
      0

  boot Monitor >
  ```

- Set DIP switch S1[1] to the OFF position and reboot the board and you should see the RedBoot banner.

Special RedBoot Commands

None.

Memory Maps

RedBoot sets up the following memory map on the Integrator board.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
ARM7TDMI
--------

Physical Address Range  C B  Description
----------------------- - -  -----------
0x00000000 - 0x0007ffff N N  SSRAM
0x00080000 - 0x0fffffff N N  SDRAM (depends on part fitted)
0x10000000 - 0x1fffffff N N  System control and peripheral registers
0x20000000 - 0x23ffffff N N  Boot ROM (contains boot Monitor)
0x24000000 - 0x27ffffff N N  FLASH ROM (contains RedBoot)
0x28000000 - 0x2bffffff N N  SSRAM echo area
0x40000000 - 0x5fffffff N N  PCI Memory access windows
0x60000000 - 0x60ffffff N N  PCI IO access window
0x61000000 - 0x61ffffff N N  PCI config space window
0x62000000 - 0x6200ffff N N  PCI bridge register window
0x80000000 - 0x8fffffff N N  SDRAM echo area (used for PCI accesses)


ARM966E
-------

Physical Address Range  C B  Description
----------------------- - -  -----------
0x00000000 - 0x000fffff N N  SSRAM
0x00100000 - 0x0fffffff N N  SDRAM (depends on part fitted)
0x10000000 - 0x1fffffff N N  System control and peripheral registers
0x20000000 - 0x23ffffff N N  Boot ROM (contains boot Monitor)
0x24000000 - 0x27ffffff N N  FLASH ROM (contains RedBoot)
0x28000000 - 0x2bffffff N N  SSRAM echo area
0x40000000 - 0x5fffffff N N  PCI Memory access windows
0x60000000 - 0x60ffffff N N  PCI IO access window
0x61000000 - 0x61ffffff N N  PCI config space window
0x62000000 - 0x6200ffff N N  PCI bridge register window
0x80000000 - 0x8fffffff N N  SDRAM echo area (used for PCI accesses)
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=integrator
export ARCH_DIR=arm
export PLATFORM_DIR=integrator
```

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM7+ARM9 ARM PID Board and EPI Dev7+Dev9

Overview

RedBoot uses either of the serial ports. The default serial port settings are 38400,8,N,1. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

Device programmer is used to program socketed flash parts with ROM version of RedBoot.

Alternatively, to install RedBoot on a target that already has eCos GDB stubs, download the RAM mode image of RedBoot and run it. Initialize the flash image directory: **fis init** Then download the ROM version of RedBoot and program it into flash:

```
RedBoot> load -b %{FREEMEMLO} -m ymodem
RedBoot> fi cr RedBoot
```

Special RedBoot Commands

None.

Memory Maps

RedBoot sets up the following memory map on the PID board.

```
Physical Address Range Description
----------------------- -----------
0x00000000 - 0x0007ffff DRAM
0x04000000 - 0x04080000 flash
0x08000000 - 0x09ffffff ASB Expansion
0x0a000000 - 0x0bffffff APB Reference Peripheral
0x0c000000 - 0x0fffffff NISA Serial, Parallel and PC Card ports
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=pid
export ARCH_DIR=arm
export PLATFORM_DIR=pid
```

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM7 Atmel AT91 Evaluation Board (EB40)

Overview

RedBoot supports both serial ports. The default serial port settings are 38400,8,N,1. RedBoot also supports minimal flash management on the EB40. However, since the flash device (AT29LV1024) is so small (only the upper 64K is available for general use), only the simple flash write command ’fis write’ is supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board’s flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board’s flash boot sector.	redboot_ROMRAM.ecm

Initial Installation Method

This development board comes with ARM’s debug tool, Angel, installed in flash. At this time, Angel will not be replaced. Rather, RedBoot will be placed in the alternate half of flash. Switch SW1 is used which monitor to boot. Selecting SW1 to "lower mem" will choose Angel. Select SW1 to "Upper mem" for RedBoot once it has been installed.

Set SW1 to "lower mem" and connect serial port A to a host computer. Using GDB from the host and Angel on the board, download the RAM mode image of RedBoot to the board. SW1 should then be set to "upper mem" just before starting RedBoot using the ’cont’ command. Once RedBoot is started, the Angel session must be interrupted (on Linux this can be done using ^Z). Follow this by connecting to the board using minicom at 38400-8N1. At this point, RedBoot will be running on the board in RAM. Now, download the ROMRAM mode image and program it to flash.

```
arm-elf-gdb redboot_RAM.elf
(gdb) tar rdi s=/dev/ttyS0
Angel Debug Monitor (serial) 1.04 (Advanced RISC Machines SDT 2.5) for
AT91EB40 (2.00)
Angel Debug Monitor rebuilt on Apr 07 2000 at 12:40:31
Serial Rate:   9600
Connected to ARM RDI target.
(gdb) set $cpsr=0xd3
(gdb) load
Loading section .rom_vectors, size 0x40 lma 0x2020000
Loading section .text, size 0x7fd8 lma 0x2020040
Loading section .rodata, size 0x15a0 lma 0x2028018
Loading section .data, size 0x2e4 lma 0x20295b8
Start address 0x2020040 , load size 39068
Transfer rate: 6250 bits/sec, 500 bytes/write.
```

At this point, set SW1 to "upper mem".

```
(gdb) cont
Continuing.
```

At this point, suspend the GDB session (use Ctrl-Z) and start a terminal emulator:

```
RedBoot> version

RedBoot(tm) bootstrap and debug environment [RAM]
Non-certified release, version UNKNOWN - built 14:09:27, Jul 20 2001

Platform: Atmel AT91/EB40 (ARM7TDMI)
Copyright (C) 2000, 2001, Red Hat, Inc.

RAM: 0x02000000-0x02080000, 0x020116d8-0x0207fd00 available
FLASH: 0x01010000 - 0x01020000, 256 blocks of 0x00000100 bytes each.
```

```
RedBoot> load -m ymodem -b %{FREEMEMLO}
```

Use minicom to send the file redboot_ROMRAM.srec via YModem.

```
RedBoot> fi wr -f 0x01010000 -b %{FREEMEMLO} -l 0xe100
```

Press the "reset" pushbutton and RedBoot should come up on the board.

Special RedBoot Commands

None.

Memory Maps

This processor has no MMU, so the only memory map is for physical addresses.

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x00000fff    On-chip SRAM
0x01000000 - 0x0101ffff    Flash
0x02000000 - 0x0207ffff    RAM
0xffe00000 - 0xffffffff    I/O registers

The flash based RedBoot image occupies virtual addresses 0x01010000 - 0x0101dfff
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=eb40
export ARCH_DIR=arm
export PLATFORM_DIR=at91
```

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM7 Cirrus Logic EP7xxx (EDB7211, EDB7212, EDB7312)

Overview

RedBoot supports both serial ports on the board and the ethernet port. The default serial port settings are 38400,8,N,1. RedBoot also supports flash management on the EDB7xxx for the NOR flash only.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector (EDB7312 only).	redboot_ROMRAM.ecm

Initial Installation Method

A Windows or Linux utility is used to program flash using serial port #1 via on-chip programming firmware. See board documentation for details on in situ flash programming.

Special RedBoot Commands

None.

Memory Maps

The MMU page tables and LCD display buffer, if enabled, are located at the end of DRAM.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x01ffffff    NOR Flash (EDB7211, EDB7212)
0x00000000 - 0x00ffffff    NOR Flash (EDB7312)
0x10000000 - 0x11ffffff    NAND Flash
0x20000000 - 0x2fffffff    Expansion 2
0x30000000 - 0x3fffffff    Expansion 3
0x40000000 - 0x4fffffff    PCMCIA 0
0x50000000 - 0x5fffffff    PCMCIA 1
0x60000000 - 0x600007ff    On-chip SRAM
0x80000000 - 0x8fffffff    I/O registers
0xc0000000 - 0xc1ffffff    DRAM (EDB7211, EDB7212)
0xc0000000 - 0xc0ffffff    DRAM (EDB7312)

Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x01ffffff  Y Y  DRAM
0x00000000 - 0x00fcffff  Y Y  DRAM (EDB7312)
0x20000000 - 0x2fffffff  N N  Expansion 2
0x30000000 - 0x3fffffff  N N  Expansion 3
0x40000000 - 0x4fffffff  N N  PCMCIA 0
0x50000000 - 0x5fffffff  N N  PCMCIA 1
0x60000000 - 0x600007ff  Y Y  On-chip SRAM
0x80000000 - 0x8fffffff  N N  I/O registers
0xc0000000 - 0xc001ffff  N Y  LCD buffer (if configured)
0xe0000000 - 0xe1ffffff  Y Y  NOR Flash (EDB7211, EDB7212)
0xe0000000 - 0xe0ffffff  Y Y  NOR Flash (EDB7312)
0xf0000000 - 0xf1ffffff  Y Y  NAND Flash

The flash based RedBoot image occupies virtual addresses 0xe0000000 - 0xe003ffff.
```

Platform Resource Usage

The EP7xxx timer #2 is used as a polled timer to provide timeout support for network and XModem file transfers.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=edb7211
export TARGET=edb7212
export TARGET=edb7312
export ARCH_DIR=arm
export PLATFORM_DIR=edb7xxx
```

Use one of the TARGET settings only.

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM9 Agilent AAED2000

Overview

RedBoot supports the serial and ethernet ports on the board. The default serial port settings are 38400,8,N,1. RedBoot also supports flash management on the AAED2000.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector.	redboot_primary_ROMRAM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_primary_RAM.ecm

Initial Installation Method

It is possible to install RedBoot in one of two ways. Either as the primary bootmonitor on the board (installed to blocks 0-1 of the flash) or as the secondary bootmonitor on the board (installed to blocks 1-2 of the flash).

Presently, only the former method is supported.

RedBoot as Primary Bootmonitor

RedBoot is installed in flash using the on-board ARM Boot Monitor.

Boot the board while pressing SPACE. This should bring up the Boot Monitor:

```
ARM bootPROM [Version 1.3] Rebuilt on Jul 16 2001 at 16:21:36
Running on a P920 board Evaluation Board
Board Revision V1.0, ARM920T processor Processor
Memory Size is 32MBytes, Flash Size is 32MBytes
Copyright (c) ARM Limited 1999 - 2001. All rights reserved.
Board designed by ARM Limited
Hardware support provided at http://www.arm.com/
For help on the available commands type ? or h
boot Monitor >
```

Download the RAM mode image of RedBoot configured as a primary bootmonitor using the ARM bootmonitor's SREC-download command:

```
boot Monitor > m
Load Motorola S-Record image into memory and execute it
The S-Record loader only accepts input on the serial port.
Record addresses must be between 0x00008000 and 0x01E0F510.
Type Ctrl/C to exit loader.
```

Use the terminal emulator's ASCII upload command, or (on Linux) simply cat the file to the serial port:

```
$ cat redboot_primary_RAM/redboot.srec >/dev/ttyS1
```

You should see RedBoot start up:

```
FLASH configuration checksum error or invalid key
Ethernet eth0: MAC address 00:30:d3:03:04:99
IP: 192.168.42.111, Default server: 192.168.42.3

RedBoot(tm) bootstrap and debug environment [RAM]
Non-certified release, version UNKNOWN - built 13:15:40, Nov  9 2001

Platform: AAED2000 system (ARM9) [Primary]
Copyright (C) 2000, 2001, Red Hat, Inc.

RAM: 0x00000000-0x01f80000, 0x0006f208-0x01f51000 available
FLASH: 0x60000000 - 0x62000000, 256 blocks of 0x00020000 bytes each.
RedBoot>
```

As can be seen from the output above, the network has been configured to give the board an IP address and information about the default server. If things are not set up on your network, you can still continue, but use the Y-modem download method when loading the RedBoot ROMRAM mode image. Now initialize RedBoot's FIS:

```
RedBoot> fis init
About to initialize [format] FLASH image system - continue (y/n)? y
*** Initialize FLASH Image System
    Warning: device contents not erased, some blocks may not be usable
... Erase from 0x61fe0000-0x62000000: .
... Program from 0x01f5f000-0x01f5f300 at 0x61fe0000: .
```

Download the ROMRAM mode image of RedBoot via ethernet:

```
RedBoot> load -b %{FREEMEMLO} redboot_primary_ROMRAM/redboot.srec
```

or using serial Y-modem protocol:

```
RedBoot> load -mode ymodem -b %{FREEMEMLO}
```

(Use the terminal emulator's Y-modem upload command to send the file `redboot_primary_ROMRAM/redboot.srec`.) When the image has been downloaded, program it into flash:

```
Address offset = 0x00ff8000
Entry point: 0x00008040, address range: 0x00008000-0x0002da80
RedBoot> fi cr RedBoot
An image named 'RedBoot' exists - continue (y/n)? y
* CAUTION * about to program 'RedBoot'
            at 0x60000000..0x6003ffff from 0x00100000 - continue (y/n)? y
... Erase from 0x60000000-0x60040000: ..
... Program from 0x00100000-0x00140000 at 0x60000000: ..
... Erase from 0x61fe0000-0x62000000: .
... Program from 0x01f5f000-0x01f7f000 at 0x61fe0000: .
```

Now reset the board. You should see the RedBoot banner.

Special RedBoot Commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the AAED2000 are:

-b <*addr*>

Location Linux kernel was loaded to

-l <*len*>

Length of kernel

-c *"params"*

Parameters passed to kernel

-r <*addr*>

'initrd' ramdisk location

-s <*len*>

Length of initrd ramdisk

The parameters for kernel image base and size are automatically set after a load operation. So one way of starting the kernel would be:

```
RedBoot> load -r -b 0x100000 zImage
```

```
Raw file loaded 0x00100000-0x001a3d6c
RedBoot> exec -c "console=ttyAC0,38400"
Using base address 0x00100000 and length 0x000a3d6c
Uncompressing Linux.....
```

An image could also be put in flash and started directly:

```
RedBoot> exec -b 0x60040000 -l 0xc0000 -c "console=ttyAC0,38400"
Uncompressing Linux.....
```

Memory Maps

The MMU page tables are located at 0x4000.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ---------------------------------
0x00000000 - 0x01ffffff    Flash
0x10000000 - 0x100fffff    Ethernet
0x30000000 - 0x300fffff    Board registers
0x40000000 - 0x4fffffff    PCMCIA Slot (0)
0x50000000 - 0x5fffffff    Compact Flash Slot (1)
0x80000000 - 0x800037ff    I/O registers
0xb0060000 - 0xb00fffff    On-chip SRAM
0xf0000000 - 0xfd3fffff    SDRAM

Virtual Address Range    C B  Description
-----------------------  - -  ---------------------------------
0x00000000 - 0x01f7ffff  Y Y  SDRAM
0x01f80000 - 0x01ffffff  Y Y  SDRAM (used for LCD frame buffer)
0x10000000 - 0x100fffff  N N  Ethernet
0x30000000 - 0x300fffff  N N  Board registers
0x40000000 - 0x4fffffff  N N  PCMCIA Slot (0)
0x50000000 - 0x5fffffff  N N  Compact Flash Slot (1)
0x60000000 - 0x61ffffff  N N  Flash
0x80000000 - 0x800037ff  N N  I/O registers
0xf0000000 - 0xffffffff  N N  SDRAM (uncached)
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=aaed
```

```
export ARCH_DIR=arm
export PLATFORM_DIR=arm9/aaed2000
```

The names of configuration files are listed above with the description of the associated modes.

ARM/ARM9 Altera Excalibur

Overview

RedBoot supports the serial port labelled P2 on the board. The default serial port settings are 57600,8,N,1. RedBoot also supports flash management on the Excalibur.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector.	redboot_ROMRAM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm
REDBOOT	[ROMRAM]	RedBoot running from top of RAM, but contained in the board's flash boot sector.	redboot_REDBOOT.ecm

NOTE: RedBoot is currently hardwired to use a 128MB SDRAM SIMM module.

Initial Installation Method

A Windows utility (exc_flash_programmer.exe) is used to program flash using the ByteBlasterMV JTAG unit. See board documentation for details on in situ flash programming.

For ethernet to work (under Linux) the following jumper settings should be used on a REV 2 board:

SW2-9 : OFF
U179 : 2-3
JP14-18 : OPEN
JP40-41 : 2-3
JP51-55 : 2-3

Flash management

The ROMRAM and REDBOOT configurations supported on this platform differ only in the memory layout (ROMRAM configuration runs RedBoot from 0x00008000 while REDBOOT configuration runs RedBoot from 0x07f80000). The REDBOOT configuration allows applications to be loaded and run from address 0x00008000.

Special RedBoot Commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the Excalibur are:

-b <*addr*>

Location Linux kernel was loaded to

-l <*len*>

Length of kernel

-c *"params"*

Parameters passed to kernel

-r <*addr*>

'initrd' ramdisk location

-s <*len*>

Length of initrd ramdisk

The parameters for kernel image base and size are automatically set after a load operation. So one way of starting the kernel would be:

```
RedBoot> load -r -b 0x100000 zImage
Raw file loaded 0x00100000-0x001a3d6c
RedBoot> exec -c "console=ttyUA0,57600"
Using base address 0x00100000 and length 0x000a3d6c
Uncompressing Linux.....
```

An image could also be put in flash and started directly:

```
RedBoot> exec -b 0x40400000 -l 0xc0000 -c "console=ttyUA0,57600"
Uncompressing Linux.....
```

Memory Maps

The MMU page tables are located at 0x4000.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x07ffffff    SDRAM
0x08000000 - 0x0805ffff    On-chip SRAM
0x40000000 - 0x40ffffff    Flash
0x7fffc000 - 0x7fffffff    I/O registers
0x80000000 - 0x8001ffff    PLD

Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x07ffffff  Y Y  SDRAM
0x08000000 - 0x0805ffff  Y Y  On-chip SRAM
0x40000000 - 0x403fffff  N Y  Flash
0x7fffc000 - 0x7fffffff  N N  I/O registers
0x80000000 - 0x8001ffff  N N  PLD
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=excalibur_arm9
export ARCH_DIR=arm
export PLATFORM_DIR=arm9/excalibur
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA110) Intel EBSA 285

Overview

RedBoot uses the single EBSA-285 serial port. The default serial port settings are 38400,8,N,1. If the EBSA-285 is used as a host on a PCI backplane, ethernet is supported using an Intel PRO/100+ ethernet adapter. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board’s flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

A linux application is used to program the flash over the PCI bus. Sources and build instructions for this utility are located in the RedBoot sources in: `packages/hal/arm/ebsa285/current/support/linux/safl_util`

Communication Channels

Serial, Intel PRO 10/100+ 82559 PCI ethernet card.

Special RedBoot Commands

None.

Memory Maps

Physical and virtual mapping are mapped one to one on the EBSA-285 using a first level page table located at address 0x4000. No second level tables are used.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Address Range            C B  Description
-----------------------  - -  ---------------------------------
0x00000000 - 0x01ffffff  Y Y  SDRAM
0x40000000 - 0x400fffff  N N  21285 Registers
0x41000000 - 0x413fffff  Y N  flash
0x42000000 - 0x420fffff  N N  21285 CSR Space
0x50000000 - 0x50ffffff  Y Y  Cache Clean
0x78000000 - 0x78ffffff  N N  Outbound Write Flush
0x79000000 - 0x7c0fffff  N N  PCI IACK/Config/IO
0x80000000 - 0xffffffff  N Y  PCI Memory
```

Platform Resource Usage

Timer3 is used as a polled timer to provide timeout support for networking and XModem file transfers.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=ebsa285
export ARCH_DIR=arm
export PLATFORM_DIR=ebsa285
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA1100) Intel Brutus

Overview

RedBoot supports both board serial ports on the Brutus board. The default serial port settings are 38400,8,N,1. flash management is not currently supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

Device programmer is used to program socketed flash parts.

Special RedBoot Commands

None.

Memory Maps

The first level page table is located at physical address 0xc0004000. No second level tables are used.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ---------------------------------
0x00000000 - 0x000fffff    Boot ROM
0x08000000 - 0x083fffff    Application flash
0x10000000 - 0x100fffff    SRAM
0x18000000 - 0x180fffff    Chip Select 3
0x20000000 - 0x3fffffff    PCMCIA
0x80000000 - 0xbfffffff    SA-1100 Internal Registers
0xc0000000 - 0xc7ffffff    DRAM Bank 0
0xc8000000 - 0xcfffffff    DRAM Bank 1
0xd0000000 - 0xd7ffffff    DRAM Bank 2
0xd8000000 - 0xdfffffff    DRAM Bank 3
0xe0000000 - 0xe7ffffff    Cache Clean


Virtual Address Range    C B  Description
-----------------------  - -  ---------------------------------
0x00000000 - 0x003fffff  Y Y  DRAM Bank 0
0x00400000 - 0x007fffff  Y Y  DRAM Bank 1
0x00800000 - 0x00bfffff  Y Y  DRAM Bank 2
0x00c00000 - 0x00ffffff  Y Y  DRAM Bank 3
0x08000000 - 0x083fffff  Y Y  Application flash
0x10000000 - 0x100fffff  Y N  SRAM
0x20000000 - 0x3fffffff  N N  PCMCIA
0x40000000 - 0x400fffff  Y Y  Boot ROM
0x80000000 - 0xbfffffff  N N  SA-1100 Internal Registers
0xe0000000 - 0xe7ffffff  Y Y  Cache Clean
```

Platform Resource Usage

The SA11x0 OS timer is used as a polled timer to provide timeout support for XModem file transfers.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=brutus
export ARCH_DIR=arm
export PLATFORM_DIR=sa11x0/brutus
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA1100) Intel SA1100 Multimedia Board

Overview

RedBoot supports both board serial ports. The default serial port settings are 38400,8,N,1. flash management is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

A device programmer is used to program socketed flash parts.

Special RedBoot Commands

None.

Memory Maps

The first level page table is located at physical address 0xc0004000. No second level tables are used.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x000fffff    Boot flash
0x08000000 - 0x083fffff    Application flash
0x10000000 - 0x107fffff    SA-1101 Board Registers
0x18000000 - 0x180fffff    Ct8020 DSP
0x18400000 - 0x184fffff    XBusReg
0x18800000 - 0x188fffff    SysRegA
0x18c00000 - 0x18cfffff    SysRegB
```

```
0x19000000 - 0x193fffff    Spare CPLD A
0x19400000 - 0x197fffff    Spare CPLD B
0x20000000 - 0x3fffffff    PCMCIA
0x80000000 - 0xbfffffff    SA1100 Internal Registers
0xc0000000 - 0xc07fffff    DRAM Bank 0
0xe0000000 - 0xe7ffffff    Cache Clean
Virtual Address Range    C B  Description


-----------------------  - -  ----------------------------------
0x00000000 - 0x007fffff  Y Y  DRAM Bank 0
0x08000000 - 0x083fffff  Y Y  Application flash
0x10000000 - 0x100fffff  N N  SA-1101 Registers
0x18000000 - 0x180fffff  N N  Ct8020 DSP
0x18400000 - 0x184fffff  N N  XBusReg
0x18800000 - 0x188fffff  N N  SysRegA
0x18c00000 - 0x18cfffff  N N  SysRegB
0x19000000 - 0x193fffff  N N  Spare CPLD A
0x19400000 - 0x197fffff  N N  Spare CPLD B
0x20000000 - 0x3fffffff  N N  PCMCIA
0x50000000 - 0x500fffff  Y Y  Boot flash
0x80000000 - 0xbfffffff  N N  SA1100 Internal Registers
0xc0000000 - 0xc07fffff  N Y  DRAM Bank 0
0xe0000000 - 0xe7ffffff  Y Y  Cache Clean
```

Platform Resource Usage

The SA11x0 OS timer is used as a polled timer to provide timeout support for XModem file transfers.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=sa1100mm
export ARCH_DIR=arm
export PLATFORM_DIR=sa11x0/sa1100mm
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA1110) Intel SA1110 (Assabet)

Overview

RedBoot supports the board serial port and the compact flash ethernet port. The default serial port settings are 38400,8,N,1. RedBoot also supports flash management on the Assabet.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

A Windows or Linux utility is used to program flash over parallel port driven JTAG interface. See board documentation for details on in situ flash programming.

The flash parts are also socketed and may be programmed in a suitable device programmer.

Special RedBoot Commands

None.

Memory Maps

The first level page table is located at physical address 0xc0004000. No second level tables are used.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x07ffffff    flash
0x08000000 - 0x0fffffff    SA-1111 Board flash
0x10000000 - 0x17ffffff    Board Registers
0x18000000 - 0x1fffffff    Ethernet
0x20000000 - 0x2fffffff    SA-1111 Board PCMCIA
0x30000000 - 0x3fffffff    Compact Flash
0x40000000 - 0x47ffffff    SA-1111 Board
0x48000000 - 0x4bffffff    GFX
0x80000000 - 0xbfffffff    SA-1110 Internal Registers
```

```
0xc0000000 - 0xc7ffffff    DRAM Bank 0
0xc8000000 - 0xcfffffff    DRAM Bank 1
0xd0000000 - 0xd7ffffff    DRAM Bank 2
0xd8000000 - 0xdfffffff    DRAM Bank 3
0xe0000000 - 0xe7ffffff    Cache Clean


Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x01ffffff  Y Y  DRAM Bank 0
0x08000000 - 0x0fffffff  Y Y  SA-1111 Board flash
0x10000000 - 0x17ffffff  N N  Board Registers
0x18000000 - 0x1fffffff  N N  Ethernet
0x20000000 - 0x2fffffff  N N  SA-1111 Board PCMCIA
0x30000000 - 0x3fffffff  N N  Compact Flash
0x40000000 - 0x47ffffff  N N  SA-1111 Board
0x48000000 - 0x4bffffff  N N  GFX
0x50000000 - 0x57ffffff  Y Y  flash
0x80000000 - 0xbfffffff  N N  SA-1110 Internal Registers
0xc0000000 - 0xc1ffffff  N Y  DRAM Bank 0
0xe0000000 - 0xe7ffffff  Y Y  Cache Clean
```

Platform Resource Usage

The SA11x0 OS timer is used as a polled timer to provide timeout support for network and XModem file transfers.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=assabet
export ARCH_DIR=arm
export PLATFORM_DIR=sa11x0/assabet
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA11X0) Bright Star Engineering commEngine and nanoEngine

Overview

RedBoot supports a serial port and the built in ethernet port for communication and downloads. The default serial port settings are 38400,8,N,1. RedBoot runs from and supports flash management for the system flash region.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
POST	[ROM]	RedBoot running from the first free flash block at 0x40000.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation

Unlike other targets, the nanoEngine comes equipped with boot firmware which you cannot modify. See chapter 5, "nanoEngine Firmware" of the *nanoEngine Hardware Reference Manual* (we refer to "July 17, 2000 Rev 0.6") from Bright Star Engineering.

Because of this, eCos, and therefore Redboot, only supports a special configuration of the ROM mode, starting at offset 0x40000 in the flash.

Briefly, the POST-configuration RedBoot image lives in flash following the BSE firmware. The BSE firmware is configured, using its standard **bootcmd** command, to run RedBoot at startup.

Download Instructions

You can perform the initial load of the POST-configuration RedBoot image into flash using the BSE firmware's **load** command. This will load a binary file, using TFTP, and program it into flash in one operation. Because no memory management is used in the BSE firmware, flash is mapped from address zero upwards, so the address for the RedBoot POST image is 0x40000. You must use the binary version of RedBoot for this, `redboot-post.bin`.

This assumes you have set up the other BSE firmware config parameters such that it can communicate over your network to your TFTP server.

```
>load redboot-post.bin 40000
loading ... erasing blk at 00040000
erasing blk at 00050000
94168 bytes loaded cksum 00008579
done
>
> set bootcmd "go 40000"
> get
myip = 10.16.19.198
netmask = 255.255.255.0
eth = 0
gateway = 10.16.19.66
serverip = 10.16.19.66
bootcmd = go 40000
>
```

NOTE: the BSE firmware runs its serial IO at 9600 Baud; RedBoot runs instead at 38400 Baud. You must select the right baud rate in your terminal program to be able to set up the BSE firmware.

After a reset, the BSE firmware will print

```
Boot: BSE 2000 Sep 12 2000 14:00:30
autoboot: "go 40000" [hit ESC to abort]
```

and then RedBoot starts, switching to 38400 Baud.

Once you have installed a bootable RedBoot in the system in this manner, we advise re-installing using the generic method described in Chapter 4 in order that the Flash Image System contains an appropriate description of the flash entries.

Cohabiting with POST in Flash

The configuration file named `redboot_POST.ecm` configures RedBoot to build for execution at address 0x50040000 (or, during bootup, 0x00040000). This is to allow power-on self-test (POST) code or immutable firmware to live in the lower addresses of the flash and to run before RedBoot gets control. The assumption is that RedBoot will be entered at its base address in physical memory, that is 0x00040000.

Alternatively, for testing, you can call it in an already running system by using **`go 0x50040040`** at another RedBoot prompt, or a branch to that address. The address is where the reset vector points. It is reported by RedBoot's **load** command and listed by the **fis list** command, amongst other places.

Using the POST configuration enables a normal config option which causes linking and initialization against memory layout files called "...post..." rather than "...rom..." or "...ram..." in the `include/pkgconf` directory. Specifically:

```
include/pkgconf/mlt_arm_sa11x0_nano_post.h
include/pkgconf/mlt_arm_sa11x0_nano_post.ldi
include/pkgconf/mlt_arm_sa11x0_nano_post.mlt
```

It is these you should edit if you wish to move the execution address from 0x50040000 in the POST configuration. Startup mode naturally remains ROM in this configuration.

Because the nanoEngine contains immutable boot firmware at the start of flash, RedBoot for this target is configured to reserve that area in the Flash Image System, and to create by default an entry for the POST mode RedBoot.

```
RedBoot> fis list
Name              FLASH addr  Mem addr    Length      Entry point
(reserved)        0x50000000  0x50000000  0x00040000  0x00000000
RedBoot[post]     0x50040000  0x00100000  0x00020000  0x50040040
RedBoot config    0x503E0000  0x503E0000  0x00010000  0x00000000
FIS directory     0x503F0000  0x503F0000  0x00010000  0x00000000
RedBoot>
```

The entry "(reserved)" ensures that the FIS cannot attempt to overwrite the BSE firmware, thus ensuring that the board remains bootable and recoverable even after installing a broken RedBoot image.

Special RedBoot Commands

The nanoEngine/commEngine has one or two Intel i82559 Ethernet controllers installed, but these have no associated serial EEPROM in which to record their Ethernet Station Address (ESA, or MAC address). The BSE firmware records an ESA for the device it uses, but this information is not available to RedBoot; we cannot share it.

To keep the ESAs for the two ethernet interfaces, two new items of RedBoot configuration data are introduced. You can list them with the RedBoot command **fconfig -l** thus:

```
RedBoot> fconfig -l
Run script at boot: false
Use BOOTP for network configuration: false
Local IP address: 10.16.19.91
Default server IP address: 10.16.19.66
Network hardware address [MAC] for eth0: 0x00:0xB5:0xE0:0xB5:0xE0:0x99
Network hardware address [MAC] for eth1: 0x00:0xB5:0xE0:0xB5:0xE0:0x9A
GDB connection port: 9000
Network debug at boot time: false
RedBoot>
```

You should set them before running RedBoot or eCos applications with the board connected to a network. The **fconfig** command can be used as for any configuration data item; the entire ESA is entered in one line.

Memory Maps

The first level page table is located at physical address 0xc0004000. No second level tables are used.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x003fffff    4Mb FLASH (nCS0)
0x18000000 - 0x18ffffff    Internal PCI bus - 2 x i82559 ethernet
0x40000000 - 0x4fffffff    External IO or PCI bus
0x80000000 - 0xbfffffff    SA-1110 Internal Registers
0xc0000000 - 0xc7ffffff    DRAM Bank 0 - 32Mb SDRAM
0xc8000000 - 0xcfffffff    DRAM Bank 1 - empty
0xe0000000 - 0xe7ffffff    Cache Clean

Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x001fffff  Y Y  DRAM - 8Mb to 32Mb
0x18000000 - 0x180fffff  N N  Internal PCI bus - 2 x i82559 ethernet
0x40000000 - 0x4fffffff  N N  External IO or PCI bus
0x50000000 - 0x51ffffff  Y Y  Up to 32Mb FLASH (nCS0)
0x80000000 - 0xbfffffff  N N  SA-1110 Internal Registers
0xc0000000 - 0xc0ffffff  N Y  DRAM Bank 0: 8 or 16Mb
0xc8000000 - 0xc8ffffff  N Y  DRAM Bank 1: 8 or 16Mb or absent
0xe0000000 - 0xe7ffffff  Y Y  Cache Clean
```

The ethernet devices use a "PCI window" to communicate with the CPU. This is 1Mb of SDRAM which is shared with the ethernet devices that are on the PCI bus. It is neither cached nor buffered, to ensure that CPU and PCI accesses see correct data in the correct order. By default it is configured to be megabyte number 30, at addresses 0x01e00000-0x01efffff. This can be modified, and indeed must be, if less than 32Mb of SDRAM is installed, via the memory layout tool, or by moving the section `__pci_window` referred to by symbols `CYGMEM_SECTION_pci_window*` in the linker script.

Though the nanoEngine ships with 32Mb of SDRAM all attached to DRAM bank 0, the code can cope with any of these combinations also; "2 x " in this context means one device in each DRAM Bank.

1 x 8Mb = 8Mb	2 x 8Mb = 16Mb
1 x 16Mb = 16Mb	2 x 16Mb = 32Mb

All are programmed the same in the memory controller.

Startup code detects which is fitted and programs the memory map accordingly. If the device(s) is 8Mb, then there are gaps in the physical memory map, because a high order address bit is not connected. The gaps are the higher 2Mb out of every 4Mb.

The SA11x0 OS timer is used as a polled timer to provide timeout support within RedBoot.

Nano Platform Port

The nano is in the set of SA11X0-based platforms. It uses the arm architectural HAL, the sa11x0 variant HAL, plus the nano platform hal. These are components

CYGPKG_HAL_ARM	hal/arm/arch/
CYGPKG_HAL_ARM_SA11X0	hal/arm/sa11x0/var
CYGPKG_HAL_ARM_SA11X0_NANO	hal/arm/sa11x0/nano

respectively.

The target name is "nano" which includes all these, plus the ethernet driver packages, flash driver, and so on.

Ethernet Driver

The ethernet driver is in two parts:

A generic ether driver for Intel i8255x series devices, specifically the i82559, is `devs/eth/intel/i82559`. Its package name is `CYGPKG_DEVS_ETH_INTEL_I82559`.

The platform-specific ether driver is `devs/eth/arm/nano`. Its package is `CYGPKG_DEVS_ETH_ARM_NANO`. This tells the generic driver the address in IO memory of the chip, for example, and other configuration details. This driver picks up the ESA from RedBoot's configuration data - unless configured to use a static ESA in the usual manner.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=nano
export ARCH_DIR=arm
export PLATFORM_DIR=sa11x0/nano
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA11X0) Compaq iPAQ PocketPC

Overview

RedBoot supports the serial port via cradle or cable, and Compact Flash ethernet cards if fitted for communication and downloads. The LCD touchscreen may also be used for the console, although by default RedBoot will switch exclusively to one channel once input arrives.

The default serial port settings are 38400,8,N,1. RedBoot runs from and supports flash management for the system flash region.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board’s flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm
WinCE	[RAM]	RedBoot running from RAM, started from OSloader.	redboot_WinCE.ecm

Initial Installation

RedBoot ROM and WinCE mode images are needed by the installation process.

Installing RedBoot on the iPAQ using Windows/CE

The Windows/CE environment originally shipped with the iPAQ contains a hidden mini-loader, sometimes referred to as the "Parrot" loader. This loader can be started by holding down the action button (the joypad) while resetting the unit or when powering on. At this point, a blue bird will appear on the LCD screen. Also at this point, a simple loader can be accessed over the serial port at 115200/8N1. Using this loader, the contents of the iPAQ flash memory can be saved to a Compact Flash memory card.

> **NOTE:** We have only tested this operation with a 32Mbyte CF memory card. Given that the backup will take 16MBytes + 1KByte, something more than a 16MByte card will be required.

Use the "r2c" command to dump Flash contents to the CF memory card. Once this completes, RedBoot can be installed with no fear since the Parrot loader can be used to restore the Flash contents at a later time.

If you expect to completely recover the state of the iPAQ Win/CE environment, then HotSync should be run to backup all "RAM" files as well before installing RedBoot.

The next step in installing RedBoot on the iPAQ actually involves Windows/CE, which is the native environment on the unit. Using WinCE, you need to install an application which will run a RAM based version of RedBoot. Once this is installed and running, RedBoot can be used to update the flash with a native/ROM version of RedBoot.

- Using ActiveSync, copy the file OSloader to your iPAQ.
- Using ActiveSync, copy the file redboot_WinCE.bin to the iPAQ as bootldr in its root directory. Note: this is not the top level folder displayed by Windows (Mobile Device), but rather the 'My Pocket PC' folder within it.
- Execute OSloader. If you didn't create a shortcut, then you will have to poke around for it using the WinCE file explorer.
- Choose the Tools->BootLdr->Run after loading from file menu item.

At this point, the RAM based version of RedBoot should be running. You should be able to return to this point by just executing the last two steps of the previous process if necessary.

Installing RedBoot on the iPAQ - using the Compaq boot loader

This method of installation is no longer supported. If you have previously installed either the Compaq boot loader or older versions of RedBoot, restore the Win/CE environment and proceed as outlined above.

Setting up and testing RedBoot

When RedBoot first comes up, it will want to initialize its LCD touch screen parameters. It does this by displaying a keyboard graphic and asks you to press certain keys. Using the stylus, press and hold until the prompt is withdrawn. When you lift the stylus, RedBoot will continue with the next calibration.

Once the LCD touchscreen has been calibrated, RedBoot will start. The calibration step can be skipped by pressing the return/abort button on the unit (right most button with a curved arrow icon). Additionally, the unit will assume default values if the screen is not touched within about 15 seconds.

Once RedBoot has started, you should get information similar to this on the LCD screen. It will also appear on the serial port at 38400,8,N,1.

```
RedBoot(tm) bootstrap and debug environment [ROM]
Non-certified release, version UNKNOWN - built 06:17:41, Mar 19 2001
```

```
Platform: Compaq iPAQ Pocket PC (StrongARM 1110)

Copyright (C) 2000, 2001, Red Hat, Inc.

RAM: 0x00000000-0x01fc0000, 0x0001f200-0x01f70000 available
FLASH: 0x50000000 - 0x51000000, 64 blocks of 0x00040000 bytes
each.
```

Since the LCD touchscreen is only 30 characters wide, some of this data will be off the right hand side of the display. The joypad may be used to pan left and right in order to see the full lines.

If you have a Compact Flash ethernet card, RedBoot should find it. You'll need to have BOOTP enabled for this unit (see your sysadmin for details). If it does, it will print a message like:

```
... Waiting for network card: .Ready!
Socket Communications Inc: CF+ LPE Revision E 08/04/99
IP: 192.168.1.34, Default server: 192.168.1.101
```

Installing RedBoot permanently

Once you are satisfied with the setup and that RedBoot is operating properly in your environment, you can set up your iPAQ unit to have RedBoot be the bootstrap application.

CAUTION

This step will destroy your Windows/CE environment.

Before you take this step, it is strongly recommended you save your WinCE FLASH contents as outlined above using the "parrot" loader, or by using the Compaq OSloader:

- Using OSloader on the iPAQ, select the Tools->Flash->Save to files.... menu item.
- Four (4) files, 4MB each in size will be created.
- After each file is created, copy the file to your computer, then delete the file from the iPAQ to make room in the WinCE ramdisk for the next file.

You will need to download the version of RedBoot designed as the ROM bootstrap. Then install it permanently using these commands:

```
RedBoot> lo -r -b 0x100000 redboot_ROM.bin
RedBoot> fi loc -f 0x50000000 -l 0x40000
RedBoot> fis init
RedBoot> fi unl -f 0x50040000 -l 0x40000
RedBoot> fi cr RedBoot -b 0x100000
RedBoot> fi loc -f 0x50040000 -l 0x40000
RedBoot> reset
```

> **WARNING**
>
> You must type these commands exactly! Failure to do so may render your iPAQ totally useless. Once you've done this, RedBoot should come up every time you reset.

Restoring Windows/CE

To restore Windows/CE from the backup taken in the Section called *Installing RedBoot permanently*, visit http://www.handhelds.org/projects/wincerestoration.html for directions.

Additional commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the iPAQ are:

-b <*addr*>

Location Linux kernel was loaded to

-l <*len*>

Length of kernel

-c *"params"*

Parameters passed to kernel

-r <*addr*>

'initrd' ramdisk location

-s <*len*>

Length of initrd ramdisk

Linux kernels may be run on the iPAQ using the sources from the anonymous CVS repository at the Handhelds project (http://www.handhelds.org/) with the `elinux.patch` patch file applied. This file can be found in the `misc/` subdirectory of the iPAQ platform HAL in the RedBoot sources, normally `hal/arm/sa11x0/ipaq/`*`VERSION`*`/misc/`

On the iPAQ (and indeed all SA11x0 platforms), Linux expects to be loaded at address 0xC0008000 and the entry point is also at 0xC0008000.

Memory Maps

RedBoot sets up the following memory map on the iPAQ: The first level page table is located at physical address 0xC0004000. No second level tables are used.

NOTE: The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x01ffffff    16Mb to 32Mb FLASH (nCS0) [organized as below]
  0x000000 - 0x0003ffff      Parrot Loader
  0x040000 - 0x0007ffff      RedBoot
  0xf80000 - 0x00fbffff      Fconfig data
  0xfc0000 - 0x00ffffff      FIS directory
0x30000000 - 0x3fffffff    Compact Flash
0x48000000 - 0x4bffffff    iPAQ internal registers
0x80000000 - 0xbfffffff    SA-1110 Internal Registers
0xc0000000 - 0xc1ffffff    DRAM Bank 0 - 32Mb SDRAM
0xe0000000 - 0xe7ffffff    Cache Clean


Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x01ffffff  Y Y  DRAM - 32Mb
0x30000000 - 0x3fffffff  N N  Compact Flash
0x48000000 - 0x4bffffff  N N  iPAQ internal registers
0x50000000 - 0x51ffffff  Y Y  Up to 32Mb FLASH (nCS0)
0x80000000 - 0xbfffffff  N N  SA-1110 Internal Registers
0xc0000000 - 0xc1ffffff  N Y  DRAM Bank 0: 32Mb
0xe0000000 - 0xe7ffffff  Y Y  Cache Clean
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=ipaq
export ARCH_DIR=arm
export PLATFORM_DIR=sa11x0/ipaq
```

The names of configuration files are listed above with the description of the associated modes.

ARM/StrongARM(SA11X0) Intrinsyc CerfCube

Overview

RedBoot supports the serial port and the builtin ethernet connection for communication and downloads.

The default serial port settings are 38400,8,N,1. RedBoot runs from and supports flash management for the system flash region.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation

The original boot loader supplied with the CerfCube can be used to install RedBoot. Connect to the device using a serial port at 38400/8N1. Copy the binary RedBoot ROM mode image to an available TFTP server. Issue these commands to the Instrinsyc loader:

```
download tftp:x.x.x.x redboot_ROM.bin 0xc0000000
flashloader 0x00000000 0xc0000000 0x20000
```

where *x.x.x.x* is the IP address of the TFTP server.

> **NOTE:** Other installation methods may be available via the Intrinsyc loader. Contact Intrinsyc for details.

Additional commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the CerfCube are:

-b <*addr*>

Location Linux kernel was loaded to

-l <*len*>

Length of kernel

-c *"params"*

Parameters passed to kernel

-r <*addr*>

'initrd' ramdisk location

-s <*len*>

Length of initrd ramdisk

Memory Maps

RedBoot sets up the following memory map on the CerfCube: The first level page table is located at physical address 0xC0004000. No second level tables are used.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x01ffffff    16Mb to 32Mb FLASH (nCS0) [organized as below]
  0x000000 - 0x0001ffff      RedBoot
  0x020000 - 0x0003ffff      RedBoot [RAM version]
  0xfc0000 - 0x00fdffff      Fconfig data
  0xfe0000 - 0x00ffffff      FIS directory
0x0f000000 - 0x0fffffff    Onboard ethernet
0x10000000 - 0x17ffffff    CerfCube internal registers
0x20000000 - 0x3fffffff    PCMCIA / Compact Flash
0x80000000 - 0xbfffffff    SA-1110 Internal Registers
0xc0000000 - 0xc1ffffff    DRAM Bank 0 - 32Mb SDRAM
0xe0000000 - 0xe7ffffff    Cache Clean


Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x01ffffff  Y Y  DRAM - 32Mb
0x08000000 - 0x0fffffff  N N  Onboard ethernet controller
0x10000000 - 0x17ffffff  N N  CerfCube internal registers
0x20000000 - 0x3fffffff  N N  PCMCIA / Compact Flash
0x50000000 - 0x51ffffff  Y Y  Up to 32Mb FLASH (nCS0)
0x80000000 - 0xbfffffff  N N  SA-1110 Internal Registers
0xc0000000 - 0xc1ffffff  N Y  DRAM Bank 0: 32Mb
0xe0000000 - 0xe7ffffff  Y Y  Cache Clean
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=cerf
export ARCH_DIR=arm
export PLATFORM_DIR=sa11x0/cerf
```

The names of configuration files are listed above with the description of the associated modes.

ARM/Xscale Cyclone IQ80310

Overview

RedBoot supports both serial ports and the built-in ethernet port for communication and downloads. The default serial port settings are 115200,8,N,1. RedBoot also supports flash management for the onboard 8MB flash.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm
ROMA	[ROM]	RedBoot running from flash address 0x40000, with ARM bootloader in flash boot sector.	redboot_ROMA.ecm
RAMA	[RAM]	RedBoot running from RAM with ARM bootloader in flash boot sector.	redboot_RAMA.ecm

Initial Installation Method

The board manufacturer provides a DOS application which is capable of programming the flash over the PCI bus, and this is required for initial installations of RedBoot. Please see the board manual for information on using this utility. In general, the process involves programming one of the two flash based RedBoot images to flash. The ROM mode RedBoot (which runs from the flash boot sector) should be programmed to flash address 0x00000000. The ROMA RedBoot mode (which is started by the ARM bootloader) should be programmed to flash address 0x00004000.

To install RedBoot to run from the flash boot sector, use the manufacturer's flash utility to install the ROM mode image at address zero.

To install RedBoot to run from address 0x40000 with the ARM bootloader in the flash boot sector, use the manufacturer's flash utility to install the ROMA mode image at address 0x40000.

After booting the initial installation of RedBoot, this warning may be printed:

```
flash configuration checksum error or invalid key
```

This is normal, and indicates that the flash must be configured for use by RedBoot. Even if the above message is not printed, it may be a good idea to reinitialize the flash anyway. Do this with the **fis** command:

```
RedBoot> fis init
About to initialize [format] flash image system - continue (y/n)? y
*** Initialize flash Image System
Warning: device contents not erased, some blocks may not be usable
... Unlock from 0x007e0000-0x00800000: .
... Erase from 0x007e0000-0x00800000: .
... Program from 0xa1fd0000-0xa1fd0400 at 0x007e0000: .
... Lock from 0x007e0000-0x00800000: .
Followed by the fconfig command:
   RedBoot> fconfig
   Run script at boot: false
   Use BOOTP for network configuration: false
   Local IP address: 192.168.1.153
   Default server IP address: 192.168.1.10
   GDB connection port: 1000
   Network debug at boot time: false
   Update RedBoot non-volatile configuration - continue (y/n)? y
   ... Unlock from 0x007c0000-0x007e0000: .
   ... Erase from 0x007c0000-0x007e0000: .
   ... Program from 0xa0013018-0xa0013418 at 0x007c0000: .
   ... Lock from 0x007c0000-0x007e0000: .
```

Note: When later updating RedBoot in situ, it is important to use a matching ROM and RAM mode pair of images. So use either RAM/ROM or RAMA/ROMA images. Do not mix them.

Error codes

RedBoot uses the two digit LED display to indicate errors during board initialization. Possible error codes are:

88 - Unknown Error
55 - I2C Error
FF - SDRAM Error
01 - No Error

Using RedBoot with ARM Bootloader

RedBoot can coexist with ARM tools in flash on the IQ80310 board. In this configuration, the ARM bootloader will occupy the flash boot sector while RedBoot is located at flash address 0x40000. The sixteen position rotary switch is used to tell the ARM bootloader to jump to the RedBoot image located at address 0x40000. RedBoot is selected by switch position 0 or 1. Other switch positions are used by the ARM firmware and RedBoot will not be started.

Special RedBoot Commands

A special RedBoot command, **diag**, is used to access a set of hardware diagnostics provided by the board manufacturer. To access the diagnostic menu, enter diag at the RedBoot prompt:

```
RedBoot> diag
Entering Hardware Diagnostics - Disabling Data Cache!
1 - Memory Tests
2 - Repeating Memory Tests
3 - 16C552 DUART Serial Port Tests
4 - Rotary Switch S1 Test for positions 0-3
5 - seven Segment LED Tests
6 - Backplane Detection Test
7 - Battery Status Test
8 - External Timer Test
9 - i82559 Ethernet Configuration
10 - i82559 Ethernet Test
11 - Secondary PCI Bus Test
12 - Primary PCI Bus Test
13 - i960Rx/303 PCI Interrupt Test
14 - Internal Timer Test
15 - GPIO Test
0 - quit Enter the menu item number (0 to quit):
```

Tests for various hardware subsystems are provided, and some tests require special hardware in order to execute normally. The Ethernet Configuration item may be used to set the board ethernet address.

IQ80310 Hardware Tests

```
1 - Memory Tests
2 - Repeating Memory Tests
3 - 16C552 DUART Serial Port Tests
4 - Rotary Switch S1 Test for positions 0-3
5 - 7 Segment LED Tests
6 - Backplane Detection Test
7 - Battery Status Test
8 - External Timer Test
9 - i82559 Ethernet Configuration
10 - i82559 Ethernet Test
11 - i960Rx/303 PCI Interrupt Test
12 - Internal Timer Test
13 - Secondary PCI Bus Test
14 - Primary PCI Bus Test
```

```
15 - Battery Backup SDRAM Memory Test
16 - GPIO Test
17 - Repeat-On-Fail Memory Test
18 - Coyonosa Cache Loop (No return)
19 - Show Software and Hardware Revision
0 - quit
Enter the menu item number (0 to quit):
```

Tests for various hardware subsystems are provided, and some tests require special hardware in order to execute normally. The Ethernet Configuration item may be used to set the board ethernet address.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=iq80310
export ARCH_DIR=arm
export PLATFORM_DIR=iq80310
```

The names of configuration files are listed above with the description of the associated modes.

Interrupts

RedBoot uses an interrupt vector table which is located at address 0xA000A004. Entries in this table are pointers to functions with this protoype::

```
int irq_handler( unsigned vector, unsigned data )
```

On an IQ80310 board, the vector argument is one of 49 interrupts defined in `hal/arm/iq80310/current/include/hal_platform_ints.h`::

```
// *** 80200 CPU ***
#define CYGNUM_HAL_INTERRUPT_reserved0     0
#define CYGNUM_HAL_INTERRUPT_PMU_PMN0_OVFL 1 // See Ch.12 - Performance Mon.
#define CYGNUM_HAL_INTERRUPT_PMU_PMN1_OVFL 2 // PMU counter 0/1 overflow
#define CYGNUM_HAL_INTERRUPT_PMU_CCNT_OVFL 3 // PMU clock overflow
#define CYGNUM_HAL_INTERRUPT_BCU_INTERRUPT 4 // See Ch.11 - Bus Control Unit
#define CYGNUM_HAL_INTERRUPT_NIRQ          5 // external IRQ
#define CYGNUM_HAL_INTERRUPT_NFIQ          6 // external FIQ


// *** XINT6 interrupts ***
#define CYGNUM_HAL_INTERRUPT_DMA_0         7
#define CYGNUM_HAL_INTERRUPT_DMA_1         8
#define CYGNUM_HAL_INTERRUPT_DMA_2         9
#define CYGNUM_HAL_INTERRUPT_GTSC         10 // Global Time Stamp Counter
#define CYGNUM_HAL_INTERRUPT_PEC          11 // Performance Event Counter
#define CYGNUM_HAL_INTERRUPT_AAIP         12 // application accelerator unit
```

```
// *** XINT7 interrupts ***
// I2C interrupts
#define CYGNUM_HAL_INTERRUPT_I2C_TX_EMPTY 13
#define CYGNUM_HAL_INTERRUPT_I2C_RX_FULL  14
#define CYGNUM_HAL_INTERRUPT_I2C_BUS_ERR  15
#define CYGNUM_HAL_INTERRUPT_I2C_STOP     16
#define CYGNUM_HAL_INTERRUPT_I2C_LOSS     17
#define CYGNUM_HAL_INTERRUPT_I2C_ADDRESS  18


// Messaging Unit interrupts
#define CYGNUM_HAL_INTERRUPT_MESSAGE_0           19
#define CYGNUM_HAL_INTERRUPT_MESSAGE_1           20
#define CYGNUM_HAL_INTERRUPT_DOORBELL            21
#define CYGNUM_HAL_INTERRUPT_NMI_DOORBELL        22
#define CYGNUM_HAL_INTERRUPT_QUEUE_POST          23
#define CYGNUM_HAL_INTERRUPT_OUTBOUND_QUEUE_FULL 24
#define CYGNUM_HAL_INTERRUPT_INDEX_REGISTER      25
// PCI Address Translation Unit
#define CYGNUM_HAL_INTERRUPT_BIST                26


// *** External board interrupts (XINT3) ***
#define CYGNUM_HAL_INTERRUPT_TIMER        27 // external timer
#define CYGNUM_HAL_INTERRUPT_ETHERNET     28 // onboard enet
#define CYGNUM_HAL_INTERRUPT_SERIAL_A     29 // 16x50 uart A
#define CYGNUM_HAL_INTERRUPT_SERIAL_B     30 // 16x50 uart B
#define CYGNUM_HAL_INTERRUPT_PCI_S_INTD   31 // secondary PCI INTD
// The hardware doesn’t (yet?) provide masking or status for these
// even though they can trigger cpu interrupts. ISRs will need to
// poll the device to see if the device actually triggered the
// interrupt.
#define CYGNUM_HAL_INTERRUPT_PCI_S_INTC   32 // secondary PCI INTC
#define CYGNUM_HAL_INTERRUPT_PCI_S_INTB   33 // secondary PCI INTB
#define CYGNUM_HAL_INTERRUPT_PCI_S_INTA   34 // secondary PCI INTA


// *** NMI Interrupts go to FIQ ***
#define CYGNUM_HAL_INTERRUPT_MCU_ERR       35
#define CYGNUM_HAL_INTERRUPT_PATU_ERR      36
#define CYGNUM_HAL_INTERRUPT_SATU_ERR      37
#define CYGNUM_HAL_INTERRUPT_PBDG_ERR      38
#define CYGNUM_HAL_INTERRUPT_SBDG_ERR      39
#define CYGNUM_HAL_INTERRUPT_DMA0_ERR      40
#define CYGNUM_HAL_INTERRUPT_DMA1_ERR      41
#define CYGNUM_HAL_INTERRUPT_DMA2_ERR      42
#define CYGNUM_HAL_INTERRUPT_MU_ERR        43
#define CYGNUM_HAL_INTERRUPT_reserved52    44
#define CYGNUM_HAL_INTERRUPT_AAU_ERR       45
#define CYGNUM_HAL_INTERRUPT_BIU_ERR       46


// *** ATU FIQ sources ***
```

```
#define CYGNUM_HAL_INTERRUPT_P_SERR        47
#define CYGNUM_HAL_INTERRUPT_S_SERR        48
```

The data passed to the ISR is pulled from a data table (`hal_interrupt_data`) which immediately follows the interrupt vector table. With 49 interrupts, the data table starts at address 0xA000A0C8.

An application may create a normal C function with the above prototype to be an ISR. Just poke its address into the table at the correct index and enable the interrupt at its source. The return value of the ISR is ignored by RedBoot.

Memory Maps

The first level page table is located at 0xa0004000. Two second level tables are also used. One second level table is located at 0xa0008000 and maps the first 1MB of flash. The other second level table is at 0xa0008400, and maps the first 1MB of SDRAM.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x00000fff    flash Memory
0x00001000 - 0x00001fff    80312 Internal Registers
0x00002000 - 0x007fffff    flash Memory
0x00800000 - 0x7fffffff    PCI ATU Outbound Direct Window
0x80000000 - 0x83ffffff    Primary PCI 32-bit Memory
0x84000000 - 0x87ffffff    Primary PCI 64-bit Memory
0x88000000 - 0x8bffffff    Secondary PCI 32-bit Memory
0x8c000000 - 0x8fffffff    Secondary PCI 64-bit Memory
0x90000000 - 0x9000ffff    Primary PCI IO Space
0x90010000 - 0x9001ffff    Secondary PCI IO Space
0x90020000 - 0x9fffffff    Unused
0xa0000000 - 0xbfffffff    SDRAM
0xc0000000 - 0xefffffff    Unused
0xf0000000 - 0xffffffff    80200 Internal Registers


Virtual Address Range    C B  Description
-----------------------  - -  ----------------------------------
0x00000000 - 0x00000fff  Y Y  SDRAM
0x00001000 - 0x00001fff  N N  80312 Internal Registers
0x00002000 - 0x007fffff  Y N  flash Memory
0x00800000 - 0x7fffffff  N N  PCI ATU Outbound Direct Window
0x80000000 - 0x83ffffff  N N  Primary PCI 32-bit Memory
0x84000000 - 0x87ffffff  N N  Primary PCI 64-bit Memory
0x88000000 - 0x8bffffff  N N  Secondary PCI 32-bit Memory
0x8c000000 - 0x8fffffff  N N  Secondary PCI 64-bit Memory
0x90000000 - 0x9000ffff  N N  Primary PCI IO Space
0x90010000 - 0x9001ffff  N N  Secondary PCI IO Space
0xa0000000 - 0xbfffffff  Y Y  SDRAM
```

```
0xc0000000 - 0xcfffffff  Y Y  Cache Flush Region
0xd0000000 - 0xd0000fff  Y N  first 4k page of flash
0xf0000000 - 0xffffffff  N N  80200 Internal Registers
```

Platform Resource Usage

The external timer is used as a polled timer to provide timeout support for networking and XModem file transfers.

ARM/Xscale Intel IQ80321

Overview

RedBoot supports the serial port and the built-in ethernet port for communication and downloads. The default serial port settings are 115200,8,N,1. RedBoot also supports flash management for the onboard 8MB flash.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

The board manufacturer provides a DOS application which is capable of programming the flash over the PCI bus, and this is required for initial installations of RedBoot. Please see the board manual for information on using this utility. In general, the process involves programming the ROM mode RedBoot image to flash. RedBoot should be programmed to flash address 0x00000000 using the DOS utility.

After booting the initial installation of RedBoot, this warning may be printed:

```
flash configuration checksum error or invalid key
```

This is normal, and indicates that the flash must be configured for use by RedBoot. Even if the above message is not printed, it may be a good idea to reinitialize the flash anyway. Do this with the **fis** command:

```
RedBoot> fis init
About to initialize [format] FLASH image system - continue (y/n)? y
*** Initialize FLASH Image System
    Warning: device contents not erased, some blocks may not be usable
    ... Unlock from 0xf07e0000-0xf0800000: .
```

```
... Erase from 0xf07e0000-0xf0800000: .
... Program from 0x01ddf000-0x01ddf400 at 0xf07e0000: .
... Lock from 0xf07e0000-0xf0800000: .
```

Switch Settings

The 80321 board is highly configurable through a number of switches and jumpers. RedBoot makes some assumptions about board configuration and attention must be paid to these assumptions for reliable RedBoot operation:

- The onboard ethernet and the secondary slot may be placed in a private space so that they are not seen by a PC BIOS. If the board is to be used in a PC with BIOS, then the ethernet should be placed in this private space so that RedBoot and the BIOS do not conflict.
- RedBoot assumes that the board is plugged into a PC with BIOS. This requires RedBoot to detect when the BIOS has configured the PCI-X secondary bus. If the board is placed in a backplane, RedBoot will never see the BIOS configure the secondary bus. To prevent this wait, set switch S7E1-3 to ON when using the board in a backplane.
- For the remaining switch settings, the following is a known good configuration:

S1D1	All OFF
S7E1	7 is ON, all others OFF
S8E1	2,3,5,6 are ON, all others OFF
S8E2	2,3 are ON, all others OFF
S9E1	3 is ON, all others OFF
S4D1	1,3 are ON, all others OFF
J9E1	2,3 jumpered
J9F1	2,3 jumpered
J3F1	Nothing jumpered
J3G1	2,3 jumpered
J1G2	2,3 jumpered

LED Codes

RedBoot uses the two digit LED display to indicate status during board initialization. Possible codes are:

LED Actions

Power-On/Reset
88
Set the CPSR

Enable coprocessor access
Drain write and fill buffer
Setup PBIU chip selects

A1
: Enable the Icache

A2
: Move FLASH chip select from 0x0 to 0xF0000000
Jump to new FLASH location

A3
: Setup and enable the MMU

A4
: I2C interface initialization

90
: Wait for I2C initialization to complete

91
: Send address (via I2C) to the DIMM

92
: Wait for transmit complete

93
: Read SDRAM PD data from DIMM

94
: Read remainder of EEPROM data.
An error will result in one of the following
error codes on the LEDs:
77 BAD EEPROM checksum
55 I2C protocol error
FF bank size error

A5
: Setup DDR memory interface

A6
: Enable branch target buffer
Drain the write & fill buffers
Flush Icache, Dcache and BTB
Flush instuction and data TLBs
Drain the write & fill buffers

SL
: ECC Scrub Loop

SE

A7
: Clean, drain, flush the main Dcache

A8
: Clean, drain, flush the mini Dcache
Flush Dcache
Drain the write & fill buffers

A9
: Enable ECC

AA
: Save SDRAM size

Move MMU tables into RAM

AB

Clean, drain, flush the main Dcache
Clean, drain, flush the mini Dcache
Drain the write & fill buffers

AC

Set the TTB register to DRAM mmu_table

AD

Set mode to IRQ mode

A7

Move SWI & Undefined "vectors" to RAM (at 0x0)

A6

Switch to supervisor mode

A5

Move remaining "vectors" to RAM (at 0x0)

A4

Copy DATA to RAM
Initialize interrupt exception environment
Initialize stack
Clear BSS section

A3

Call platform specific hardware initialization

A2

Run through static constructors

A1

Start up the eCos kernel or RedBoot

Special RedBoot Commands

A special RedBoot command, **diag**, is used to access a set of hardware diagnostics. To access the diagnostic menu, enter **diag** at the RedBoot prompt:

```
RedBoot> diag
Entering Hardware Diagnostics - Disabling Data Cache!

  IQ80321 Hardware Tests

 1 - Memory Tests
 2 - Repeating Memory Tests
 3 - Repeat-On-Fail Memory Tests
 4 - Rotary Switch S1 Test
 5 - 7 Segment LED Tests
 6 - i82544 Ethernet Configuration
 7 - Baterry Status Test
 8 - Battery Backup SDRAM Memory Test
 9 - Timer Test
10 - PCI Bus test
11 - CPU Cache Loop (No Return)
 0 - quit
```

```
Enter the menu item number (0 to quit):
```

Tests for various hardware subsystems are provided, and some tests require special hardware in order to execute normally. The Ethernet Configuration item may be used to set the board ethernet address.

Memory Tests

This test is used to test installed DDR SDRAM memory. Five different tests are run over the given address ranges. If errors are encountered, the test is aborted and information about the failure is printed. When selected, the user will be prompted to enter the base address of the test range and its size. The numbers must be in hex with no leading "0x"

```
Enter the menu item number (0 to quit): 1

Base address of memory to test (in hex): 100000

Size of memory to test (in hex): 200000

Testing memory from 0x00100000 to 0x002fffff.

Walking 1's test:
0000000100000002000000040000000800000010000000200000004000000080
0000010000000200000004000000080000001000000020000000400000008000
0001000000020000000400000008000000100000002000000040000000800000
0100000002000000040000000800000010000000200000004000000080000000
passed
32-bit address test: passed
32-bit address bar test: passed
8-bit address test: passed
Byte address bar test: passed
Memory test done.
```

Repeating Memory Tests

The repeating memory tests are exactly the same as the above memory tests, except that the tests are automatically rerun after completion. The only way out of this test is to reset the board.

Repeat-On-Fail Memory Tests

This is similar to the repeating memory tests except that when an error is found, the failing test continuously retries on the failing address.

Rotary Switch S1 Test

This tests the operation of the sixteen position rotary switch. When run, this test will display the current position of the rotary switch on the LED display. Slowly dial through each position and confirm reading on LED.

7 Segment LED Tests

This tests the operation of the seven segment displays. When run, each LED cycles through 0 through F and a decimal point.

i82544 Ethernet Configuration

This test initializes the ethernet controller's serial EEPROM if the current contents are invalid. In any case, this test will also allow the user to enter a six byte ethernet MAC address into the serial EEPROM.

```
Enter the menu item number (0 to quit): 6


Current MAC address: 00:80:4d:46:00:02
Enter desired MAC address: 00:80:4d:46:00:01
Writing to the Serial EEPROM... Done

******** Reset The Board To Have Changes Take Effect ********
```

Battery Status Test

This tests the current status of the battery. First, the test checks to see if the battery is installed and reports that finding. If the battery is installed, the test further determines whether the battery status is one or more of the following:

- Battery is charging.
- Battery is fully discharged.
- Battery voltage measures within normal operating range.

Battery Backup SDRAM Memory Test

This tests the battery backup of SDRAM memory. This test is a three step process:

1. Select Battery backup test from main diag menu, then write data to SDRAM.
2. Turn off power for 60 seconds, then repower the board.
3. Select Battery backup test from main diag menu, then check data that was written in step 1.

Timer Test

This tests the internal timer by printing a number of dots at one second intervals.

PCI Bus Test

This tests the secondary PCI-X bus and socket. This test requires that an IQ80310 board be plugged into the secondary slot of the IOP80321 board. The test assumes at least 32MB of installed memory on the IQ80310. That memory is mapped into the IOP80321 address space and the memory tests are run on that memory.

CPU Cache Loop

This test puts the CPU into a tight loop run entirely from the ICache. This should prevent all external bus accesses.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=iq80321
export ARCH_DIR=arm
export PLATFORM_DIR=xscale/iq80321
```

The names of configuration files are listed above with the description of the associated modes.

Interrupts

RedBoot uses an interrupt vector table which is located at address 0x8004. Entries in this table are pointers to functions with this protoype::

```
int irq_handler( unsigned vector, unsigned data )
```

On an IQ80321 board, the vector argument is one of 32 interrupts defined in `hal/arm/xscale/verde/current/include/hal_var_ints.h`::

```
// *** 80200 CPU ***
#define CYGNUM_HAL_INTERRUPT_DMA0_EOT      0
#define CYGNUM_HAL_INTERRUPT_DMA0_EOC      1
#define CYGNUM_HAL_INTERRUPT_DMA1_EOT      2
#define CYGNUM_HAL_INTERRUPT_DMA1_EOC      3
#define CYGNUM_HAL_INTERRUPT_RSVD_4        4
#define CYGNUM_HAL_INTERRUPT_RSVD_5        5
#define CYGNUM_HAL_INTERRUPT_AA_EOT        6
#define CYGNUM_HAL_INTERRUPT_AA_EOC        7
#define CYGNUM_HAL_INTERRUPT_CORE_PMON     8
#define CYGNUM_HAL_INTERRUPT_TIMER0        9
#define CYGNUM_HAL_INTERRUPT_TIMER1        10
#define CYGNUM_HAL_INTERRUPT_I2C_0         11
#define CYGNUM_HAL_INTERRUPT_I2C_1         12
#define CYGNUM_HAL_INTERRUPT_MESSAGING     13
#define CYGNUM_HAL_INTERRUPT_ATU_BIST      14
#define CYGNUM_HAL_INTERRUPT_PERFMON       15
#define CYGNUM_HAL_INTERRUPT_CORE_PMU      16
```

```
#define CYGNUM_HAL_INTERRUPT_BIU_ERR       17
#define CYGNUM_HAL_INTERRUPT_ATU_ERR       18
#define CYGNUM_HAL_INTERRUPT_MCU_ERR       19
#define CYGNUM_HAL_INTERRUPT_DMA0_ERR      20
#define CYGNUM_HAL_INTERRUPT_DMA1_ERR      22
#define CYGNUM_HAL_INTERRUPT_AA_ERR        23
#define CYGNUM_HAL_INTERRUPT_MSG_ERR       24
#define CYGNUM_HAL_INTERRUPT_SSP           25
#define CYGNUM_HAL_INTERRUPT_RSVD_26       26
#define CYGNUM_HAL_INTERRUPT_XINT0         27
#define CYGNUM_HAL_INTERRUPT_XINT1         28
#define CYGNUM_HAL_INTERRUPT_XINT2         29
#define CYGNUM_HAL_INTERRUPT_XINT3         30
#define CYGNUM_HAL_INTERRUPT_HPI           31
```

The data passed to the ISR is pulled from a data table (`hal_interrupt_data`) which immediately follows the interrupt vector table. With 32 interrupts, the data table starts at address 0x8084.

An application may create a normal C function with the above prototype to be an ISR. Just poke its address into the table at the correct index and enable the interrupt at its source. The return value of the ISR is ignored by RedBoot.

Memory Maps

The RAM based page table is located at RAM start + 0x4000. RedBoot may be configured for one of two memory maps. The difference between them is the location of RAM and the PCI outbound windows. The alternative memory map may be used when building RedBoot or eCos by using the `RAM_ALTMAP` and `ROM_ALTMAP` startup types in the configuration.

> **NOTE:** 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

Physical Address Range     Description
-----------------------    ----------------------------------
0x00000000 - 0x7fffffff    ATU Outbound Direct Window
0x80000000 - 0x900fffff    ATU Outbound Translate Windows
0xa0000000 - 0xbfffffff    SDRAM
0xf0000000 - 0xf0800000    FLASH               (PBIU CS0)
0xfe800000 - 0xfe800fff    UART                (PBIU CS1)
```

```
0xfe840000 - 0xfe840fff    Left 7-segment LED  (PBIU CS3)
0xfe850000 - 0xfe850fff    Right 7-segment LED (PBIU CS2)
0xfe8d0000 - 0xfe8d0fff    Rotary Switch       (PBIU CS4)
0xfe8f0000 - 0xfe8f0fff    Baterry Status      (PBIU CS5)
0xfff00000 - 0xffffffff    Verde Memory mapped Registers


Default Virtual Map      X C B  Description
-----------------------  - - -  ----------------------------------
0x00000000 - 0x1fffffff  1 1 1  SDRAM
0x20000000 - 0x9fffffff  0 0 0  ATU Outbound Direct Window
0xa0000000 - 0xb00fffff  0 0 0  ATU Outbound Translate Windows
0xc0000000 - 0xdfffffff  0 0 0  Uncached alias for SDRAM
0xe0000000 - 0xe00fffff  1 1 1  Cache flush region (no phys mem)
0xf0000000 - 0xf0800000  0 1 0  FLASH               (PBIU CS0)
0xfe800000 - 0xfe800fff  0 0 0  UART                (PBIU CS1)
0xfe840000 - 0xfe840fff  0 0 0  Left 7-segment LED  (PBIU CS3)
0xfe850000 - 0xfe850fff  0 0 0  Right 7-segment LED (PBIU CS2)
0xfe8d0000 - 0xfe8d0fff  0 0 0  Rotary Switch       (PBIU CS4)
0xfe8f0000 - 0xfe8f0fff  0 0 0  Baterry Status      (PBIU CS5)
0xfff00000 - 0xffffffff  0 0 0  Verde Memory mapped Registers

Alternate Virtual Map    X C B  Description
-----------------------  - - -  ----------------------------------
0x00000000 - 0x000fffff  1 1 1  Alias for 1st MB of SDRAM
0x00100000 - 0x7fffffff  0 0 0  ATU Outbound Direct Window
0x80000000 - 0x900fffff  0 0 0  ATU Outbound Translate Windows
0xa0000000 - 0xbfffffff  1 1 1  SDRAM
0xc0000000 - 0xdfffffff  0 0 0  Uncached alias for SDRAM
0xe0000000 - 0xe00fffff  1 1 1  Cache flush region (no phys mem)
0xf0000000 - 0xf0800000  0 1 0  FLASH               (PBIU CS0)
0xfe800000 - 0xfe800fff  0 0 0  UART                (PBIU CS1)
0xfe840000 - 0xfe840fff  0 0 0  Left 7-segment LED  (PBIU CS3)
0xfe850000 - 0xfe850fff  0 0 0  Right 7-segment LED (PBIU CS2)
0xfe8d0000 - 0xfe8d0fff  0 0 0  Rotary Switch       (PBIU CS4)
0xfe8f0000 - 0xfe8f0fff  0 0 0  Baterry Status      (PBIU CS5)
0xfff00000 - 0xffffffff  0 0 0  Verde Memory mapped Registers
```

Platform Resource Usage

The Verde programmable timer0 is used for timeout support for networking and XModem file transfers.

CalmRISC/CalmRISC16 Samsung CalmRISC16 Core Evaluation Board

Overview

The Samsung CalmRISC16 evaluation platform consists of two boards connected by a ribbon cable. One board contains the CPU core and memory. The other board is called the MDSChip board and provides the host interface.

The calmRISC16 is a harvard architecture with separate 22-bit program and data addresses. The instruction set provides no instruction for writing to program memory. The MDSChip board firmware (called CalmBreaker) provides a pseudo register interface so that code running on the core has access to a serial channel and a mechanism to write to program memory. The serial channel is fixed at 57600-8-N-1 by the firmware. The CalmBreaker firmware also provides a serial protocol which allows a host to download a program and to start or stop the core board.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running via the MDSChip board.	redboot_ROM.ecm

Initial Installation Method

The CalmRISC16 core is controlled through the MDSChip board. There is no non-volatile storage available for RedBoot, so RedBoot must be downloaded to the board on every power cycle. A small utility program is used to download S-record files to the eval board. Sources and build instructions for this utility are located in the RedBoot sources in: `packages/hal/calmrisc16/ceb/current/support`

To download the RedBoot image, first press the reset button on the MDSChip board. The green ’Run’ LED on the core board should go off. Now, use the utility to download the RedBoot image with:

```
$ calmbreaker -p /dev/term/b --reset --srec-code -f redboot.elf
```

Note that the ’-p /dev/term/b’ specifies the serial port to use and will vary from system to system. The download will take about two minutes. After it finishes, start RedBoot with:

```
$ calmbreaker -p /dev/term/b --run
```

The ’Run’ LED on the core board should be on. Connecting to the MDSboard with a terminal and typing enter should result in RedBoot reprinting the command prompt.

Special RedBoot Commands

None.

Special Note on Serial Channel

The MDSChip board uses a relatively slow microcontroller to provide the pseudo-register interface to the core board. This pseudo-register interface provides access to the serial channel and write access to program memory. Those interfaces are slow and the serial channel is easily overrun by a fast host. For this reason, GDB must be told to limit the size of code download packets to avoid serial overrun. This is done with the following GDB command:

```
(gdb) set download-write-size 25
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=calm16_ceb
export ARCH_DIR=calmrisc16
export PLATFORM_DIR=ceb
```

The names of configuration files are listed above with the description of the associated modes.

CalmRISC/CalmRISC32 Samsung CalmRISC32 Core Evaluation Board

Overview

The Samsung CalmRISC32 evaluation platform consists of two boards connected by a ribbon cable. One board contains the CPU core and memory. The other board is called the MDSChip board and provides the host interface. The calmRISC32 is a harvard architecture with separate 32-bit program and data addresses. The instruction set provides no instruction for writing to program memory. The MDSChip board firmware (called CalmBreaker) provides a pseudo register interface so that code running on the core has access to a serial channel and a mechanism to write to program memory. The serial channel is fixed at 57600-8-N-1 by the firmware. The CalmBreaker firmware also provides a serial protocol which allows a host to download a program and to start or stop the core board.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running via the MDSChip board.	redboot_ROM.ecm

Initial Installation Method

The calmRISC32 core is controlled through the MDSChip board. There is no non-volatile storage available for RedBoot, so RedBoot must be downloaded to the board on every power cycle. A small utility program is used to download S-record files to the eval board. Sources and build instructions for this utility are located in the RedBoot sources in: `packages/hal/calmrisc32/ceb/current/support`

To download the RedBoot image, first press the reset button on the MDSChip board. The green ’Run’ LED on the core board should go off. Now, use the utility to download the RedBoot image with:

```
$ calmbreaker -p /dev/term/b --reset --srec-code -f redboot.elf
```

Note that the ’-p /dev/term/b’ specifies the serial port to use and will vary from system to syetm. The download will take about two minutes. After it finishes, start RedBoot with:

```
$ calmbreaker -p /dev/term/b --run
```

The 'Run' LED on the core board should be on. Connecting to the MDSboard with a terminal and typing enter should result in RedBoot reprinting the command prompt.

Special RedBoot Commands

None.

Special Note on Serial Channel

The MDSChip board uses a relatively slow microcontroller to provide the pseudo-register interface to the core board. This pseudo-register interface provides access to the serial channel and write access to program memory. Those interfaces are slow and the serial channel is easily overrun by a fast host. For this reason, GDB must be told to limit the size of code download packets to avoid serial overrun. This is done with the following GDB command:

```
(gdb) set download-write-size 25
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=calm32_ceb
export ARCH_DIR=calmrisc32
export PLATFORM_DIR=ceb
```

The names of configuration files are listed above with the description of the associated modes.

FRV/FRV400 Fujitsu FR-V 400 (MB-93091)

Overview

RedBoot supports both serial ports, which are available via the stacked serial connectors on the mother board. The topmost port is the default and is considered to be port 0 by RedBoot. The bottommost port is serial port 1. The default serial port settings are 38400,8,N,1.

FLASH management is also supported, but only for the FLASH device in IC7. This arrangement allows for IC8 to retain either the original Fujitsu board firmware, or some application specific contents.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File

Configuration	Mode	Description	File
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector.	redboot_ROMRAM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

RedBoot can be installed by directly programming the FLASH device in IC7 or by using the Fujitsu provided software to download and install a version into the FLASH device. Complete instructions are provided separately.

Special RedBoot Commands

None.

Memory Maps

The memory map of this platform is fixed by the hardware (cannot be changed by software). The only attributes which can be modified are control over cacheability, as noted below.

```
Address                 Cache?      Resource
00000000-03EFFFFF         Yes       SDRAM (via plugin DIMM)
03F00000-03FFFFFF         No        SDRAM (used for PCI window)
10000000-1FFFFFFF         No        MB86943 PCI bridge
20000000-201FFFFF         No        SRAM
21000000-23FFFFFF         No        Motherboard resources
24000000-25FFFFFF         No        PCI I/O space
26000000-2FFFFFFF         No        PCI Memory space
30000000-FDFFFFFF         ??        Unused
FE000000-FEFFFFFF         No        I/O devices
FF000000-FF1FFFFF         No        IC7 - RedBoot FLASH
FF200000-FF3FFFFF         No        IC8 - unused FLASH
FF400000-FFFFFFFF         No        Misc other I/O
```

> **NOTE:** The only configuration currently suppored requires a 64MB SDRAM DIMM to be present on the CPU card. No other memory configuration is supported at this time.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=frv400
export ARCH_DIR=frv
export PLATFORM_DIR=frv400
```

The names of configuration files are listed above with the description of the associated modes.

IA32/x86 x86-Based PC

Overview

RedBoot supports two serial ports and an Intel i82559 based ethernet card (for example an Intel EtherExpress Pro 10/100) for communication and downloads. The default serial port settings are 38400,8,N,1.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
Floppy	[Floppy]	RedBoot running from a boot floppy disk installed in the A: drive of the PC.	redboot_ROM.ecm

Initial Installation

RedBoot takes the form of a self-booting image that must be written onto a formatted floppy disk. The process will erase any file system or data that already exists on that disk, so proceed with caution.

For Red Hat Linux users, this can be done by:

```
$ dd conv=sync if=install/bin/redboot.bin of=/dev/fd0H1440
```

For NT Cygwin users, this can be done by first ensuring that the raw floppy device is mounted as `/dev/fd0`. To check if this is the case, type the command **mount** at the Cygwin bash prompt. If the floppy drive is already mounted, it will be listed as something similar to the following line:

```
  \\.\a: /dev/fd0 user binmode
```

If this line is not listed, then mount the floppy drive using the command:

```
$ mount -f -b //./a: /dev/fd0
```

To actually install the boot image on the floppy, use the command:

```
$ dd conv=sync if=install/bin/redboot.bin of=/dev/fd0
```

Insert this floppy in the A: drive of the PC to be used as a target and ensure that the BIOS is configured to boot from A: by default. On reset, the PC will boot from the floppy and be ready to be debugged via either serial line, or via the ethernet interface if it is installed.

> **NOTE:** Unreliable floppy media may cause the write to silently fail. This can be determined if the RedBoot image does not correctly boot. In such cases, the floppy should be (unconditionally) reformatted using the **fdformat** command on Linux, or **format a: /u** on DOS/Windows.

Flash management

PC RedBoot does not support any FLASH commands.

Special RedBoot Commands

None.

Memory Maps

All selectors are initialized to map the entire 32-bit address space in the familiar protected mode flat model. Page translation is not used. RAM up to 640K is mapped to 0x0 to 0xa0000. RAM above 640K is mapped from address 0x100000 upwards. Space is reserved between 0xa0000 and 0x100000 for option ROMs and the BIOS.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=pc
export ARCH_DIR=i386
export PLATFORM_DIR=pc
```

The names of configuration files are listed above with the description of the associated modes.

MIPS/MIPS32(CoreLV 4Kc)+MIPS64(CoreLV 5Kc) Atlas Board

Overview

RedBoot supports the DgbSer serial port and the built in ethernet port for communication and downloads. The default serial port settings are 115200,8,N,1. RedBoot runs from and supports flash management for the system flash region.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation

RedBoot is installed using the code download facility built into the Atlas board. See the Atlas User manual for details, and also the Atlas download format in the Section called *Atlas download format*.

Quick download instructions

Here are quick start instructions for downloading the prebuilt RedBoot image.

1. Locate the prebuilt files in the bin directory: `deleteall.dl` and `redboot.dl`.
2. Make sure switch S1-1 is OFF and switch S5-1 is ON. Reset the board and verify that the LED display reads `Flash DL`.
3. Make sure your parallel port is connected to the 1284 port Of the Atlas board.
4. Send the `deleteall.dl` file to the parallel port to erase previous images:

   ```
   $ cat deleteall.dl >/dev/lp0
   ```

   When this is complete, the LED display should read `Deleted`.
5. Send the ROM mode RedBoot image to the board:

   ```
   $ cat redboot.dl >/dev/lp0
   ```

   When this is complete, the LED display should show the last address programmed. This will be something like: `1fc17000`.
6. Change switch S5-1 to OFF and reset the board. The LED display should read `RedBoot`.
7. Run the RedBoot **fis init** and **fconfig** commands to initialize the flash. See the Section called *Additional config options*, the Section called *Flash Image System (FIS)* in Chapter 2 and the Section called *Persistent State Flash-based Configuration and Control* in Chapter 2 for details.

Atlas download format

In order to download RedBoot to the Atlas board, it must be converted to the Atlas download format. There are different ways of doing this depending on which version of the developer's kit is shipped with the board.

The *Atlas Developer's Kit* CD contains an srec2flash utility. The source code for this utility is part of the `yamon/yamon-src-01.01.tar.gz` tarball on the Dev Kit CD. The path in the expanded tarball is `yamon/bin/tools`. To use srec2flash to convert the S-record file:

```
$ srec2flash -EL -S29 redboot.srec >redboot.dl
```

The *Atlas/Malta Developer's Kit* CD contains an srecconv.pl utility which requires Perl. This utilty is part of the `yamon/yamon-src-02.00.tar.gz` tarball on the Dev Kit CD. The path in the expanded tarball is `yamon/bin/tools`. To use srecconv to convert the S-record file:

```
$ cp redboot_ROM.srec redboot_ROM.rec
$ srecconv.pl -ES L -A 29 redboot_ROM
```

The resulting file is named `redboot_ROM.fl`.

Flash management

Additional config options

The ethernet MAC address is stored in flash manually using the **fconfig** command. You can use the YAMON **setenv ethaddr** command to print out the board ethernet address. Typically, it is:

`00:0d:a0:00:`*`xx:xx`*

where *`xx.xx`* is the hex representation of the board serial number.

Additional commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this architecture (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for MIPS boards are:

-b <*`addr`*>

Location to store command line and environment passed to kernel

-w <*`time`*>

Wait time in seconds before starting kernel

-c *`"params"`*

Parameters passed to kernel

<*`addr`*>

Kernel entry point, defaulting to the entry point of the last image loaded

Linux kernels on MIPS platforms expect the entry point to be called with arguments in the registers equivalent to a C call with prototype:

```
void Linux(int argc, char **argv, char **envp);
```

RedBoot will place the appropriate data at the offset specified by the `-b` parameter, or by default at address 0x80080000, and will set the arguments accordingly when calling into the kernel.

The default entry point, if no image with explicit entry point has been loaded and none is specified, is 0x80000750.

Interrupts

RedBoot uses an interrupt vector table which is located at address 0x80000400. Entries in this table are pointers to functions with this protoype:

```
int irq_handler( unsigned vector, unsigned data )
```

On an atlas board, the vector argument is one of 25 interrupts defined in `hal/mips/atlas/VERSION/include/plf_intr.h`:

```
#define CYGNUM_HAL_INTERRUPT_SER                 0
#define CYGNUM_HAL_INTERRUPT_TIM0                1
#define CYGNUM_HAL_INTERRUPT_2                   2
#define CYGNUM_HAL_INTERRUPT_3                   3
#define CYGNUM_HAL_INTERRUPT_RTC                 4
#define CYGNUM_HAL_INTERRUPT_COREHI              5
#define CYGNUM_HAL_INTERRUPT_CORELO              6
#define CYGNUM_HAL_INTERRUPT_7                   7
#define CYGNUM_HAL_INTERRUPT_PCIA                8
#define CYGNUM_HAL_INTERRUPT_PCIB                9
#define CYGNUM_HAL_INTERRUPT_PCIC               10
#define CYGNUM_HAL_INTERRUPT_PCID               11
#define CYGNUM_HAL_INTERRUPT_ENUM               12
#define CYGNUM_HAL_INTERRUPT_DEG                13
#define CYGNUM_HAL_INTERRUPT_ATXFAIL            14
#define CYGNUM_HAL_INTERRUPT_INTA               15
#define CYGNUM_HAL_INTERRUPT_INTB               16
#define CYGNUM_HAL_INTERRUPT_INTC               17
#define CYGNUM_HAL_INTERRUPT_INTD               18
#define CYGNUM_HAL_INTERRUPT_SERR               19
#define CYGNUM_HAL_INTERRUPT_HW1                20
#define CYGNUM_HAL_INTERRUPT_HW2                21
#define CYGNUM_HAL_INTERRUPT_HW3                22
#define CYGNUM_HAL_INTERRUPT_HW4                23
#define CYGNUM_HAL_INTERRUPT_HW5                24
```

The data passed to the ISR is pulled from a data table (`hal_interrupt_data`) which immediately follows the interrupt vector table. With 25 interrupts, the data table starts at address 0x80000464 on atlas.

An application may create a normal C function with the above prototype to be an ISR. Just poke its address into the table at the correct index and enable the interrupt at its source. The return value of the ISR is ignored by RedBoot.

Memory Maps

Memory Maps RedBoot sets up the following memory map on the Atlas board.

```
Physical Address Range Description
----------------------- -------------
0x00000000 - 0x07ffffff SDRAM
0x08000000 - 0x17ffffff PCI Memory Space
0x18000000 - 0x1bdfffff PCI I/O Space
0x1be00000 - 0x1bffffff System Controller
0x1c000000 - 0x1dffffff System flash
0x1e000000 - 0x1e3fffff Monitor flash
0x1f000000 - 0x1fbfffff FPGA
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=atlas_mips32_4kc
export TARGET=atlas_mips64_5kc
export ARCH_DIR=mips
export PLATFORM_DIR=atlas
```

Use one of the TARGET settings only.

The names of configuration files are listed above with the description of the associated modes.

MIPS/MIPS32(CoreLV 4Kc)+MIPS64(CoreLV 5Kc) Malta Board

Overview

RedBoot supports both front facing serial ports and the built in ethernet port for communication and downloads. The default serial port settings are 38400,8,N,1. RedBoot runs from and supports flash management for the system flash region.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation

RedBoot is installed using the code download facility built into the Malta board. See the Malta User manual for details, and also the Malta download format in the Section called *Malta download format*.

Quick download instructions

Here are quick start instructions for downloading the prebuilt RedBoot image.

1. Locate the prebuilt files in the bin directory: `deleteall.fl` and `redboot_ROM.fl`.
2. Make sure switch S5-1 is ON. Reset the board and verify that the LED display reads `Flash DL`.
3. Make sure your parallel port is connected to the 1284 port Of the Atlas board.
4. Send the `deleteall.fl` file to the parallel port to erase previous images:

   ```
   $ cat deleteall.fl >/dev/lp0
   ```

   When this is complete, the LED display should read `Deleted`.
5. Send the RedBoot image to the board:

   ```
   $ cat redboot_ROM.fl >/dev/lp0
   ```

   When this is complete, the LED display should show the last address programmed. This will be something like: `1fc17000`.
6. Change switch S5-1 to OFF and reset the board. The LED display should read `RedBoot`.
7. Run the RedBoot **fis init** and **fconfig** commands to initialize the flash. See the Section called *Flash Image System (FIS)* in Chapter 2 and the Section called *Persistent State Flash-based Configuration and Control* in Chapter 2 for details.

Malta download format

In order to download RedBoot to the Malta board, it must be converted to the Malta download format.

The *Atlas/Malta Developer's Kit* CD contains an srecconv.pl utility which requires Perl. This utility is part of the `yamon/yamon-src-02.00.tar.gz` tarball on the Dev Kit CD. The path in the expanded tarball is `yamon/bin/tools`. To use srecconv to convert the S-record file:

```
$ cp redboot_ROM.srec redboot_ROM.rec
$ srecconv.pl -ES L -A 29 redboot_ROM
```

The resulting file is named `redboot_ROM.fl`.

Additional commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this architecture (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for MIPS boards are:

-b <*addr*>

Location to store command line and environment passed to kernel

-w <*time*>

Wait time in seconds before starting kernel

-c *"params"*

Parameters passed to kernel

<*addr*>

Kernel entry point, defaulting to the entry point of the last image loaded

Linux kernels on MIPS platforms expect the entry point to be called with arguments in the registers equivalent to a C call with prototype:

```
void Linux(int argc, char **argv, char **envp);
```

RedBoot will place the appropriate data at the offset specified by the *-b* parameter, or by default at address 0x80080000, and will set the arguments accordingly when calling into the kernel.

The default entry point, if no image with explicit entry point has been loaded and none is specified, is 0x80000750.

Interrupts

RedBoot uses an interrupt vector table which is located at address 0x80000200. Entries in this table are pointers to functions with this protoype:

```
int irq_handler( unsigned vector, unsigned data )
```

On the malta board, the vector argument is one of 22 interrupts defined in `hal/mips/malta/`*`VERSION`*`/include/plf_intr.h`:

```
#define CYGNUM_HAL_INTERRUPT_SOUTH_BRIDGE_INTR   0
#define CYGNUM_HAL_INTERRUPT_SOUTH_BRIDGE_SMI    1
#define CYGNUM_HAL_INTERRUPT_CBUS_UART           2
#define CYGNUM_HAL_INTERRUPT_COREHI              3
#define CYGNUM_HAL_INTERRUPT_CORELO              4
#define CYGNUM_HAL_INTERRUPT_COMPARE             5
#define CYGNUM_HAL_INTERRUPT_TIMER               6
#define CYGNUM_HAL_INTERRUPT_KEYBOARD            7
#define CYGNUM_HAL_INTERRUPT_CASCADE             8
#define CYGNUM_HAL_INTERRUPT_TTY1                9
#define CYGNUM_HAL_INTERRUPT_TTY0               10
#define CYGNUM_HAL_INTERRUPT_11                 11
#define CYGNUM_HAL_INTERRUPT_FLOPPY             12
#define CYGNUM_HAL_INTERRUPT_PARALLEL           13
#define CYGNUM_HAL_INTERRUPT_REAL_TIME_CLOCK    14
#define CYGNUM_HAL_INTERRUPT_I2C                15
#define CYGNUM_HAL_INTERRUPT_PCI_AB             16
#define CYGNUM_HAL_INTERRUPT_PCI_CD             17
```

```
#define CYGNUM_HAL_INTERRUPT_MOUSE              18
#define CYGNUM_HAL_INTERRUPT_19                 19
#define CYGNUM_HAL_INTERRUPT_IDE_PRIMARY        20
#define CYGNUM_HAL_INTERRUPT_IDE_SECONDARY      21
```

The data passed to the ISR is pulled from a data table (`hal_interrupt_data`) which immediately follows the interrupt vector table. With 22 interrupts, the data table starts at address 0x80000258.

An application may create a normal C function with the above prototype to be an ISR. Just poke its address into the table at the correct index and enable the interrupt at its source. The return value of the ISR is ignored by RedBoot.

Memory Maps

Memory Maps RedBoot sets up the following memory map on the Malta board.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range  C B  Description
----------------------- - -  -----------
0x80000000 - 0x81ffffff Y Y  SDRAM
0x9e000000 - 0x9e3fffff Y N  System flash (cached)
0x9fc00000 - 0x9fffffff Y N  System flash (mirrored)
0xa8000000 - 0xb7ffffff N N  PCI Memory Space
0xb4000000 - 0xb40fffff N N  Galileo System Controller
0xb8000000 - 0xb80fffff N N  Southbridge / ISA
0xb8100000 - 0xbbdfffff N N  PCI I/O Space
0xbe000000 - 0xbe3fffff N N  System flash (noncached)
0xbf000000 - 0xbfffffff N N  Board logic FPGA
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=malta_mips32_4kc
export ARCH_DIR=mips
export PLATFORM_DIR=malta
```

The names of configuration files are listed above with the description of the associated modes.

MIPS/RM7000 PMC-Sierra Ocelot

Overview

RedBoot uses the front facing serial port. The default serial port settings are 38400,8,N,1. RedBoot also supports ethernet. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Additional commands

The **exec** command which allows the loading and execution of Linux kernels, is supported for this architecture (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for MIPS boards are:

-b <*addr*>

Location to store command line and environment passed to kernel

-w <*time*>

Wait time in seconds before starting kernel

-c *"params"*

Parameters passed to kernel

<*addr*>

Kernel entry point, defaulting to the entry point of the last image loaded

Linux kernels on MIPS platforms expect the entry point to be called with arguments in the registers equivalent to a C call with prototype:

```
void Linux(int argc, char **argv, char **envp);
```

RedBoot will place the appropriate data at the offset specified by the *-b* parameter, or by default at address 0x80080000, and will set the arguments accordingly when calling into the kernel.

The default entry point, if no image with explicit entry point has been loaded and none is specified, is 0x80000750.

Memory Maps

RedBoot sets up the following memory map on the Ocelot board.

Note that these addresses are accessed through kseg0/1 and thus translate to the actual address range 0x80000000-0xbfffffff, depending on the need for caching/non-caching access to the bus.

> **NOTE:** The virtual memory maps in this section use a C and B column to indicate whether or not the region is cached (C) or buffered (B).

```
Physical Address Range Description
----------------------- -----------
0x00000000 - 0x0fffffff SDRAM
0x10000000 - 0x10ffffff PCI I/O space
0x12000000 - 0x13ffffff PCI Memory space
0x14000000 - 0x1400ffff Galileo system controller
0x1c000000 - 0x1c0000ff PLD (board logic)
0x1fc00000 - 0x1fc7ffff flash
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=ocelot
export ARCH_DIR=mips
export PLATFORM_DIR=rm7000/ocelot
```

The names of configuration files are listed above with the description of the associated modes.

MIPS/VR4375 NEC DDB-VRC4375

Overview

RedBoot supports only serial port 1, which is connected to the upper of the stacked serial connectors on the board. The default serial port settings are 38400,8,N,1. FLASH management is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector.	redboot_ROMRAM.ecm

Configuration	Mode	Description	File
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

A device programmer should be used to program a socketed FLASH part (AMD 29F040). The board as delivered is configured for a 512K EPROM. To install a FLASH ROM, Jumpers J30, J31 and J36 need to be changed as described in the board's User Manual.

Special RedBoot Commands

None.

Memory Maps

RedBoot sets up the memory map primarily as described in the board's User Manual. There are some minor differences, noted in the following table:

```
Physical                Virtual                 Resource
Addresses               Addresses
00000000-01FFFFFF       80000000-81FFFFFF       Base SDRAM (cached)
00000000-01FFFFFF       A0000000-A1FFFFFF       Base SDRAM (uncached)
0C000000-0C0BFFFF       AC000000-AC0B0000       PCI IO space
0F000000-0F0001FF       AF000000-AF0001FF       VRC4375 Registers
1C000000-1C0FFFFF       BC000000-BC0FFFFF       VRC4372 Registers
1C100000-1DFFFFFF       BC100000-BDFFFFFF       PCI Memory space
1FC00000-1FC7FFFF       BFC00000-BFC7FFFF       FLASH ROM
80000000-8000000D       C0000000-C000000D       RTC
8000000E-80007FFF       C000000E-C0007FFF       NVRAM
81000000-81FFFFFF       C1000000-C1FFFFFF       Z85C30 DUART
82000000-82FFFFFF       C2000000-C2FFFFFF       Z8536 Timer
83000000-83FFFFFF       C3000000-C3FFFFFF       8255 Parallel port
87000000-87FFFFFF       C7000000-C7FFFFFF       Seven segment display
```

> **NOTE:** By default the VRC4375 SIMM control registers are not programmed since the values used must depend on the SIMMs installed. If SIMMs are to be used, correct values must be placed in these registers before accessing the SIMM address range.

> **NOTE:** The allocation of address ranges to devices in the PCI IO and memory spaces is handled by the eCos PCI support library. They do not correspond to those described in the board User Manual.

NOTE: The MMU has been set up to relocate the VRC4372 supported devices mapped at physical addresses 0x8xxxxxxx to virtual addresses 0xCxxxxxxx.

Ethernet Driver

The ethernet driver is in two parts:

A generic ether driver for the Intel i21143 device is located in `devs/eth/intel/i21143`. Its package name is `CYGPKG_DEVS_ETH_INTEL_I21143`.

The platform-specific ether driver is `devs/eth/mips/vrc4375`. Its package is `CYGPKG_DEVS_ETH_MIPS_VRC4375`. This tells the generic driver the address in IO memory of the chip, for example, and other configuration details. The ESA (MAC address) is by default collected from on-board serial EEPROM, unless configured statically within this package.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=vrc4373
export ARCH_DIR=mips
export PLATFORM_DIR=vrc4373
```

The names of configuration files are listed above with the description of the associated modes.

PowerPC/MPC860T Analogue & Micro PowerPC 860T

Overview

RedBoot uses the SMC1 serial port. The default serial port settings are 38400,8,N,1. Ethernet is also supported using the RJ-45 connector. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROMRAM	[ROMRAM]	RedBoot running from RAM, but contained in the board's flash boot sector.	redboot_ROMRAM.ecm

Initial Installation Method

RedBoot must be installed at the A & M factory.

Special RedBoot Commands

None.

Memory Maps

Memory Maps RedBoot sets up the following memory map on the MBX board.

```
Physical Address Range Description
----------------------- -----------
0x00000000 - 0x007fffff DRAM
0xfe000000 - 0xfe0fffff flash (AMD29LV8008B)
0xff000000 - 0xff0fffff MPC registers
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=viper
export ARCH_DIR=powerpc
export PLATFORM_DIR=viper
```

The names of configuration files are listed above with the description of the associated modes.

PowerPC/MPC8XX Motorola MBX

Overview

RedBoot uses the SMC1/COM1 serial port. The default serial port settings are 38400,8,N,1. Ethernet is also supported using the 10-base T connector.

Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm

Configuration	Mode	Description	File
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

Device programmer is used to program the XU1 socketed flash part (AM29F040B) with the ROM mode image of RedBoot. Use the on-board EPPC-Bug monitor to update RedBoot.

This assumes that you have EPPC-Bug in the on-board flash. This can be determined by setting up the board according to the following instructions and powering up the board.

The EPPC-Bug prompt should appear on the SMC1 connector at 9600 baud, 8N1.

1. Set jumper 3 to 2-3 [allow XU1 flash to be programmed]
2. Set jumper 4 to 2-3 [boot EPPC-Bug]

If it is available, program the flash by following these steps:

1. Prepare EPPC-Bug for download:

   ```
   EPPC-Bug>lo 0
   ```

   At this point the monitor is ready for input. It will not return the prompt until the file has been downloaded.

2. Use the terminal emulator's ASCII download feature (or a simple clipboard copy/paste operation) to download the `redboot.ppcbug` file.

   Note that on Linux, Minicom's ASCII download feature seems to be broken. A workaround is to load the file into emacs (or another editor) and copy the full contents to the clipboard. Then press the mouse paste-button (usually the middle one) over the Minicom window.

3. Program the flash with the downloaded data:

   ```
   EPPC-Bug>pflash 40000 60000 fc000000
   ```

4. Switch off the power, and change jumper 4 to 1-2. Turn on the power again. The board should now boot using the newly programmed RedBoot.

Special RedBoot Commands

None.

Memory Maps

Memory Maps RedBoot sets up the following memory map on the MBX board.

```
Physical Address Range Description
----------------------- -----------
0x00000000 - 0x003fffff DRAM
0xfa100000 - 0xfa100003 LEDs
0xfe000000 - 0xfe07ffff flash (AMD29F040B)
0xff000000 - 0xff0fffff MPC registers
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=mbx
export ARCH_DIR=powerpc
export PLATFORM_DIR=mbx
```

The names of configuration files are listed above with the description of the associated modes.

SuperH/SH3(SH7708) Hitachi EDK7708

Overview

RedBoot uses the serial port. The default serial port settings are 38400,8,N,1.

Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

Program the ROM RedBoot image into flash using an eprom programmer.

Memory Maps

RedBoot sets up the following memory map on the EDK7708 board.

```
Physical Address Range  Description
----------------------- -----------
0x80000000 - 0x8001ffff Flash (AT29LV1024)
0x88000000 - 0x881fffff DRAM
0xa4000000 - 0xa40000ff LED ON
0xb8000000 - 0xb80000ff LED ON
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=edk7708
export ARCH_DIR=sh
export PLATFORM_DIR=edk7708
```

The names of configuration files are listed above with the description of the associated modes.

SuperH/SH3(SH7709) Hitachi Solution Engine 7709

Overview

This description covers the MS7709SE01 variant. See the Section called *SuperH/SH3(SH77X9) Hitachi Solution Engine 77X9* for instructions for the MS7729SE01 and MS7709SSE0101 variants.

RedBoot uses the COM1 and COM2 serial ports. The default serial port settings are 38400,8,N,1. Ethernet is also supported using the 10-base T connector.

Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

The Solution Engine ships with the Hitachi boot monitor in EPROM which allows for initial programming of RedBoot:

1. Set switch SW4-1 to ON [boot from EPROM]
2. Connect a serial cable to CN1 (SCI) and power up the board.
3. After the boot monitor banner, invoke the flash download/program command:

   ```
   Ready >fl
   ```

4. The monitor should now ask for input:

   ```
   Flash ROM data copy to RAM
   Please Send A S-format Record
   ```

   At this point copy the RedBoot ROM SREC file to the serial port:

   ```
   $ cat redboot_SE7709RP_ROM.eprom.srec > /dev/ttyS0
   ```

   Eventually you should see something like

   ```
   Start Addrs = A1000000
   End Addrs = A1xxxxxx
   Transfer complete
   ```

   from the monitor.

5. Set switch SW4-1 to OFF [boot from flash] and reboot the board. You should now see the RedBoot banner.

Special RedBoot Commands

The **exec** command which allows the loading and execution of Linux kernels is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the SE77x9 are:

-b <*addr*>

   Parameter block address. This is normally the first page of the kernel image and defaults to 0x8c101000

-i <*addr*>

   Start address of initrd image

-j <*size*>

   Size of initrd image

-c *"args"*

   Kernel arguments string

-m <*flags*>

   Mount rdonly flags. If set to a non-zero value the root partition will be mounted read-only.

-f <*flags*>

   RAM disk flags. Should normally be 0x4000

-r <*device number*>

Root device specification. /dev/ram is 0x0101

-l <*type*>

Loader type

Finally the kernel entry address can be specified as an optional argument. The default is 0x8c102000

For the the SE77x9, Linux by default expects to be loaded at 0x8c001000 which conflicts with the data space used by RedBoot. To work around this, either change the CONFIG_MEMORY_START kernel option to a higher address, or use the compressed kernel image and load it at a higher address. For example, setting CONFIG_MEMORY_START to 0x8c100000, the kernel expects to be loaded at address 0x8c101000 with the entry point at 0x8c102000.

Memory Maps

RedBoot sets up the following memory map on the SE77x9 board.

```
Physical Address Range  Description
----------------------- -----------
0x80000000 - 0x803fffff Flash (MBM29LV160)
0x81000000 - 0x813fffff EPROM (M27C800)
0x8c000000 - 0x8dffffff DRAM
0xb0000000 - 0xb03fffff Ethernet (DP83902A)
0xb0800000 - 0xb08fffff 16C552A
0xb1000000 - 0xb100ffff Switches
0xb1800000 - 0xb18fffff LEDs
0xb8000000 - 0xbbffffff PCMCIA (MaruBun)
```

Ethernet Driver

The ethernet driver uses a hardwired ESA which can, at present, only be changed in CDL.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=se77x9
export ARCH_DIR=sh
export PLATFORM_DIR=se77x9
```

The names of configuration files are listed above with the description of the associated modes.

SuperH/SH3(SH7729) Hitachi HS7729PCI

Overview

RedBoot uses the COM1 and COM2 serial ports (and the debug port on the motherboard). The default serial port settings are 38400,8,N,1. Ethernet is also supported using a D-Link DFE-530TX PCI plugin card. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

A ROM mode RedBoot image must be programmed into the two EPROMs. Two files with a split version of the ROM mode image is provided: it is also possible to recreate these from the `redboot.bin` file, but requires the split_word.c program in `hal/sh/hs7729pci/`*`VERSION`*`/misc` to be built and executed with the `redboot.bin` filename as sole argument.

After doing this it is advised that another ROM mode image of RedBoot is programmed into the on-board flash, and that copy be used for booting the board. This allows for software programmed updates of RedBoot instead of having to reprogram the EPROMs.

1. Program the EPROMs with RedBoot. The .lo image should go in socket M1 and the .hi image in socket M2.
2. Set switch SW1-6 to ON [boot from EPROM]
3. Follow the instructions under Flash management for updating the flash copy of RedBoot, but force the flash destination address with

   `-f 0x80400000`

   due to setting of the SW1-6 switch.
4. Set switch SW1-6 to OFF [boot from flash] and reboot the board. You should now see the RedBoot banner. At this time you may want to issue the command **fis init** to initialize the flash table with the correct addresses.

Special RedBoot Commands

The **exec** command which allows the loading and execution of Linux kernels is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the HS7729PCI are:

-b <*addr*>

Parameter block address. This is normally the first page of the kernel image and defaults to 0x8c101000

-i <*addr*>

Start address of initrd image

-j <*size*>

Size of initrd image

-c *"args"*

Kernel arguments string

-m <*flags*>

Mount rdonly flags. If set to a non-zero value the root partition will be mounted read-only.

-f <*flags*>

RAM disk flags. Should normally be 0x4000

-r <*device number*>

Root device specification. /dev/ram is 0x0101

-l <*type*>

Loader type

Finally the kernel entry address can be specified as an optional argument. The default is 0x8c102000

On the HS7729PCI, Linux expects to be loaded at address 0x8c101000 with the entry point at 0x8c102000. This is configurable in the kernel using the CONFIG_MEMORY_START option.

Memory Maps

RedBoot sets up the following memory map on the HS7729PCI board.

```
Physical Address Range  Description
----------------------- -----------
0x80000000 - 0x803fffff Flash (MBM29LV160)
0x80400000 - 0x807fffff EPROM (M27C800)
0x82000000 - 0x82ffffff SRAM
0x89000000 - 0x89ffffff SRAM
0x8c000000 - 0x8fffffff SDRAM
0xa8000000 - 0xa800ffff SuperIO (FDC37C935A)
0xa8400000 - 0xa87fffff USB function (ML60851C)
0xa8800000 - 0xa8bfffff USB host (SL11HT)
0xa8c00000 - 0xa8c3ffff Switches
0xa8c40000 - 0xa8c7ffff LEDs
0xa8c80000 - 0xa8cfffff Interrupt controller
0xb0000000 - 0xb3ffffff PCI (SD0001)
0xb8000000 - 0xbbffffff PCMCIA (MaruBun)
```

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=hs7729pci
export ARCH_DIR=sh
export PLATFORM_DIR=hs7729pci
```

The names of configuration files are listed above with the description of the associated modes.

SuperH/SH3(SH77X9) Hitachi Solution Engine 77X9

Overview

This description covers the MS7729SE01 and MS7709SSE0101 variants. See the Section called *SuperH/SH3(SH7709) Hitachi Solution Engine 7709* for instructions for the MS7709SE01 variant.

RedBoot uses the COM1 and COM2 serial ports. The default serial port settings are 38400,8,N,1. Ethernet is also supported using the 10-base T connector. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board's flash boot sector.	redboot_ROM.ecm
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

The Solution Engine ships with the Hitachi boot monitor in EPROM which allows for initial programming of RedBoot:

1. Set switches SW4-3 and SW4-4 to ON [boot from EPROM]
2. Connect a serial cable to COM2 and power up the board.
3. After the boot monitor banner, invoke the flash download/program command:

   ```
   Ready >fl
   ```

4. The monitor should now ask for input:

```
Flash ROM data copy to RAM
Please Send A S-format Record
```

At this point copy the RedBoot ROM SREC file to the serial port:

```
$ cat redboot_ROM.eprom.srec > /dev/ttyS0
```

Eventually you should see something like

```
Start Addrs = A1000000
End Addrs = A1xxxxxx
Transfer complete
```

from the monitor.

5. Set switch SW4-3 to OFF [boot from flash] and reboot the board. You should now see the RedBoot banner.

Special RedBoot Commands

The **exec** command which allows the loading and execution of Linux kernels is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the SE77x9 are:

-b <*addr*>

Parameter block address. This is normally the first page of the kernel image and defaults to 0x8c101000

-i <*addr*>

Start address of initrd image

-j <*size*>

Size of initrd image

-c *"args"*

Kernel arguments string

-m <*flags*>

Mount rdonly flags. If set to a non-zero value the root partition will be mounted read-only.

-f <*flags*>

RAM disk flags. Should normally be 0x4000

-r <*device number*>

Root device specification. /dev/ram is 0x0101

-l <*type*>

Loader type

Finally the kernel entry address can be specified as an optional argument. The default is 0x8c102000

On the SE77x9, Linux expects to be loaded at address 0x8c101000 with the entry point at 0x8c102000. This is configurable in the kernel using the CONFIG_MEMORY_START option.

Memory Maps

RedBoot sets up the following memory map on the SE77x9 board.

```
Physical Address Range  Description
----------------------- -----------
0x80000000 - 0x803fffff Flash (MBM29LV160)
0x81000000 - 0x813fffff EPROM (M27C800)
0x8c000000 - 0x8dffffff SDRAM
0xb0000000 - 0xb03fffff Ethernet (DP83902A)
0xb0400000 - 0xb07fffff SuperIO (FDC37C935A)
0xb0800000 - 0xb0bfffff Switches
0xb0c00000 - 0xbfffffff LEDs
0xb1800000 - 0xb1bfffff PCMCIA (MaruBun)
```

Ethernet Driver

The ethernet driver uses a hardwired ESA which can, at present, only be changed in CDL.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=se77x9
export ARCH_DIR=sh
export PLATFORM_DIR=se77x9
```

The names of configuration files are listed above with the description of the associated modes.

SuperH/SH4(SH7751) Hitachi Solution Engine 7751

Overview

RedBoot uses the COM1 serial port. The default serial port settings are 38400,8,N,1. Ethernet is also supported using the 10-base T connector. Management of onboard flash is also supported.

The following RedBoot configurations are supported:

Configuration	Mode	Description	File
ROM	[ROM]	RedBoot running from the board’s flash boot sector.	redboot_ROM.ecm

Configuration	Mode	Description	File
RAM	[RAM]	RedBoot running from RAM with RedBoot in the flash boot sector.	redboot_RAM.ecm

Initial Installation Method

The Solution Engine ships with the Hitachi boot monitor in EPROM which allows for initial programming of RedBoot:

1. Set switches SW5-3 and SW5-4 to ON [boot from EPROM]
2. Connect a serial cable to COM1 and power up the board.
3. After the boot monitor banner, invoke the flash download/program command:

   ```
   Ready >fl
   ```

4. The monitor should now ask for input:

   ```
   Flash ROM data copy to RAM
   Please Send A S-format Record
   ```

   At this point copy the RedBoot ROM SREC file to the serial port:

   ```
   $ cat redboot_ROM.eprom.srec > /dev/ttyS0
   ```

   Eventually you should see something like

   ```
   Start Addrs = A1000000
   End Addrs = A1xxxxxx
   Transfer complete
   ```

   from the monitor.
5. Set switch SW5-3 to OFF [boot from flash] and reboot the board. You should now see the RedBoot banner.

Special RedBoot Commands

The **exec** command which allows the loading and execution of Linux kernels is supported for this board (see the Section called *Executing Programs from RedBoot* in Chapter 2). The **exec** parameters used for the SE7751 are:

-b <*addr*>

Parameter block address. This is normally the first page of the kernel image and defaults to 0x8c101000

-i <*addr*>

Start address of initrd image

-j <*size*>

Size of initrd image

-c *"args"*

Kernel arguments string

-m <*flags*>

Mount rdonly flags. If set to a non-zero value the root partition will be mounted read-only.

-f <*flags*>

RAM disk flags. Should normally be 0x4000

-r <*device number*>

Root device specification. /dev/ram is 0x0101

-l <*type*>

Loader type

Finally the kernel entry address can be specified as an optional argument. The default is 0x8c102000

On the SE7751, Linux expects to be loaded at address 0x8c101000 with the entry point at 0x8c102000. This is configurable in the kernel using the CONFIG_MEMORY_START option.

Memory Maps

RedBoot sets up the following memory map on the SE7751 board.

```
Physical Address Range  Description
----------------------- -----------
0x80000000 - 0x803fffff Flash (MBM29LV160)
0x81000000 - 0x813fffff EPROM (M27C800)
0x8c000000 - 0x8fffffff SDRAM
0xb8000000 - 0xb8ffffff PCMCIA (MaruBun)
0xb9000000 - 0xb9ffffff Switches
0xba000000 - 0xbaffffff LEDs
0xbd000000 - 0xbdffffff PCI MEM space
0xbe200000 - 0xbe23ffff PCI Ctrl space
0xbe240000 - 0xbe27ffff PCI IO space
```

Ethernet Driver

The ethernet driver uses a hardwired ESA which can, at present, only be changed in CDL.

Rebuilding RedBoot

These shell variables provide the platform-specific information needed for building RedBoot according to the procedure described in Chapter 3:

```
export TARGET=se7751
export ARCH_DIR=sh
```

```
export PLATFORM_DIR=se7751
```

The names of configuration files are listed above with the description of the associated modes.

III. The eCos Hardware Abstraction Layer (HAL)

Chapter 6. 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 7. 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 8. 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 9. 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 a 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, and realtime clock operations.

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 include 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*.

`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.

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.

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 is an optional definition. If defined the macro implements a busy loop delay for the given number of microseconds. This is usually implemented by waiting for the required number of hardware timer ticks to pass.

This operation should normally be used when a very short delay is needed when controlling hardware, programming FLASH devices and similar situations where a wait/timeout loop would otherwise be used. Since it may disable interrupts, and is implemented by busy waiting, it should not be used in code that is sensitive to interrupt or context switch latencies.

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 Section called *PCI Library reference* in Chapter 30.

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 include 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'ed` 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 the 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 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 reg-

isters 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` of 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 10. 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 9).
- 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.

Chapter 11. 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://sourceware.cygnus.com/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://sourceware.cygnus.com/ecos/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://sourceware.cygnus.com/ecos/docs-latest/), FAQ (http://sourceware.cygnus.com/fom/ecos) or source code (http://sourceware.cygnus.com/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@sourceware.cygnus.com?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 7. 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
Common HAL (hal/common) (http://sourceware.cygnus.com/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://sourceware.cygnus.com/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/arch/current?cvsroot=ecos)	Functionality specific to the given architecture. Also default implementations of some functionality 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://sourceware.cygnus.com/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/mpc8xx/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://sourceware.cygnus.com/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/mbx/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://sourceware.cygnus.com/cgi-bin/cvsweb.cgi/ecos/packages/hal/powerpc/quicc/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
`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.
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

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.
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.

File	Description
`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)

Some eCos platforms have supported full debugging capabilities via CygMon since day one. Platforms of the architectures PowerPC, ARM, and SH do not provide those features unless a GDB stub is included in the application.

This is going to change. All platforms will (eventually) support all the debugging features by relying on a ROM/RAM calling interface (also referred to as virtual vector table) provided by the ROM monitor. This calling interface is based on the tables used by libbsp and is thus backwards compatible with the existing CygMon supported platforms.

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 RedBoot 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 extend - 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 provided 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 is 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 CYGHWR_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 where 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, Red Hat, 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_jmt3904.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-
virtual -g -O2 -ffunction-sections -fdata-sections -fno-rtti -fno-exceptions -fvtable-gc -
finit-priority" }
        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 my 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 and 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 FPUs 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.
   - 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.

- `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 10 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 10 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 10 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.

- Define any data items needed. Typically `vectors.S` may contain definitions for the VSR table, the interrupt tables and the interrupt stack. Sometimes these are only default definitions that may be overridden by the variant or platform HALs.

7. Write `context.S`. This file contains the context switch code. See the Section called *Thread Context Switching* in Chapter 9 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 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 { CYGHWR_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 CYGHWR_HAL_I386_FPU {
 display       "Enable I386 FPU support"
 default_value 1
 description   "This component enables support for the
               I386 floating point unit."

 cdl_option CYGHWR_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 CYGHWR_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 CYGHWR_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 12. 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.

IV. The ISO Standard C and Math Libraries

Chapter 13. 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:

```
CYG_LIBC_TIME_DSTNA   unknown
CYG_LIBC_TIME_DSTOFF  off
```

```
CYG_LIBC_TIME_DSTON   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 inplementation.

```
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 13-1. Behavior of math exception handling

Type	Behavior

Type	Behavior
DOMAIN	0.0 returned, errno=EDOM, and a message printed on stderr
SING	HUGE of appropriate sign is returned, errno=EDOM, and a message is printed on stderr
OVERFLOW	HUGE of appropriate sign is returned, and errno=ERANGE
UNDERFLOW	0.0 is returned and errno=ERANGE
TLOSS	0.0 is returned, errno=ERANGE, and a message is printed on stderr
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. But if you disable the kernel, you will be unable to use memory allocation, thread-safety and certain stdio functions such as input. Other C library functionality is unaffected.
- 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 place its own *built-in* implementations instead of some C library functions. This can be turned off with the *-fno-builtin* option. The functions affected by this are `abs()` , `cos()` , `fabs()` , `labs()` , `memcmp()` , `memcpy()` , `sin()` , `sqrt()` , `strcmp()` , `strcpy()` , and `strlen()` .

- For faster execution speed you should avoid this option and let the compiler use its built-ins. This can be turned off by invoking *GCC* with the *-fno-builtin* option.
- `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.
- When `free()` is invoked, heap memory will normally be coalesced. If the CYGSEM_KERNEL_MEMORY_COALESCE configuration parameter is not set, memory will not be coalesced, which might cause programs to fail.
- 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.
- 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 CYGDAT_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/current/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.

V. I/O Package (Device Drivers)

Chapter 14. 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 15. 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 16. 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_RTSCTS 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 send 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' => '\n\r' on output
```

If this bit is set in *tty_out_flags*, any occurrence of the character "\n" will be replaced by the sequence "\n\r" 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 '\n\r' => '\n' on input
```

If this bit is set in *tty_in_flags*, the character sequence "\n\r" (often sent by DOS/Windows based terminals) will be mapped to "\n".

```
#define CYG_TTY_IN_FLAGS_BINARY 0x0004 // 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.

```
#define CYG_TTY_IN_FLAGS_ECHO 0x0008 // 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.

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 "\n\r".

```
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 17. 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(l, name, dep_name, handlers, init, lookup, priv)
```

Arguments

l

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_buflen

The length of the output buffer.

in_buf

pointer to the input buffer. `NULL` if none required.

in_buflen

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 *funs* 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-though 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 ma 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

`serial3` [requires the serial filter]

This tests the half-duplex send and receive capabilities of the serial driver.

`serial4` [requires the serial filter]

This test attempts to use a few different serial configurations, testing the driver's configuration/setup functionality.

`serial5` [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/serial3
```

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 .. .. .. .. .. .. '1!'
```

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 18. 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 syn-

chronization, 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:

```
                                  Callable from:
Function                       ISR     DSR    Thread
-------------------------------------------------------------------------

cyg_drv_isr_lock                X       X       X
cyg_drv_isr_unlock              X       X       X
cyg_drv_spinlock_init                           X
cyg_drv_spinlock_destroy                        X
cyg_drv_spinlock_spin           X       X       X
cyg_drv_spinlock_clear          X       X       X
cyg_drv_spinlock_try            X       X       X
cyg_drv_spinlock_test           X       X       X
cyg_drv_spinlock_spin_intsave   X       X       X
cyg_drv_spinlock_clear_intsave  X       X       X
```

`cyg_drv_dsr_lock`		X	X
`cyg_drv_dsr_unlock`		X	X
`cyg_drv_mutex_init`			X
`cyg_drv_mutex_destroy`			X
`cyg_drv_mutex_lock`			X
`cyg_drv_mutex_trylock`			X
`cyg_drv_mutex_unlock`			X
`cyg_drv_mutex_release`			X
`cyg_drv_cond_init`			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 *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 *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 in made.

cyg_drv_mutex_lock

Function:

```
cyg_bool cyg_drv_mutex_lock( cyg_drv_mutex *mutex )
```

Arguments:

mutex - pointer to mutex to lock

Result:

`TRUE` it 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 *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 *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 *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 *cond, cyg_drv_mutex *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 *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 *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 *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 *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.

VI. File System Support Infrastructure

Chapter 19. 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 Chapter 31 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 20. 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 );
    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 dir1, const char *name1,
                          cyg_dir dir2, const char *name2 );
    int     (*link)     ( cyg_mtab_entry *mte, cyg_dir dir1, 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", "msdos", "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 24.

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 23 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 21. 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
    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:

```
 { "/",    "msdos", "/dev/hd0", ... }
 { "/fd",  "msdos", "/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 MSDOS 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 22. 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_ucount;       /* 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_ucount* 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 24.

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 23. 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.

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 24. 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_SOCK_FILE`

Lock the file table entry mutex during all socket operations.

`CYG_SYNCMODE_SOCK_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 25. 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 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.

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.

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 is called and if successful, the mount table entry is invalidated by setting its *valid* field false and the *name* field to NULL.

Chapter 26. 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_SOCK_*` 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 27. 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 28. 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 29. 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 );
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_mte1,
                   "/",
                   "testfs",
                   "",
                   0);
```

The first argument provides a name for the table entry. The following arguments provide initialization for the *name*, *fsname*, *devname* 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.

VII. PCI Library

Chapter 30. 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 Code List (http://www.yourvote.com/pci) (http://www.yourvote.com/pci) 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 CPUs 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/drive 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 *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_next( cyg_pci_device_id cur_devid,
       cyg_pci_device_id *next_devid );
```

Searches the PCI configuration space for the next valid device after *cur_devid*. If *cur_devid* is given the value `CYG_PCI_NULL_DEVID`, then the search starts at the first slot. It is permitted for *next_devid* to point to *cur_devid*. 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 *devid );
```

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 *devid*, or at the first slot if it contains `CYG_PCI_NULL_DEVID`. The *devid* 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 devid,
          cyg_pci_device *dev_info );
```

This function gets the PCI configuration information for the device indicated in *devid*. 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 devid,
          cyg_pci_device *dev_info );
```

This function sets the PCI configuration information for the device indicated in *devid*. 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 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 );
```

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 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 );
```

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 though 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.

VIII. 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 execle( 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_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);
```

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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IX. μITRON

Chapter 32. μITRON API

Introduction to μITRON

The μITRON 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 μITRON 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 μITRON specification exist. In this release, *eCos* supports the μITRON version 3.02 specification, with complete "Standard functionality" (level S), plus many "Extended" (level E) functions. The definitive reference on μITRON is Dr. Sakamura's book: *μITRON 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.itron.gr.jp/. The old address http://tron.um.u-tokyo.ac.jp/TRON/ITRON/ still exists as a mirror site.

μITRON and *eCos*

The *eCos* kernel implements the functionality used by the μITRON compatibility subsystem. The configuration of the kernel influences the behavior of μITRON 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 μITRON 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 μITRON 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 μITRON 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 μITRON compatibility layer, even though it only allows one task at each priority and as such is not μITRON compliant, but it supports only priority ordering of task queues. So which queueing scheme is supported is not really a property of the μITRON compatibility layer; it depends on the kernel.

In this version of the μITRON 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 μITRON layer are dependent on its configuration and the configuration of other components that it uses. The μITRON 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 μITRON 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 μITRON 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 μITRON 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 CYG-PKG_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 µITRON 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 μITRON 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 μITRON 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 μITRON task context, else E_CTX.
- `dis/ena_int()` : the interrupt number must be in range as specified by the platform HAL in qustion, 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 blksz,    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 µITRON 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.

μITRON Configuration FAQ

Q: How are μITRON objects created?

For each type of uITRON object (tasks, semaphores, flags, mboxes, 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 mboxes is the same as the initial number of mboxes, and so on for all μITRON object types.

Mboxes have no initialization, so there are only a few, simple configuration options:

- `CYGNUM_UITRON_MBOXES` is the total number of mboxes that you can have in the system. By default this is 4, so you can use mboxes 1,2,3 and 4. You cannot create mboxes outside this range; trying to `cre_mbx(5,...)` will return an error.
- `CYGNUM_UITRON_MBOXES_INITIALLY` is the number of mboxes created automatically for you, during startup. By default this is 4, so all 4 mboxes exist already, and an attempt to create one of these eg. `cre_mbx(3,...)` will return an error because the mbox in quesion 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 mboxes 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 μITRON 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 though 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 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 µITRON 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 | Exists at | Function | Priority | Stack   | Stack
 number |  startup  |  entry   |          | address | 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 µITRON 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 | Exists at | Function | Priority | Stack   | Stack
 number |  startup  |  entry   |          | address | size
--------+-----------+----------+----------+---------+----------
   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 uITRON object types)

Q: Can I have different stack sizes for µITRON 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 µITRON 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 editting 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 ) )
```

X. 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 generic ethernet device driver documentation Part XIV in *eCos Reference Manual* The driver and API is the same as the minimal debug stack used by the RedBoot application. See the RedBoot documentation Part II in *eCos Reference Manual* 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.

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.

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 LINUX) cd to the tests source directory in the eCos repository and type "`make -f make.linux`" - this should build `tcp_source` and `tcp_sink`.

The LINUX program "`tcp_source`" sends data to the target. On the target, "`tcp_echo`" sends it onwards to "`tcp_sink`" running on LINUX. 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 LINUX 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 LINUX 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 LINUX 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 LINUX 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 LINUX host, 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
```

`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 ADDRess” 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 client API is simple and can be easily understood by reading `tftp_client_test.c`.

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, struct tftpd_fileops *);` call. The first argument is the port to use for the server.

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_halt(); // tear everything down
        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_halt();
                 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.

Chapter 38. TCP/IP Library Reference

getdomainname

```
GETDOMAINNAME(3)        System 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 termi-
     nated.

     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 vari-
     able errno.

ERRORS
     The following errors may be returned by these calls:

     [EFAULT]           The name or namelen 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>) charac-
     ters, 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.

BSD                              May 6, 1994                             BSD
```

gethostname

```
GETHOSTNAME(3)          System 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 termi-
     nated.

     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 vari-
     able errno.

ERRORS
     The following errors may be returned by these calls:

     [EFAULT]           The name or namelen 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)            System Library Functions Manual           BYTEORDER(3)

NAME
     htonl, htons, ntohl, ntohs, htobe32, htobe16, betoh32, betoh16, htole32,
     htole16, letoh32, letoh16, swap32, swap16 - convert values between dif-
     ferent 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)               System 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 sepa-
     rated 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() func-
     tion 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 Eth-
     ernet 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 func-
     tions overwrite it.

BSD                             December 16, 1993                            BSD
```

getaddrinfo

```
GETADDRINFO(3)          System 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 loopback 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:

- 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.

- 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.

- 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 particular 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:

```
EAI_ADDRFAMILY  Address family for nodename not supported.
EAI_AGAIN       Temporary failure in name resolution.
EAI_BADFLAGS    Invalid value for ai_flags.
EAI_FAIL        Non-recoverable failure in name resolution.
EAI_FAMILY      ai_family not supported.
EAI_MEMORY      Memory allocation failure.
EAI_NODATA      No address associated with nodename.
EAI_NONAME      nodename nor servname provided, or not known.
EAI_SERVICE     servname not supported for ai_socktype.
EAI_SOCKTYPE    ai_socktype not supported.
EAI_SYSTEM      System error returned in errno.
```

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 speci-
     fication, 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)        System 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:

h_name       Official name of the host.

h_aliases    A zero-terminated array of alternate names for the host.

h_addrtype   The type of address being returned.

h_length     The length, in bytes, of the address.

h_addr_list  A zero-terminated array of network addresses for the host.
             Host addresses are returned in network byte order.

h_addr       The first address in h_addr_list; this is for backward com-
             patibility.

The function gethostbyname() will search for the named host in the cur-
rent 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().  Other-
wise, 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 authori-
                     tative 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() func-
     tions 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) System 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 inter-
                faces, 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                             February 24, 2003                            BSD
```

getnameinfo

```
GETNAMEINFO(3)          System 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 suc-
     cessful completion by a zero return value; a non-zero return value indi-
     cates 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 terminat-
     ing null characters.

     Unfortunately most systems do not provide constants that specify the max-
     imum 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)            System 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 bro-
     ken-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 func-
     tions overwrite it.  Only Internet network numbers are currently under-
     stood.  Expecting network numbers to fit in no more than 32 bits is
     naive.

BSD                              March 13, 1997                             BSD
```

getprotoent

```
GETPROTOENT(3)          System 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 contain-
     ing 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)       System 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 a to 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 struc-
     tures 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 rrsetinfostructure. 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:

ERRSET_NONAME	the name does not exist
ERRSET_NODATA	the name exists, but does not have data of the desired type
ERRSET_NOMEMORY	memory could not be allocated
ERRSET_INVAL	a parameter is invalid
ERRSET_FAIL	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 (autenticated 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).

getservent

```
GETSERVENT(3)           System 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)       System 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) System 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 conforms 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 speci-
     fied.  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 confus-
     ing.

     The string returned by inet_ntoa() resides in a static memory area.

BSD                              June 18, 1997                             BSD
```

inet6_option_space

```
INET6_OPTION_SPACE(3)   System 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 **cmsgp, 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 constranints, 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.

     cmsg is a pointer to cmsghdr structure of which cmsg_level equals
     IPPROTO_IPV6 and cmsg_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.  cmsg is a pointer to cmsghdr structure of which
     cmsg_level equals IPPROTO_IPV6 and cmsg_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) System 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 cmsg_len member of the cmsghdr structure is initialized to the size of the structure plus the amount of space required by the Routing header. The cmsg_level and cmsg_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 Rout-
  ing 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 cmsg_len 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)             System Library Functions Manual            INET_NET(3)

NAME
     inet_net_ntop, inet_net_pton - Internet network number manipulation rou-
     tines

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 net-
     work 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 net-
     work 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; other-
     wise, 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)                  System 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 rep-
     resenting 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 hex-
     adecimal, in a format suitable for input to ipx_addr().  Any fields lack-
     ing 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 separat-
     ing 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 trail-
     ing ‘H’ (as in Mesa), or there are any super-decimal digits present.  It
     is interpreted as octal is 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)             System 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 rep-
     resenting 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)            System 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 inter-
     face identifier of the form “name unit-number”, suitable for the first
     argument to ifconfig(8), followed in all cases by a colon and an inter-
     face 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)          System 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
```

ns

```
NS(3)                  System Library Functions Manual                  NS(3)

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 rep-
     resenting the address in a notation in common use in the Xerox Develop-
     ment Environment:

           <network number>.<host number>.<port number>

     Trailing zero fields are suppressed, and each number is printed in hex-
     adecimal, in a format suitable for input to ns_addr().  Any fields lack-
     ing 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 compati-
     ble 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 is there is a
     leading '0' and there are no super-octal digits.  Otherwise, it is con-
     verted 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)            System 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 reason-
        able 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., res_init() has been called).

        RES_DEBUG      Print debugging messages.

        RES_AAONLY     Accept authoritative answers only.  With this option,
                       res_send() should continue until it finds an authoritative
                       answer or finds an error.  Currently this is not imple-
                       mented.

        RES_USEVC      Use TCP connections for queries instead of UDP datagrams.

        RES_STAYOPEN   Used with RES_USEVC 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.  (res_send() does not do iterative queries and
                       expects the name server to handle recursion.)

        RES_DEFNAMES   If set, res_search() 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, res_search() will search for host names in the current domain and in parent domains; see hostname(7). This is used by the standard host lookup routine gethostbyname(3). 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 ::ffff:10.1.1.1. 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) 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 rejection 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 SOCK_STREAM.

[EINVAL] The referenced socket is not listening for connections (that is, listen(2) has not yet been called).

[EFAULT] The addr 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)                       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.  Con-
     sult 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
                        name->sa_family 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} charac-
                        ters, or an entire path name exceeded {PATH_MAX} char-
                        acters.

     [ENOENT]           A prefix component of the path name does not exist.

     [ELOOP]            Too many symbolic links were encountered in translat-
                        ing 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)                    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] S is not a valid descriptor.

[ENOTSOCK] S 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} charac-
                        ters, or an entire path name exceeded {PATH_MAX} char-
                        acters.

     [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 translat-
                        ing 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)                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 s is not a valid descriptor.

[ENOTSOCK] The argument s 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) 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

getsockname() returns the locally bound address information for a specified socket.

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 information.

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 s is not a valid descriptor.

     [ENOTSOCK]         The argument s 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)                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().

SO_DEBUG	enables recording of debugging information
SO_REUSEADDR	enables local address reuse
SO_REUSEPORT	enables duplicate address and port bindings
SO_KEEPALIVE	enables keep connections alive
SO_DONTROUTE	enables routing bypass for outgoing messages
SO_LINGER	linger on close if data present
SO_BROADCAST	enables permission to transmit broadcast messages
SO_OOBINLINE	enables reception of out-of-band data in band
SO_SNDBUF	set buffer size for output
SO_RCVBUF	set buffer size for input
SO_SNDLOWAT	set minimum count for output
SO_RCVLOWAT	set minimum count for input
SO_SNDTIMEO	set timeout value for output
SO_RCVTIMEO	set timeout value for input
SO_TYPE	get the type of the socket (get only)
SO_ERROR	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_KEEPALIVE 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:

[EBADF] The argument s is not a valid descriptor.

[ENOTSOCK] The argument s is a file, not a socket.

[ENOPROTOOPT] The option is unknown at the level indicated.

[EFAULT] The address pointed to by optval is not in a valid part of the process address space. For getsockopt(), this error may also be returned if optlen 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)                    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 spe-
     cial 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]            d is not a valid descriptor.

     [ENOTTY]           d is not associated with a character special device.

     [ENOTTY]           The specified request does not apply to the kind of
                        object that the descriptor d references.

     [EINVAL]           request or arg is not valid.

     [EFAULT]           arg 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)                       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 condi-
              tions found, respectively.

     nfds     The number of pollfd structures in the array.

     timeout  Maximum interval to wait for the poll to complete, in millisec-
              onds.  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 descrip-
            tor 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) 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 is 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 readfds, writefds, or exceptfds 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, NFDBITS),
                      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)   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.

[ENOBUFS] The system was unable to allocate an internal buffer. The operation may succeed when buffers become available.

[ENOBUFS] 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] len was larger than SSIZE_MAX.

Also, sendmsg() may return the following errors:

[EINVAL] The sum of the iov_len values in the msg_iov array overflowed an ssize_t.

[EMSGSIZE] The msg_iovlen member of msg was less than 0 or larger than IOV_MAX.

[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)                  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 dis-
     allowed.

RETURN VALUES
     A 0 is returned if the call succeeds, -1 if it fails.

ERRORS
     The call succeeds unless:

     [EINVAL]           how is not SHUT_RD, SHUT_WR, or SHUT_RDWR.

     [EBADF]            s is not a valid descriptor.

     [ENOTSOCK]         s 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”).
```

socket

SOCKET(2) 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 a 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
```

socketpair

```
SOCKETPAIR(2)               System Calls Manual               SOCKETPAIR(2)

NAME
     socketpair - create a pair of connected sockets

SYNOPSIS
     #include <sys/types.h>
     #include <sys/socket.h>

     int
     socketpair(int d, int type, int protocol, int *sv);

DESCRIPTION
     The socketpair() call creates an unnamed pair of connected sockets in the
     specified domain d, of the specified type, and using the optionally spec-
     ified protocol.  The descriptors used in referencing the new sockets are
     returned in sv[0] and sv[1].  The two sockets are indistinguishable.
```

RETURN VALUES

A 0 is returned if the call succeeds, -1 if it fails.

ERRORS

The call succeeds unless:

[EMFILE] Too many descriptors are in use by this process.

[EAFNOSUPPORT] The specified address family is not supported on this machine.

[EPROTONOSUPPORT] The specified protocol is not supported on this machine.

[EOPNOTSUPP] The specified protocol does not support creation of socket pairs.

[EFAULT] The address sv does not specify a valid part of the process address space.

[ENFILE] The system file table is full.

SEE ALSO

pipe(2), read(2), write(2)

BUGS

This call is currently implemented only for the LOCAL domain. Many operating systems only accept a protocol of PF_UNSPEC, so that should be used instead of PF_LOCAL for maximal portability.

STANDARDS

The socketpair() function conforms to X/Open Portability Guide Issue 4.2 (“XPG4.2”).

HISTORY

The socketpair() function call appeared in 4.2BSD.

XI. 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 relevent) 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
```

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.

XII. OpenBSD TCP/IP Stack port for eCos

TCP/IP Networking for eCos now provides a complete TCP/IP networking stack, which is derived from a recent stable release of OpenBSD. The networking support is fully featured and well tested within the eCos environment.

Chapter 42. 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

These additional features are also present in the package, but are not supported:

- Berkeley Packet Filter
- Multi-cast and uni-cast support, including multi-casting routing
- IPv6

Chapter 43. OpenBSD TCP/IP stack port

This document describes how to get started with the OpenBSD 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", "OpenBSD TCP/IP Stack" and "Common Ethernet Support" to your configuration. Their package names are CYGPKG_NET, CYGPKG_NET_OPENBSD_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 relevent) 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 44. 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 Red Hat. 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 Red Hat's 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.

XIII. DNS for eCos and RedBoot

eCos and RedBoot can both use the DNS package to perform network name lookups.

Chapter 45. DNS

DNS API

The DNS client uses the normal BSD API for performing lookups: `gethostbyname()` and `gethostbyaddr()`.

There are a few restrictions:

- Only IPv4 is supported, ie IPv6 addresses cannot be looked up.
- If the DNS server returns multiple authoritive records for a host name, the hostent will only contain a record for the first entry.
- 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.

To initialise the DNS client the following function must be called:

```
#include <network.h>
int cyg_dns_res_init(struct in_addr *dns_server)
```

where dns_server is the address of the DNS server the client should query. On Error this function returns -1, otherwise 0 for success. If lookups are attemped before this function has been called, they will fail and return NULL.

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 my 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 first perform a lookup with the domain name appended. If this fails it will then perform a second lookup without the appended domain name.

XIV. Ethernet Device Drivers

Chapter 46. Generic Ethernet Device Driver

Generic Ethernet API

This file 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->funs->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, see Chapter 47.

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 addrs[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->funs->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->funs->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->funs->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->funs->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->funs->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->funs->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->funs->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 quietens 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->funs->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 quietens 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*_recv(). *HRDWR*_recv() 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.

XV. SNMP

Chapter 47. 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/) or ftp://sunsite.cnlab-switch.ch/mirror/ucd-snmp/ (ftp://sunsite.cnlab-switch.ch/mirror/ucd-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-4.1.2.tar.gz)
```

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.
```

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 abailable 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 `snmpping` 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;
unsinged 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 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/utils/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-smnp 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 trig-
        gering 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  con-
                 tains 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-inte-
                        ger  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  informa-
                        tion  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 [ MINSPACE | MINPERCENT% ]

                 Checks  the  named disks mounted at PATH for avail-
                 able disk space.  If the disk space  is  less  than
                 MINSPACE  (kB) if specified or less than MINPERCENT
                 (%) if a  %  sign  is  specified,  or  DEFDISKMINI-
                 MUMSPACE  (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 an 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  infi-
              nite  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 PREFX 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.  PREFX 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, sepa-
        rated 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  rela-
        tively  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  pri-
                 vacy  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 char-
                 acters.

                 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.   Mul-
                     tiple  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 trapcommu-
                     nity directive will be used. If PORT is not  speci-
                     fied,  the  well known SNMP trap port (162) will be
                     used.
```

```
PASS-THROUGH CONTROL
       pass MIBOID EXEC
              Passes entire control of MIBOID to  the  EXEC  pro-
              gram.   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
                     it's 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  corre-
                     sponding 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, simple 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  pro-
                     gram  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
                     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 con-
                                 trolled by the RWRITE definition  in
                                 the snmplib/snmp_impl.h source file.

EXAMPLE
       See the EXAMPLE.CONF file in the top level  source  direc-
       tory for a more detailed example of how the above informa-
       tion is used in real examples.

RE-READING snmpd.conf and snmpd.local.conf
       The ucd-snmp agent can be forced to re-read its configura-
       tion 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  pro-
              cess.

FILES
       share/snmp/snmpd.conf

SEE ALSO
       snmp_config(5), snmpd(1), EXAMPLE.conf, read_config(3).


                              27 Jan 2000              SNMPD.CONF(5)
```

XVI. Embedded HTTP Server

Chapter 48. Embedded HTTP Server

Intrduction

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.

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 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()`.

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 hander 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_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 hander 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 containg 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

```
int 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 )

int cyg_httpd_send_data( FILE *client, char *filename, char *request, void *arg );
```

The HTTP server defines a couple of predefined handers 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. 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.

XVII. 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.

Chapter 49. 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.

XVIII. 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 50. 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.

```
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.

XIX. 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 51. 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/cpuload/cpuload.h`.

cyg_cpuload_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_cpuload_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_cpuload_create

This function starts the CPU load measurments.

```
void cyg_cpuload_create(cyg_cpuload_t *cpuload,
                        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_cpuload_delete

This function stops the measurement process.

```
void cyg_cpuload_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.

XX. Application profiling

The profile_gprof package provides a mechanism to measure the runtime performance of an application. This is done by gathering an execution histogram.

When profiling is started on the target device, a `TFTP` server will be started which exports the single file `PROFILE.DAT` This analysis data can then be fetched by connecting to the target with a `TFTP` client program and then be processed by the `gprof` utility program.

> **NOTE:** Be sure and specify binary mode transfers for this data file, which may not be the default with on some `TFTP` client programs.

> **NOTE:** The port used for this `TFTP` server is configurable. The default will be the IETF standard port of 69/UDP, but it may be changed to any UDP port via the `CYGNUM_PROFILE_TFTP_PORT` CDL option.

Chapter 52. Profiling functions

API

In order for profile data to be gathered for an application, the program has to initiate the process. Once started, execution histogram data will be collected in a dynamic memory buffer. This data can be uploaded to a host using *TFTP*. A side effect of the upload of the data is that the histogram is reset. This is useful, especially for high resolution histograms, since the histogram data are collected as 16-bit counters which can be quickly saturated. For example, if the histogram is being collected at a rate of 10,000 samples per second, a hot spot in the program could saturate after only 6.5 seconds.

The API for the application profiling functions can be found in the file `<cyg/profile/profile.h>`.

profile_on

This function is used to initiate the gathering of the runtime execution histogram data.

```
void profile_on(void *start, void *end, int bucket_size, int resolution);
```

Calling this function will initiate execution profiling. An execution histogram is collected at the rate of *`resolution`* times per second. The area between *`start`* and *`end`* will be divided up into a number of buckets, each representing *`bucket_size`* program bytes in length. Using statistical sampling (via a high speed timer), when the program counter is found to be within the range *`start`*..*`end`*, the appropriate bucket (histogram entry) will be incremented.

The choice of *`resolution`* and *`bucket_size`* control how large the data gathered will be, as well as how much overhead is encumbered for gathering the histogram. Smaller values for *`bucket_size`* will garner better results (`gprof` can more closely align the data with actual function names) at the expense of a larger data buffer.

> **NOTE:** The value of *`bucket_size`* will be rounded up to a power of two.

XXI. eCos Power Management Support

Introduction

Name

`Introduction` — eCos support for Power Management

Introduction

The eCos Power Management package provides a framework for incorporating power management facilities in an embedded application. However its functionality is deliberately limited.

1. The package does not contain any support for controlling the current power mode of any given processor, device or board. Instead it is the responsibility of the appropriate HAL or device driver package to implement such support, by implementing *power controllers*. The power management package groups these power controllers together and provides an interface for manipulating them.
2. The package does not contain any power management policy support. Specifically, including this package in an application does not by itself ever cause the system to go into low-power mode. Instead it is the responsibility of a separate policy module, provided by higher-level application code or by some other package, to decide when it would be appropriate to switch from one power mode to another. The power management package then provides the mechanisms for making it happen.

Including Power Management

The power management package is never included automatically in an eCos configuration: it is not part of any target specification or of any template. Instead it must be added explicitly to a configuration if the intended application requires power management functionality. When using the command-line **ecosconfig** tool this can be achieved using a command such as:

```
$ ecosconfig add power
```

The generic eCos user documentation should be consulted for more information on how to use the various tools. The functionality provided by the power management package is defined in the header file `cyg/power/power.h`. This header file can be used by both C and C++ code.

Power Modes

There are four defined modes of operation:

active

The system is fully operational, and power consumption is expected to be high.

idle

There has been little or no activity for a short period of time. It is up to the policy module to determine what constitutes a short period of time, but typically it will be some tenths of a second or some small number of seconds. A possible action when entering idle mode is to reduce the system's clock speed, thus reducing the power drawn by the cpu.

Note that typically this power mode is not entered automatically whenever the idle thread starts running. Instead it is entered when the policy module discovers that for a certain period of time the system has been spending most of its time in the idle thread. Theoretically it is possible to implement a policy module that would cause a switch to idle mode as soon as the idle thread starts running, but that could result in a great many power mode changes for no immediate benefit.

sleep

The system has been idle for a significant period of time, perhaps some tens of seconds. It is desirable to shut down any hardware that is drawing a significant amount of power, for example a screen backlight.

off

The system is powered down. Power consumption should be minimized. Some special action may be needed before the system comes back up, for example the user may need to press a specific button.

The exact transitions that will happen are decided by the policy module. One policy module might include transitions from active to idle, from idle to sleep, from sleep to off, and from any of idle, sleep or off directly back to active. Another policy module might only use the active and off states, bypassing the intermediate ones.

Power Controllers

The power management package operates primarily on power controllers. The main functionality provided by a power controller is to switch the power mode for some part of the system, for example the lcd display or the cpu. A power controller consists primarily of a function which will be invoked to switch the power mode for the part of the overall system being controlled, plus some auxiliary data. A typical system will include a number of different power controllers:

1. Usually there will be one power controller `power_controller_cpu` associated with the processor or with the target platform, and provided by the corresponding HAL package. It is this controller which is responsible for switching off the system when entering the off mode, which makes it somewhat special: attempting to switch off the cpu before other devices like the lcd display does not make sense because the cpu would no longer be executing any instructions for the latter operation. Therefore this power controller has to be invoked last when switching to a lower-power mode, and similarly when switching back to a higher-power mode it will be invoked first.

   It should be noted that providing power management support is not a hard requirement when porting eCos to a new processor or platform, and many eCos ports predate the availability of power management support. Therefore for any given platform it is distinctly possible that `power_controller_cpu` is not yet provided, and if full power management functionality is desired then the appropriate HAL package would have to be extended first. System developers should examine the relevant HAL documentation and sources to determine what is actually available.

2. Some or all of the device drivers will supply their own power controllers, as part of the device driver package. It is not required that all device drivers provide power controllers. In some cases, especially for devices that

are integrated with the processor, `power_controller_cpu` will take care of the integrated devices as a side effect. In other cases the hardware may not provide any functionality that allows power consumption to be controlled. For any given device driver it is also possible that no power controller exists either because it was not required when the driver was written, or because the driver predates the availability of power management. Again the relevant documentation and sources should be consulted for further information.

3. There may be power controllers which are not associated directly with any specific hardware. For example a TCP/IP stack could provide a power controller so that it gets informed when the system has been reactivated: by looking at the system clock it can determine for how long the system has been switched off; using this information it can then recover from expired dhcp leases, or even to shut down any stream connections that may have become invalid (although arguably the stack should have refused to go to off mode while there were open connections).

Basic Operation

By default the Power Management package creates a thread during initialization. It is also possible for the package to be used without such a thread, for example in configurations which do not include a full kernel, and this alternative is described below. When a separate thread is used the stacksize and priority for this thread can be controlled by configuration options `CYGNUM_POWER_THREAD_STACKSIZE` and `CYGNUM_POWER_THREAD_PRIORITY`. Typically the thread will just wait on a semaphore internal to the package, and will do nothing until some other part of the system requests a change to the power mode.

At some point the policy module will decide that the system should move into a lower-power mode, for example from active to idle. This is achieved by calling the function `power_set_mode`, provided by the power management package and declared in `cyg/power/power.h`, with a single argument, `PowerMode_Idle`. This function manipulates some internal state and posts the semaphore, thus waking up the power management thread. Note that the function returns before the mode change has completed, and in fact depending on thread priorities this return may happen before any power controller has been invoked.

When the power management thread wakes up it examines the internal state to figure out what it should be doing. In this case it is supposed to change the global power mode, so it will iterate over all the power controllers requesting each one to switch to the idle mode. It is up to each power controller to handle this request appropriately. Optionally the thread will invoke a callback function after processing each power controller, so that higher-level code such as the policy module can more easily keep track of the actual state of each controller. Once the thread has iterated through all the power controllers it will again wait on the internal semaphore for the next request to arrive.

> **Note:** At present the power management thread always runs at a single priority, which defaults to a low priority. A possible future enhancement would be to support two separate priorities. When switching to a lower-powered mode the thread would run at a low priority as before, thus allowing other threads to run and get a chance to cancel this mode change. When switching to a higher-powered mode the thread would run at a high priority. This could be especially important when moving out of the off state: for example it would ensure that all device drivers get a chance to wake up before ordinary application threads get to run again and possibly attempt I/O operations.

Although usually calls to `power_set_mode` will come from just one place in the policy module, this is not a hard requirement. It is possible for multiple threads to call this function, with no need for any synchronization. If the power management thread is in the middle of performing a mode change and a new request comes in, the thread will detect this, abort the current operation, and start iterating through the power controllers again with the new mode. This check happens between every power controller invocation. Usefully this makes it possible for power controllers themselves to manipulate power modes: a power controller is invoked to change mode; for some reason it determines that the new mode is inappropriate; it calls `power_set_mode` to move the system back to another mode; when the power controller returns this event will be detected; the power management thread will abort the current mode change, and start the new one.

In addition to changing the power mode for the system as a whole, individual controllers can be manipulated using the function `power_set_controller_mode`. For example, while the system as a whole might be in active mode certain devices might be kept in sleep mode until they are explicitly activated. It is possible to mix concurrent calls to `power_set_mode` and `power_set_controller_mode`, and when a power controller is invoked it may use `power_set_controller_mode` to request further changes to its own or to another controller's mode as required.

There are some scenarios where the power management package should not use its own thread. One scenario is if the configuration is specifically for a single-threaded application such as RedBoot. Another scenario is if the policy module already involves a separate thread: it may make more sense if the various power management operations are synchronous with respect to the calling thread. The use of a separate thread inside the power management package is controlled by the configuration option `CYGPKG_POWER_THREAD`, which is active only if the kernel package is present and enabled by default.

If no separate power management thread is used then obviously the implementations of `power_set_mode` and `power_set_controller_mode` will be somewhat different: instead of waking up a separate thread to do the work, these functions will now manipulate the power controllers directly. If the system does still involve multiple threads then only one thread may call `power_set_mode` or `power_set_controller_mode` at a time: the power management package will not provide any synchronization, that must happen at a higher level. However when a power controller is invoked it can still call these functions as required.

Power Management Information

Name

`Obtaining Power Management Information` — finding out about the various power controllers in the system

Synopsis

```
#include <cyg/power/power.h>

extern PowerController __POWER__[], __POWER_END__;
extern PowerController power_controller_cpu;
extern cyg_handle_t    power_thread_handle;
PowerMode power_get_mode (void);
PowerMode power_get_desired_mode (void);
PowerMode power_get_controller_mode ( PowerController* controller );
PowerMode power_get_controller_desired_mode ( PowerController* controller );
const char* power_get_controller_id ( PowerController* controller );
```

Accessing Power Controllers

All the power controllers in a system are held in a table, filled in at link-time. The symbols `__POWER__` and `__POWER_END` can be used to iterate through this table, for example:

```
PowerController* controller;
for (controller  = &(__POWER__[0]);
     controller != &(__POWER_END__);
     controller++) {

     ...
}
```

Each controller has an associated priority, controlling the order in which they appear in the table. Typically a software-only component such as a TCP/IP stack would use a small number for the priority, so that it appears near the start of the table, whereas a device driver would be nearer the back of the table. When switching to a lower-powered mode the power management package will iterate through this table from front to back, thus ensuring that for example the TCP/IP stack gets a chance to shut down before the underlying ethernet or other hardware that the stack depends on. Similarly when switching to a higher-powered mode the power management package will iterate through this table from back to front.

In most systems there will be one special controller, `power_controller_cpu`, which should be provided by one of the architectural, variant or platform HAL packages. This controller will always be the last entry in the table. It is responsible for the final power down operation when switching to off mode. Other packages such as device drivers may or may not declare variable identifiers for their power controllers, allowing those controllers to be accessed by name as well as by their entries in the global table.

Global Power Modes

The function power_get_mode can be called at any time to determine the current power mode for the system as a whole. The return value will be one of PowerMode_Active, PowerMode_Idle, PowerMode_Sleep or PowerMode_Off. In normal circumstances it is unlikely that PowerMode_Off would be returned since that mode generally means that the cpu is no longer running.

The function power_get_desired_mode returns the power mode that the system should be running at. Most of the time this will be the same value as returned by power_get_mode. However a different value may be returned when in the middle of changing power modes. For example, if the current thread runs at a higher priority than the power management thread then the latter may have been pre-empted in the middle of a mode change: power_get_mode will return the mode the system was running at before the mode change started, and power_get_desired_mode will return the mode the system should end up in when the mode change completes, barring further calls to power_set_mode.

Individual Controller Power Modes

The power management package keeps track of the current and desired modes for each power controller, as well as the modes for the system as a whole. The function power_get_controller_mode takes a single argument, a pointer to a power controller, and returns the power mode that controller is currently running at. Similarly power_get_controller_desired_mode returns the power mode that controller should be running at. Most of the time the current and desired modes for a given controller will be the same, and will also be the same as the global power mode. However if the power management thread is preeempted in the middle of a mode change then some of the controllers will have been updated to the desired global mode, whereas others will still be at the old mode. The power management package also provides functionality for manipulating individual controllers, and for detaching controllers from global mode changes.

Power Controller Identification

In some scenarios the power management package will run completely automated, and there is no need to identify individual power controllers. Any form of identification such as a string description would serve no purpose, but would still consume memory in the final system. In other scenarios it may be very desirable to provide some means of identification. For example, while still debugging it may be useful to see a simple string when printing the contents of a power controller structure. Alternatively, if the application is expected to provide some sort of user interface that gives control over which parts of the system are enabled or disabled, a string identifier for each controller would be useful. To cope with these scenarios the power management package provides a configuration option CYGIMP_POWER_PROVIDE_STRINGS. When enabled, each power controller will contain a pointer to a constant string which can be accessed via a function power_get_controller_id. When disabled the system will not contain these strings, and the function will not be provided. The following code illustrates how to use this function.

```
#include <stdio.h>
#include <pkgconf/system.h>
#ifndef CYGPKG_POWER
# error The power management package is not present.
#endif
#include <pkgconf/power.h>
#ifndef CYGIMP_POWER_PROVIDE_STRINGS
# error Power controller identifiers are not available.
```

```
#endif
#include <cyg/power/power.h>

static const char*
mode_to_string(PowerMode mode)
{
    const char* result;
    switch(mode) {
      case PowerMode_Active : result = "active"; break;
      case PowerMode_Idle   : result = "idle"; break;
      case PowerMode_Sleep  : result = "sleep"; break;
      case PowerMode_Off    : result = "off"; break;
      default               : result = "<unknown>"; break;
    }
    return result;
}

int
main(int argc, char** argv)
{
    PowerController* controller;

    for (controller = &(__POWER__[0]);
         controller != &(__POWER_END__);
         controller++) {
        printf("Controller @ %p: %s, %s\n", controller,
               power_get_controller_id(controller),
               mode_to_string(power_get_controller_mode(controller)));
    }
    return 0;
}
```

The Power Management Thread

If the power management package is configured to use a separate thread then a handle for that thread is made available to higher-level code via the variable `power_thread_handle`. This handle can be used for a variety of purposes, including manipulating that thread's priority.

Changing Power Modes

Name

`Changing Power Modes` — reducing or increasing power consumption as needed

Synopsis

```
#include <cyg/power/power.h>
void power_set_mode ( PowerMode new_mode );
void power_set_controller_mode ( PowerController* controller ,  PowerMode new_mode );
void power_set_controller_mode_now ( PowerController* controller ,  PowerMode new_mode
);
```

Changing the Global Power Mode

The primary functionality supported by the power management package is to change the system's global power mode. This is achieved by calling the function `power_set_mode` with a single argument, which should be one of `PowerMode_Active`, `PowerMode_Idle`, `PowerMode_Sleep` or `PowerMode_Off`. Typically this function will only be invoked in certain scenarios:

1. A typical system will contain a policy module which is primarily responsible for initiating power mode changes, and a thread inside the power management package. The policy module will call `power_set_mode`, which has the effect of manipulating some internal state in the power management package and waking up its thread. When this thread gets scheduled to run (its priority is controlled by a configuration option), it will iterate over the power controllers and invoke each controller to change its power mode. There is support for a callback function, and for detached power controllers.
2. After a call to `power_set_mode` but before the power management thread has had a chance to iterate over all the controllers, or even before the thread has been rescheduled at all, the policy module may decide that a different power mode would be more appropriate for the current situation and calls `power_set_mode` again. This has the effect of aborting the previous mode change, followed by the power management thread iterating over the power controllers again for the new mode.
3. If there is no single policy module responsible for power mode changes, any code can call `power_set_mode`. If there are multiple calls in quick succession, earlier calls will be aborted and the system should end up in the power mode corresponding to the last call
4. As a special case, it is possible for a power controller to call `power_set_mode` when invoked by the power management thread. For example a power controller could decide that it is inappropriate for the system to go to sleep because the device it is associated with is still busy. The effect is as if the policy module had called `power_set_mode` again before the mode change had completed.

If the power management package has been configured not to use a separate thread then obviously the behaviour is somewhat different. The call to `power_set_mode` will now iterate over the various power controllers immediately, rather than leaving this to a separate thread, and the whole mode change completes before `power_set_mode` returns. If some other thread or a DSR calls `power_set_mode` concurrently the behaviour of the system is undefined.

However, it is still legal for a power controller to call power_set_mode: effectively this is a recursive call; it is detected by the system, and internal state is updated; the recursive power_set_mode call now returns, and when the power controller returns back to the original power_set_mode call it detects what has happened, aborts the previous mode change, and starts a new mode change as requested by the controller.

power_set_mode is normally invoked from thread context. If a separate power management thread is used it can be invoked safely from DSR context. If the system is configured not to use such a thread, it may or may not be safe to invoke this function from DSR context: essentially the function just iterates through the various power controllers, and the documentation or source code of each controller present in the current system will have to be examined to determine whether or not this can happen safely in DSR context. power_set_mode should never be invoked from ISR context.

Manipulating an Individual Power Controller

In some cases it is desirable to set the power mode of an individual controller separately from the mode for the system as a whole. For example if a device is not currently being used then the associated power controller could be set to PowerMode_Off, even while the system as a whole is still active. This can be achieved by calling the function power_set_controller_mode. It takes two arguments: the first identifies a particular controller; the second specifies the desired new power mode for that controller. The function operates in much the same way as power_set_mode, for example if a separate power management thread is being used then power_set_controller_mode operates by manipulating some internal state and waking up that thread. The limitations are also much the same as for power_set_mode, so for example power_set_controller_mode should not be invoked from inside ISRs.

Manipulating individual controllers is often used in conjunction with the function power_set_controller_attached, allowing the policy module to specify which controllers are affected by global mode changes.

Direct Manipulation of a Power Controller

In exceptional circumstances it may be necessary to invoke a power controller directly, bypassing the power management thread and higher-level functionality such as callback functions. The function power_set_controller_mode_now allows this. It takes two arguments, a controller and a mode, just like power_set_controller_mode.

Use of power_set_controller_mode_now is dangerous. For example no attempt is made to synchronise with any other power mode changes that might be happening concurrently. A possible use is when the system gets woken up out of sleep mode: depending on the hardware, on which power controllers are present, and on the application code it may be necessary to wake up some power controllers immediately before the system as a whole is ready to run again.

Support for Policy Modules

Name

`Support for Policy Modules` — closer integration with higher-level code

Synopsis

```
#include <cyg/power/power.h>
void power_set_policy_callback ( void (*)(PowerController*, PowerMode, PowerMode,
PowerMode, PowerMode) callback );
void (*)(PowerController*, PowerMode, PowerMode, PowerMode, PowerMode)
power_get_policy_callback (void);
CYG_ADDRWORD power_get_controller_policy_data ( PowerController* controller );
void power_set_controller_policy_data ( PowerController* controller ,  CYG_ADDRWORD
data );
```

Policy Callbacks

The use of a separate thread to perform power mode changes in typical configurations can cause problems for some policy modules. Specifically, the policy module can request a mode change for the system as a whole or for an individual controller, but it does not know when the power management thread actually gets scheduled to run again and carry out the request. Although it would be possible for the policy module to perform some sort of polling, in general that is undesirable.

To avoid such problems the policy module can install a callback function using `power_set_policy_callback`. The current callback function can be retrieved using `power_get_policy_callback`. If a callback function has been installed then it will be called by the power management package whenever a power controller has been invoked to perform a mode change. The callback will be called in the context of the power management thread, so usually it will have to make use of thread synchronisation primitives to interact with the main policy module. It is passed five arguments:

1. The power controller that has just been invoked to perform a mode change.
2. The mode this controller was running at before the invocation.
3. The current mode this controller is now running at.
4. The desired mode before the power controller was invoked. Usually this will be the same as the current mode, unless the controller has decided for some reason that this was inappropriate.
5. The current desired mode. This will differ from the previous argument only if there has was another call to `power_set_mode` or `power_set_controller_mode` while the power controller was being invoked, probably by the power controller itself.

A simple example of a policy callback function would be:

```
static void
power_callback(
```

```
    PowerController* controller,
    PowerMode old_mode,
    PowerMode new_mode,
    PowerMode old_desired_mode,
    powerMode new_desired_mode)
{
    printf("Power mode change: %s, %s -> %d\n",
        power_get_controller_id(controller),
        mode_to_string(old_mode),
        mode_to_string(new_mode));

    CYG_UNUSED_PARAM(PowerMode, old_desired_mode);
    CYG_UNUSED_PARAM(PowerMode, new_desired_mode);
}

int
main(int argc, char** argv)
{
    ...
    power_set_policy_callback(&power_callback);
    ...
}
```

If `power_set_controller_mode_now` is used to manipulate an individual controller the policy callback will not be invoked. This function may get called from any context including DSRs, and even if there is already a call to the policy callback happening in some other context, so invoking the callback would usually be unsafe.

If the power management package has not been configured to use a separate thread then `power_set_mode` and `power_set_controller_mode` will manipulate the power controllers immediately and invoke the policy callback afterwards. Therefore the policy callback will typically run in the same context as the main policy module.

Policy-specific Controller Data

Some policy modules may want to associate some additional data with each power controller. This could be achieved by for example maintaining a hash table or similar data structure, but for convenience the power management package allows higher-level code, typically the policy module, to store and retrieve one word of data in each power controller. The function `power_set_controller_policy_data` takes two arguments, a pointer to a power controller and a CYG_ADDRWORD of data: by appropriate use of casts this word could be an integer or a pointer to some data structure. The matching function `power_get_controller_policy_data` retrieves the word previously installed, and can be cast back to an integer or pointer. The default value for the policy data is 0.

For example the following code fragment stores a simple index value in each power controller. This could then be retrieved by the policy callback.

```
unsigned int     i = 0;
PowerController* controller;

for (controller = &(__POWER__[0]);
     controller != &(__POWER_END__);
     controller++) {
    power_set_controller_policy_data(controller, (CYG_ADDRWORD) i++);
}
```

Not all policy modules will require per-controller data. The configuration option CYGIMP_POWER_PROVIDE_POLICY_DATA can be used to control this functionality, thus avoiding wasting a small amount of memory inside each power controller structure.

Attached and Detached Controllers

Name

`Attached and Detached Controllers` — control which power controllers are affected by global changes

Synopsis

```
#include <cyg/power/power.h>
cyg_bool power_get_controller_attached ( PowerController* controller );
void power_set_controller_attached ( PowerController* controller , cyg_bool new_state
);
```

Detaching Power Controllers

By default the global operation `power_set_mode` affects all power controllers. There may be circumstances when this is not desirable. For example if a particular device is not currently being used then it can be left switched off: the rest of the system could be moving between active, idle and sleep modes, but there is no point in invoking the power controller for the unused device. To support this the power management package supports the concept of attached and detached controllers. By default all controllers are attached, and hence will be affected by global mode changes. A specific controller can be detached using the function `power_set_controller_attached`. This function takes two arguments, one to specify a particular controller and another to specify the desired new state. `power_get_controller_attached` can be used to determine whether or not a specific controller is currently attached.

The attached or detached state of a controller only affects what happens during a global mode change, in other words following a call to `power_set_mode`. It is still possible to manipulate a detached controller using `power_set_controller_mode` or `power_set_controller_mode_now`.

Implementing a Power Controller

Name

`Implementing a Power Controller` — adding power management support to device drivers and other packages

Implementing a Power Controller

A system will have some number of power controllers. Usually there will be one power controller for the cpu, `power_controller_cpu`, typically provided by one of the HAL packages and responsible for managing the processor itself and associated critical components such as memory. Some or all of the device drivers will provide power controllers, allowing the power consumption of the associated devices to be controlled. There may be some arbitrary number of other controllers present in the system. The power management package does not impose any restrictions on the number or nature of the power controllers in the system, other than insisting that at most one `power_controller_cpu` be provided.

Each power controller involves a single data structure of type PowerController, defined in the header file `cyg/power/power.h`. These data structures should all be placed in the table `__POWER__`, so that the power management package and other code can easily locate all the controllers in the system. This table is constructed at link-time, avoiding code-size or run-time overheads. To facilitate this the package provides two macros which should be used to define a power controller, `POWER_CONTROLLER()` and `POWER_CONTROLLER_CPU()`.

The macro `POWER_CONTROLLER` takes four arguments:

1. A variable name. This can be used to access the power controller directly, as well as via the table.
2. A priority. The table of power controllers is sorted, such that power controllers with a numerically lower priority come earlier in the table. The special controller `power_controller_cpu` always comes at the end of the table. When moving from a high-power mode to a lower-powered mode, the power management package iterates through the table from front to back. When moving to a higher-powered mode the reverse direction is used. The intention is that the power controller for a software-only package such as a TCP/IP stack should appear near the start of the table, whereas the controllers for the ethernet and similar devices would be near the end of the table. Hence when the policy module initiates a mode change to a lower-powered mode the TCP/IP stack gets a chance to cancel this mode change, before the devices it depends on are powered down. Similarly when moving to a higher-powered mode the devices will be re-activated before any software that depends on those devices.

   The header file `cyg/power/power.h` defines three priorities `PowerPri_Early`, `PowerPri_Typical` and `PowerPri_Late`. For most controllers one of these priorities, possibly with a small number added or subtracted, will give sufficient control. If an application developer is uncertain about the relative priorities of the various controllers, a simple test program that iterates over the table will quickly eliminate any confusion.

3. A constant string identifier. If the system has been configured without support for such identifiers (`CYGIMP_POWER_PROVIDE_STRINGS`) then this identifer will be discarded at compile-time. Otherwise it will be made available to higher-level code using the function `power_get_controller_id`.
4. A function pointer. This will be invoked to perform actual mode changes, as described below.

A typical example of the use of the `POWER_CONTROLLER` macro would be as follows:

```
#include <pkgconf/system.h>

#ifdef CYGPKG_POWER
# include <cyg/power/power.h>

static void
xyzzy_device_power_mode_change(
    PowerController* controller,
    PowerMode        desired_mode,
    PowerModeChange  change)
{
   // Do the work
}

static POWER_CONTROLLER(xyzzy_power_controller, \
                        PowerPri_Late,          \
                        "xyzzy device",         \
                        &xyzzy_device_power_mode_change);
#endif
```

This creates a variable `xyzzy_power_controller`, which is a power controller data structure that will end up near the end of the table of power controllers. Higher-level code can iterate through this table and report the string `"xyzzy device"` to the user. Whenever there is a mode change operation that affects this controller, the function `xyzzy_device_power_mode_change` will be invoked. The variable is declared static so this controller cannot be manipulated by name in any other code. Alternatively, if the variable had not been declared static other code could manipulate this controller by name as well as through the table, especially if the package for the xyzzy device driver explicitly declared this variable in an exported header file. Obviously exporting the variable involves a slight risk of a name clash at link time.

The above code explicitly checks for the presence of the power management package before including that package's header file or providing any related functionality. Since power management functionality is optional, such checks are recommended.

The macro `POWER_CONTROLLER_CPU` only takes two arguments, a string identifier and a mode change function pointer. This macro always instantiates a variable `power_controller_cpu` so there is no need to provide a variable name. The resulting power controller structure always appears at the end of the table, so there is no need to specify a priority. Typical usage of the `POWER_CONTROLLER_CPU` macro would be:

```
static void
wumpus_processor_power_mode_change(
    PowerController* controller,
    PowerMode        desired_mode,
    PowerModeChange  change)
{
   // Do the work
}

POWER_CONTROLLER_CPU("wumpus processor", \
                     &wumpus_processor_power_mode_change);
```

This defines a power controller structure `power_controller_cpu`. It should not be declared static since higher-level code may well want to manipulate the cpu's power mode directly, and the variable is declared by the power management package's header file.

Some care has to be taken to ensure that the power controllers actually end up in the final executable. If a power controller variable ends up in an ordinary library and is never referenced directly then typically the linker will believe that the variable is not needed and it will not end up in the executable. For eCos packages this can be achieved in the CDL, by specifying that the containing source file should end up in `libextras.a` rather than the default `libtarget.a`:

```
cdl_package CYGPKG_HAL_WUMPUS_ARCH {
    ...
    compile -library=libextras.a data.c
}
```

If the file `data.c` instantiates a power controller this is now guaranteed to end up in the final executable, as intended. Typically HAL and device driver packages will already have some data that must not be eliminated by the linker, so they will already contain a file that gets built into `libextras.a`. For power controllers defined inside application code it is important that the power controllers end up in `.o` object files rather than in `.a` library archive files.

All the real work of a power controller is done by the mode change function. If the power management package has been configured to use a separate thread then this mode change function will be invoked by that thread (except for the special case of `power_set_controller_mode_now`). If no separate thread is used then the mode change function will be invoked directly by `power_set_mode` or `power_set_controller_mode`.

The mode change function will be invoked with three arguments. The first argument identifies the power controller. Usually this argument is not actually required since a given mode change function will only ever be invoked for a single power controller. For example, `xyzzy_device_power_mode_change` will only ever be used in conjunction with `xyzzy_power_controller`. However there may be some packages which contain multiple controllers, all of which can share a single mode change function, and in that case it is essential to identify the specific controller. The second argument specifies the mode the controller should switch to, if possible: it will be one of `PowerMode_Active`, `PowerMode_Idle`, `PowerMode_Sleep` or `PowerMode_Off`. The final argument will be one of `PowerModeChange_Controller`, PowerModeChange_ControllerNow, or `PowerModeChange_Global`, and identifies the call that caused this invocation. For example, if the mode change function was invoked because of a call to `power_set_mode` then this argument will be `PowerModeChange_Global`. It is up to each controller to decide how to interpret this final argument. A typical controller might reject a global request to switch to off mode if the associated device is still busy, but if the request was aimed specifically at this controller then it could instead abort any current I/O operations and switch off the device.

The PowerController data structure contains one field, *`mode`*, that needs to be updated by the power mode change function. At all times it should indicate the current mode for this controller. When a mode change is requested the desired mode is passed as the second argument. The exact operation of the power mode change function depends very much on what is being controlled and the current circumstances, but some guidelines are possible:

1. If the request can be satisfied without obvious detriment, do so and update the *`mode`* field. Reducing the power consumption of a device that is not currently being used is generally harmless.
2. If a request is a no-op, for example if the system is switching from idle to sleep mode and the controller does not distinguish between these modes, simply act as if the request was satisfied.
3. If a request is felt to be unsafe, for example shutting down a device that is still in use, then the controller may decide to reject this request. This is especially true if the request was a global mode change as opposed to one intended specifically for this controller: in the latter case the policy module should be given due deference. There are a number of ways in which a request can be rejected:

a. If the request cannot be satisfied immediately but may be feasible in a short while, leave the *mode* field unchanged. Higher-level code in the policy module can interpret this as a hint to retry the operation a little bit later. This approach is also useful if the mode change can be started but will take some time to complete, for example shutting down a socket connection, and additional processing will be needed later on.

b. If the request is felt to be inappropriate, for example switching off a device that is still in use, the mode change function can call `power_set_controller_mode` to reset the desired mode for this controller back to the current mode. Higher-level code can then interpret this as a hint that there is more activity in the system than had been apparent.

c. For a global mode change, if the new mode is felt to be inappropriate then the power controller can call `power_set_mode` to indicate this. An example of this would be the policy module deciding to switch off the whole unit while there is still I/O activity.

Mode change functions should not directly manipulate any other fields in the PowerController data structure. If it is necessary to keep track of additional data then static variables can be used.

It should be noted that the above are only guidelines. Their application in any given situation may be unclear. In addition the detailed requirements of specific systems will vary, so even if the power controller for a given device driver follows the above guidelines exactly it may turn out that slightly different behaviour would be more appropriate for the actual system that is being developed. Fortunately the open source nature of eCos allows system developers to fine-tune power controllers to meet their exact requirements.

XXII. 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 than 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 `CYG-`

GLO_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_sa11x0_ep0.enumeration_data = &usb_enum_data;
    ...
    usbs_start(&usbs_sa11x0_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 possible 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`, `ISOCHRONOUS`, `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_sa11x0_ep0.enumeration_data = &usb_enum_data;
    ...
    usbs_start(&usbs_sa11x0_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 argument, 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 messsage.

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 {
    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* wit *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 invoked 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_SA11X0_EP1_DEVTAB_ENTRY

static CHAR_DEVIO_TABLE(usbs_sa11x0_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_sa11x0_ep1_devtab_entry,
                         CYGDAT_DEVS_USB_SA11X0_DEVTAB_BASENAME "1r",
                         0,
                         &usbs_sa11x0_ep1_devtab_functions,
                         &usbs_sa11x0_devtab_dummy_init,
                         0,
                         (void*) &usbs_sa11x0_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`, `ISOCHRONOUS` 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            : 0x0FFFF,
        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 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 usbtarget. 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. usbtarget provides mechanisms for running a wide range of tests.
2. usbtarget 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 usbtarget. 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 usbtarget 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_USBTEST` 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 suid root 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 necessarary, 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 0x0FFFF 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 $usbtest::bulk_in($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 `usbtest::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 `usbtest::bulk_in_endpoints` or `usbtest::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*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* $usbtest::MULTIPLIER data+ $usbtest::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 was 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.

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.

XXIII. eCos Support for Developing USB-ethernet Peripherals

Introduction

Name

`Introduction` — eCos support for developing USB ethernet peripherals

Introduction

The eCos USB-ethernet package provides additional support for USB peripherals that involve some sort of ethernet-style network. This can be a traditional ethernet, or it can involve some other networking technology that uses ethernet frames as a unit of transfer. It provides functions to transfer ethernet frames over the USB bus, handles certain control messages from the host, and optionally it can provide a network device driver for use by the eCos TCP/IP stack. The package comes with an example host-side device driver.

The USB-ethernet package is not tied to any specific hardware. It requires the presence of USB hardware and a suitable device driver, but not all USB peripherals involve ethernet communications. Hence the configuration system cannot load the 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:

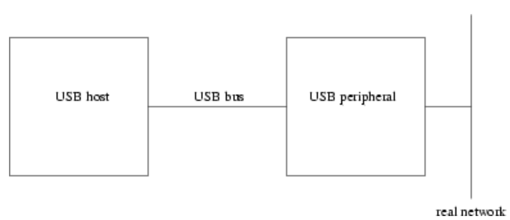
```
$ ecosconfig add usbs_eth
```

Typically, this will automatically cause the USB device driver to become active. Loading the USB-ethernet package automatically provides functionality for initialization, data transfer, and the handling of control messages and state changes. If the current configuration includes the eCos TCP/IP stack then the network device driver support will be enabled as well by default, allowing the stack to exchange ethernet frames over the USB bus.

There is a USB standard for a class of communication devices including ethernet. The package does not implement this standard, due to limitations in the hardware for which the package was first developed. Instead, the package uses its own protocol between USB host device driver and the peripheral.

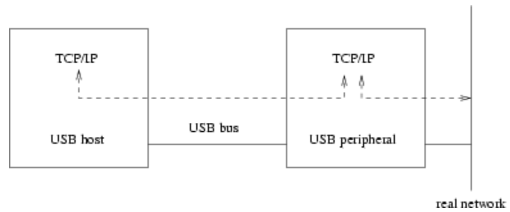
Usage Scenarios

The USB-ethernet package can be used several different scenarios. In a simple scenario, the peripheral serves only to connect the USB host to a suitable network:



After initialization, and once the USB connection between host and peripheral has been established, higher-level code needs to detect packets that are intended for the host, and to forward these. This can be achieved by the low-level `usbs_eth_start_tx` function. Similarly, higher-level code needs to detect packets coming from the host, using `usbs_eth_start_rx`, and to forward these using the real network. As far as the host is concerned it is connected directly to the network. In this scenario there is no confusion about addresses: there is a single MAC address for the host/peripheral combination, corresponding to the connection to the real network, and it is this address which should be supplied during initialization.

In a more complicated scenario, there is a TCP/IP stack running inside the peripheral.



This involves the USB-ethernet package providing a service both to the host and to the eCos TCP/IP stack. It achieves the latter by acting as an eCos network device. Typically, the TCP/IP stack will be configured to act as a network bridge. The USB peripheral needs to examine the packets arriving over the real network. Some of these packets will be intended for the host, while others will be intended for the peripheral itself. To distinguish between these two scenarios, two distinct MAC addresses are needed: one for the host, and one for the peripheral. Similarly, packets sent by the host may have to be forwarded via the real network, or they may be intended for the TCP/IP stack inside the peripheral. Packets generated inside the peripheral's TCP/IP stack may need to be sent via the real network or over the USB bus. The network bridge software will have to take care of all these possibilities. Unusually for a network bridge, one of the network segments being bridged will only ever have one machine attached.

There are other possible usage scenarios. For example, the peripheral might not be attached to a real network at all. Instead it could be the USB host that acts as a network bridge, allowing a TCP/IP stack inside the peripheral to communicate with the outside world. The various details will depend on the exact type of peripheral being developed.

Initializing the USB-ethernet Package

Name

usbs_eth_init — Initializing the USB-ethernet Package

Synopsis

```
#include <cyg/io/usb/usbs_eth.h>
void usbs_eth_init(usbs_eth* usbeth, usbs_control_endpoint* ep0, usbs_rx_endpoint* ep1,
usbs_tx_endpoint* ep2, unsigned char* mac_address);
```

Description

The USB-ethernet package is not tied to any specific hardware. It requires certain functionality: there must be USB-slave hardware supported by a device driver; there must also be two endpoints for bulk transfers between host and peripheral, one for each direction; there must also be a control endpoint, although of course that is implicit with any USB hardware.

However, USB-slave hardware may well provide more endpoints than the minimum required for ethernet support. Some of those endpoints might be used by other packages, while other endpoints might be used directly by the application, or might not be needed for the peripheral being built. There is also the possibility of a USB peripheral that supports multiple configurations, with the ethernet support active in only some of those configurations. The USB-ethernet package has no knowledge about any of this, so it relies on higher-level code to tell it which endpoints should be used and other information. This is the purpose of the `usbs_eth_init` function.

The first argument identifies the specific usbs_eth data structure that is affected. It is expected that the vast majority of affected applications will only provide a single USB-ethernet device to a single host, and the package automatically provides a suitable data structure `usbs_eth0` to support this. If multiple usbs_eth structures are needed for some reason then these need to be instantiated by other code, and each one needs to be initialised by a call to `usbs_eth_init()`.

The next three arguments identify the endpoints that should be used for USB communications: a control endpoint, a receive endpoint for ethernet packets coming from the host to the peripheral, and a transmit endpoint for ethernet packets going in the other direction. Obviously all three endpoints should be provided by the same USB hardware. The USB-ethernet package assumes that it has sole access to the receive and transmit endpoints, subject to the use of `usbs_eth_disable` and `usbs_eth_enable` control functions. The package also assumes that no other code is interested in USB state changes or class control messages: it installs handlers `usbs_eth_state_change_handler` and `usbs_eth_class_control_handler` in the control endpoint. If any other code does need to handle USB state changes or class control messages then replacement handlers should be installed after the call to `usbs_eth_init`, and those replacements should invoke the USB-ethernet ones when appropriate.

The final argument to `usbs_eth_init` specifies the MAC address (or Ethernet Station Address) that should be provided to the host-side device driver. Since the USB-ethernet package does not interact directly with a real ethernet device it cannot obtain the MAC address from any hardware. Instead, it must be supplied by higher-level code. The details depend on the scenario in which the USB-ethernet package is being used.

The call to `usbs_eth_init` should normally happen after the enumeration data has been provided but before the underlying USB device driver has been started. If the USB device were to be started first then a connection between host and peripheral could be established immediately, and the host-side device driver would attempt to contact the USB-ethernet package for information such as the MAC address.

```
int
main(int argc, char** argv)
{
    unsigned char host_MAC[6] = { 0x40, 0x5d, 0x90, 0xa9, 0xbc, 0x02 };

    usbs_sa11x0_ep0.enumeration_data    = &usb_enum_data;
    ...
    usbs_eth_init(&usbs_eth0, &usbs_sa11x0_ep0, &usbs_sa11x0_ep1, &usbs_sa11x0_ep2, host_MAC);
    ...
    usbs_start(&usbs_sa11x0_ep0);
    ...
}
```

USB-ethernet Data Transfers

Name

`USB-ethernet Data Transfers` — Exchanging ethernet packets with the USB host

Synopsis

```
#include <cyg/io/usb/usbs_eth.h>
void usbs_eth_start_rx(usbs_eth* usbseth, unsigned char* buffer, void (*)(usbs_eth*,
void*, int) complete_fn, void* complete_data);
void usbs_eth_start_tx(usbs_eth* usbseth, unsigned char* buffer, void (*)(usbs_eth*,
void*, int) complete_fn, void* complete_data);
```

Description

The USB-ethernet package provides two main modes of operation. In the first mode it provides a network device driver for use by a TCP/IP stack running inside the USB peripheral. All incoming ethernet packages should be passed up the TCP/IP stack, and only the stack will generate outgoing packets. Apart from initialization and possibly certain control operations, higher-level code will not interact with the USB-ethernet package directly.

In the second mode there is no TCP/IP stack running inside the USB peripheral. For example, a simple USB-ethernet converter has an ethernet chip and a USB port: ethernet packets received by the ethernet chip need to be forwarded to the USB host, and ethernet packets sent by the USB host need to be sent out of the ethernet chip. `usbs_eth_start_rx` and `usbs_eth_start_tx` allow for this lower-level access to the USB-ethernet package.

The two modes of operation are mutually exclusive. If the network device driver mode is enabled then application code should communicate at the TCP/IP level, and not by using the lower-level functions. Instead, it is the network device driver that will make use of these functions, and it assumes that it has exclusive access. The package does not perform any locking.

The transmit and receive functions work in much the same way. The first argument identifies the usbs_eth structure that should be used. For the majority of applications this will be `usbs_eth0`. The second argument specifies the location of the ethernet packet; outgoing for `usbs_eth_start_tx` and incoming for `usbs_eth_start_rx`. This buffer should correspond to the protocol:

1. Outgoing packets can consist of up to 1516 bytes, consisting of a two-byte header specific to USB-ethernet followed by a standard ethernet frame (a header with 6-byte destination address, 6-byte source address and a further two bytes, followed by a payload of up to 1500 bytes). The two-byte USB-ethernet header consists simply of the size of the ethernet frame, i.e. the size of the rest of the packet not including the USB-ethernet header, with the least significant byte first.
2. For incoming packets the supplied buffer should usually be at least 1516 bytes. There may be special circumstances in which a smaller buffer might be safe; for example, if the host-side device driver is modified to support only smaller packets. Once the packet has been received the buffer will contain a two-byte header specific to USB-ethernet, followed by a normal ethernet frame. The header gives the size of the ethernet frame, excluding the header, with the least significant byte first.

Both `usbs_eth_start_tx` and `usbs_eth_start_rx` are asynchronous: the transfer is started and, some time later, a completion function will be invoked. The third and fourth arguments to both `usbs_eth_start_tx` and `usbs_eth_start_rx` supply the completion function and an argument to that function respectively. The completion function will be invoked with three arguments: a pointer to the usbs_eth data structure, usually `usbs_eth0`; the supplied completion data ; and a return code field. A negative value indicates that an error occurred, for example `-EPIPE` if the connection between USB host and peripheral has been broken, or `-EAGAIN` if an endpoint has been halted. A positive value indicates the total size of the transfer, which should correspond to the size in the USB-ethernet header plus an additional two bytes for the header itself.

If the data transfer is succesful then the completion function will typically be invoked in DSR context rather than in thread context, although this depends on the implementation of the underlying USB device driver. 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. Note that if the transfer finishes quickly then the completion function may be invoked before `usbs_eth_start_rx` or `usbs_eth_start_tx` returns. This is especially likely to happen if the current thread is descheduled after starting the data transfer but before returning from these functions.

For transmit operations, it is possible for `usbs_eth_start_tx` to invoke the completion function immediately. If there is no current connection between host and target then the transmit will fail immediately with `-EPIPE`. In addition the USB-ethernet package will check the destination MAC address and make sure that the ethernet frame really is intended for the host: either it must be for the address specified in the initialization call `usbs_eth_init`, or it must be a broadcast packet, or the host must have enabled promiscuous mode.

USB-ethernet State Handling

Name

`USB-ethernet State Handling` — Maintaining the USB-ethernet connection with the host

Synopsis

```
#include <cyg/io/usb/usbs_eth.h>
usbs_control_return usbs_eth_class_control_handler(usbs_control_endpoint* ep0, void*
callback_data);
void usbs_eth_state_change_handler(usbs_control_endpoint* ep0, void* callback_data,
usbs_state_change change, int old_state);
void usbs_eth_disable(usbs_eth* usbseth>);
void usbs_eth_enable(usbs_eth* usbseth>);
```

Description

When the USB-ethernet package is initialized by a call to `usbs_eth_init` it installs `usbs_eth_state_change_handler` to handle USB state changes. This allows the package to detect when the connection between the host and the peripheral is established or broken, resulting in internal calls to `usbs_eth_enable` and `usbs_eth_disable` respectively. This is appropriate if no other code needs to access the USB device. However, if there is other code, either other USB-related packages or the application itself, that needs to perform I/O over the USB bus, then typically the USB-ethernet package should not have exclusive access to state change events. Instead, the assumption is that higher-level code, typically provided by the application, will install an alternative state change handler in the control endpoint data structure after the call to `usbs_eth_init`. This alternative handler will either chain into `usbs_eth_state_change_handler` when appropriate, or else it will invoke `usbs_eth_enable` and `usbs_eth_disable` directly. For further details of state change handlers and control endpoints generally, see the documentation for the common USB-slave package.

Similarly, `usbs_eth_init` will install `usbs_eth_class_control_handler` in the control endpoint data structure as the appropriate handler for class-specific USB control messages. This code will handle the ethernet-specific control messages , for example requests by the host to enable or disable promiscuous mode or to obtain the MAC address. If the USB device is not shared with any other code then this is both necessary and sufficient. However, if other code is involved and if that code also needs to process certain control messages, higher-level code should install its own handler and chain to the USB-ethernet one when appropriate. It should be noted that the request code is encoded in just a single byte, so there is a real possibility that exactly the same number will be used by different protocols for different requests. Any such problems will have to be identified and resolved by application developers, and may involve modifying the source code for the USB-ethernet package.

As an alternative to chaining the state change handler, higher-level code can instead call `usbs_eth_disable` and `usbs_eth_enable` directly. These functions may also be called if the USB-ethernet package should become inactive for reasons not related directly to events on the USB bus. The main effect of `usbs_eth_enable` is to restart receive operations and to allow transmits. The main effect of `usbs_eth_disable` is to block further transmits: any current receive operations need to be aborted at the USB level, for example by halting the appropriate endpoint.

Network Device for the eCos TCP/IP Stack

Name

Network Device — USB-ethernet support for the eCos TCP/IP Stack

Description

If the USB peripheral involves running the eCos TCP/IP stack and that stack needs to use USB-ethernet as a transport layer (or as one of the transports), then the USB-ethernet package can provide a suitable network device driver. It is still necessary for higher-level code to perform appropriate initialization by calling `usbs_eth_init`, but after that it will be the TCP/IP stack rather than application code that transmits or receives ethernet frames.

Not all peripherals involving the USB-ethernet package will require a TCP/IP stack. Hence the provision of the network device is controlled by a configuration option `CYGPKG_USBS_ETHDRV`. By default this will be enabled if the TCP/IP package `CYGPKG_NET` is loaded, and disabled otherwise.

There are a number of other configuration options related to the network device. `CYGFUN_USBS_ETHDRV_STATISTICS` determines whether or not the package will maintain statistics, mainly intended for SNMP: by default this will be enabled if the SNMP support package `CYGPKG_SNMPAGENT` is loaded, and disabled otherwise. The name of the ethernet device is controlled by `CYGDATA_USBS_ETHDRV_NAME`, and has a default value of either `eth0` or `eth1` depending on whether or not there is another network device driver present in the configuration.

Usually eCos network device drivers default to using DHCP for obtaining necessary information such as IP addresses. This is not appropriate for USB-ethernet devices. On the host-side the USB-ethernet network device will not exist until the USB peripheral has been plugged in and communication has been established. Therefore any DHCP daemon on the host would not be listening on that network device at the point that eCos requests its IP and other information. A related issue is that the use of DHCP would imply the presence of a DHCP daemon on every affected host machine, as opposed to a single daemon (plus backups) for the network as a whole. For these reasons the USB-ethernet package precludes the use of DHCP as a way of setting the IP address, instead requiring alternatives such as manual configuration.

Example Host-side Device Driver

Name

`Example Host-side Device Driver` — Provide host-side support for the eCos USB-ethernet package

Description

The USB-ethernet package is supplied with a single host-side device driver. This driver has been developed against the Linux kernel 2.2.16-22, as shipped with Red Hat 7. The driver is provided as is and should not be considered production quality: for example it only checks for a bogus vendor id `0x4242` rather than an official vendor id supplied by the USB Implementers Forum (http://www.usb.org/). Also, if the peripheral involves multiple configurations or multiple interfaces, it will fail to detect this. However, the driver can be used for simple testing and as the basis of a full device driver. Details of the protocol used between host and peripheral can be found in the Communication Protocol section.

The host-side device driver can be found in the `host` subdirectory of the USB-ethernet package, specifically the file `ecos_usbeth.c`, and comes with a `Makefile`. Both files may need to be modified for specific applications. For example, the vendor id table `ecos_usbeth_implementations` may need to be updated for the specific USB peripheral being built. The `Makefile` assumes that the Linux kernel sources reside in `/usr/src/linux`, and that the kernel has already been configured and built. Assuming this is the case, the device driver can be built simply by invoking **make** with no additional arguments. This will result in a dynamically loadable kernel module, `ecos_usbeth.o`, in the current directory.

> **Note:** As normal for Linux kernel builds, the generated files such as `ecos_usbeth.o` live in the same directory as the source tree. This is very different from eCos where the source tree (or component repository) is kept separate from any builds. There may be problems if the component repository is kept read-only or if it is put under source code control. Any such problems can be avoided by making a copy of the `host` subdirectory and building that copy.

Loading the kernel module into the current system requires root privileges. If the generic USB support is also a loadable module and has not been loaded already, this must happen first:

```
# insmod usb-uhci
Using /lib/modules/2.2.16-22/usb/usb-uhci.o
```

Depending on the host hardware, the `uhci` or `usb-ohci` modules may be more appropriate. Loading the generic USB module will typically result in a number of messages to the logfile `/var/log/messages`, giving details of the specific host-side hardware that has been detected plus any hubs. The next step is to load the USB-ethernet module:

```
# insmod ecos_usbeth.o
```

This should result in a number of additional diagnostics in the logfile:

```
Apr 1 18:01:08 grumpy kernel: eCos USB-ethernet device driver
Apr 1 18:01:08 grumpy kernel: usb.c: registered new driver ecos_usbeth
```

If a suitable USB peripheral is now connected the host will detect this, assign an address in the local USB network, obtain enumeration data, and find a suitable device driver. Assuming the peripheral and device driver agree on the supported vendor ids, the `ecos_usbeth.o` module will be selected and this will be reported in the system log:

```
Apr 1 18:04:12 grumpy kernel: usb.c: USB new device connect, assigned device number 3
Apr 1 18:04:12 grumpy kernel: eCos-based USB ethernet peripheral active at eth1
```

What can happen next depends very much on the software that is running on top of the USB-ethernet package inside the peripheral. For example, if there is a TCP/IP stack then it should be possible to bring up a network connection between host and peripheral using **ifconfig**.

Communication Protocol

Name

`Communication Protocol` — Protocol used between the host-side device driver and the eCos USB-ethernet package

Description

There is a USB standard for the protocol to be used between the host and a class of communication devices, including ethernet. However, the eCos USB-ethernet package does not implement this protocol: the target hardware for which the package was first developed had certain limitations, and could not implement the standard. Instead, the package implements a simple new protocol.

A USB-ethernet peripheral involves bulk transfers on two endpoints: one endpoint will be used for packets from host to peripheral and the other will be used for the opposite direction. Transfers in both directions are variable length, with a lower limit of 16 bytes and an upper limit of 1516 bytes. The first two bytes of each transfer constitute a header specific to USB-ethernet. The next 14 bytes form the normal header for an ethernet frame: destination MAC address, source MAC address, and a protocol field. The remaining data, up to 1500 bytes, are the payload. The first two bytes give the size of the ethernet frame, least significant byte first, with a value between 14 and 1514.

For example an ARP request from host to peripheral involves an ethernet frame of 42 bytes (0x002A), with the usual 14-byte header and a 28-byte payload. The destination is the broadcast address 0xFFFFFFFFFFFF. The source depends on the MAC address specified for the host in the call to `usbs_eth_init`, e.g. 0x405D90A9BC02. The remaining data is as specified by the appropriate IETF RFC's (http://www.ietf.org). The actual bulk USB transfer involves the following sequence of 44 bytes:

```
2a 00 ff ff ff ff ff ff 40 5d 90 a9 bc 02 08 06
00 01 08 00 06 04 00 01 40 5d 90 a9 bc 02 0a 00
00 01 00 00 00 00 00 00 0a 00 00 02
```

In addition there are two control messages. These will be sent by the host to endpoint 0, the control endpoint, and by default they will be handled by `usbs_eth_class_control_handler`. If class-specific control messages are intercepted by other code then it is the responsibility of that code to invoke the USB-ethernet handler when appropriate.

The first control message can be used by the host to obtain a MAC address:

```
#define ECOS_USBETH_CONTROL_GET_MAC_ADDRESS         0x01
```

The control message's type field should specify IN as the direction. The request field should be `0x01`. The length fields should specify a size of 6 bytes. The remaining fields of the control message will be ignored by the USB-ethernet package. The response consists of the 6-byte MAC address supplied by the initialization call `usbs_eth_init`.

The second control message can be used by the host to enable or disable promiscuous mode.

```
#define ECOS_USBETH_CONTROL_SET_PROMISCUOUS_MODE    0x02
```

This control message involves no further data so the length field should be set to 0. The value field should be non-zero to enable promiscuous mode, zero to disable it. The request field should be `0x02`. The remaining fields in the control message will be ignored. It is the responsibility of the host-side device driver to keep track of whether or not promiscuous mode is currently enabled. It will be disabled when the peripheral changes to Configured state, typically at the point where the host-side device driver has been activated.

XXIV. 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 mimimal 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.

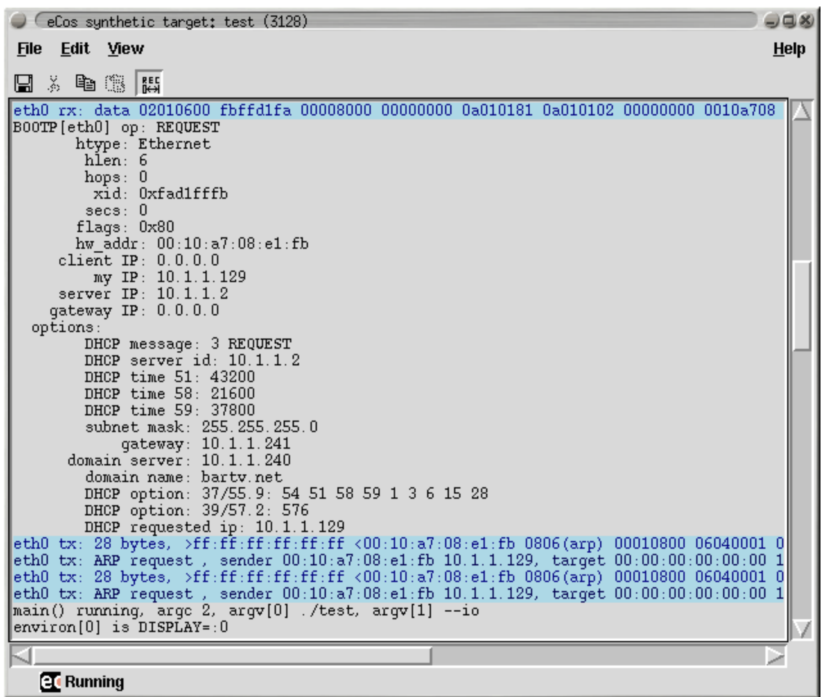
The I/O Auxiliary's User Interface

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.

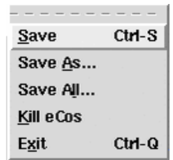


The title bar identifies the window as belonging to an eCos synthetic target application and lists both the application name and its process id. The latter is especially useful if the application was started directly from a shell prompt and the user now wants to attach a gdb session. The window has a 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.

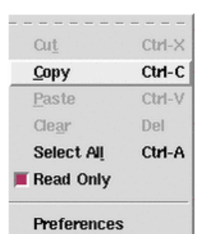


On the File menu there are three entries related to saving the current contents of the central text window. Save is used to save the currently visible contents of the text window. Any text that is hidden because of filters will not be written to the savefile. If there has been a previous Save or Save 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.

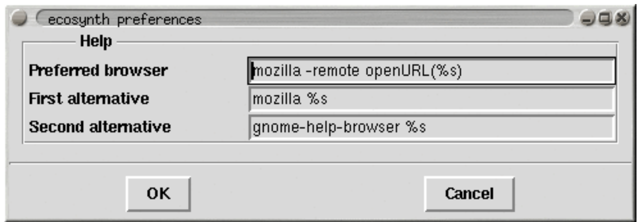
When operating in graphical mode the I/O auxiliary will normally continue to run even after the eCos application has exited. This allows the user to examine the last few lines of output, and perhaps perform actions such as saving the output to a file. The Exit menu item can be used to shut down the auxiliary. 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 checkbutton 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

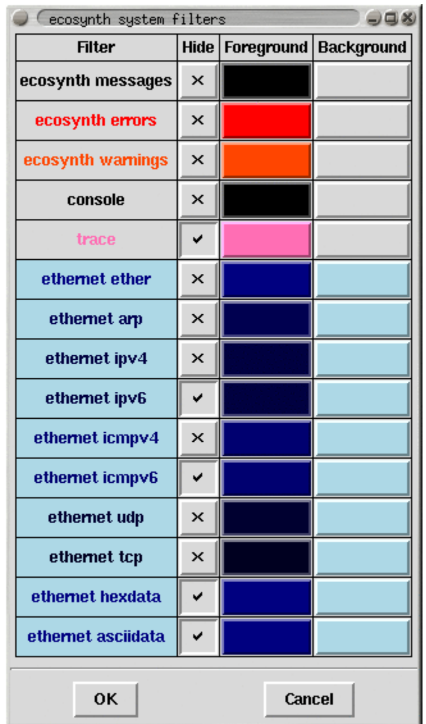
The central text window holds the console output from the eCos application: the screen shot above shows DHCP initialization data from the TCP/IP stack, and some output from the `main` thread at the bottom. Some devices can insert text of their own, for example the ethernet device support can be configured 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:

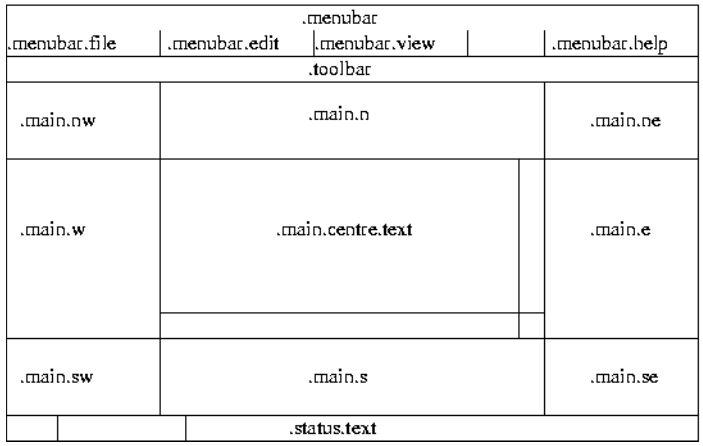


It should be noted that the text window is line-oriented, not character-oriented. If an eCos application sends a partial line of text then that will remain buffered until a newline character is received, rather than being displayed immediately. This avoids confusion when there is concurrent output from 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 checkbutton 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.



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 authoritive 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`:

```
cdl_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 software 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 " -o13          : 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]
```

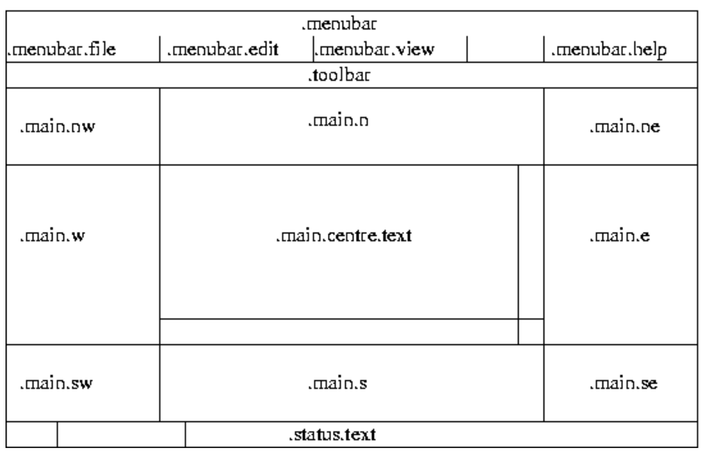
```
set message ""
if { ![synth::filter_parse_options $console_appearance parsed_options message] } {
    synth::report_error \
     "Invalid entry in target definition file $synth::target_definition\
      \n  synth_device \"console\", entry \"appearance\"\n$message"
} else {
    synth::filter_add_parsed "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.



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_ballon_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 ethertap 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.

XXV. 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.

XXVI. 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 serialization 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.

XXVII. Synthetic Target Ethernet Driver

Synthetic Target Ethernet Driver

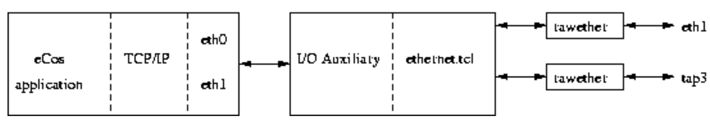
Name

`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.

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}`.

XXVIII. 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.