VxWorks®
Programmer's Guide

5.4

Edition 1

WindRiver® SYSTEMS

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Contents

1 Overview

1.1 Introduction

This manual describes VxWorks, the high-performance real-time operating system component of the Tornado development system. This manual includes the following information:

- How to use VxWorks facilities in the development of real-time applications. (VxWorks networking facilities are covered in the *VxWorks Network Programmer's Guide*.)
- How to use the optional components Wind Foundation Classes, VxMP, and VxVMI.
- How to configure and build VxWorks without using the project facility. (For more information on the project facility, see *Tornado User's Guide: Projects*.)
- How to use the target-resident tools included in VxWorks.
- Architecture-specific information for all architectures supported on VxWorks.
- Wind River Systems' C and C++ coding conventions.

This chapter begins by providing pointers to information on how to set up and start using VxWorks as part of the Tornado development system. It then provides an overview of the role of VxWorks in the development of real-time applications, an overview of VxWorks facilities, a summary of Wind River Systems customer services, and a summary of the document conventions followed in this manual.

1.2 Getting Started with the Tornado Development System

See the following documents for information on installing and configuring the Tornado development system, including VxWorks. Information on configuration differs depending on whether your development host is UNIX or Windows; thus, the *Tornado User's Guide* is host specific.

- *Tornado Getting Started* provides information on installing all components of the Tornado Development System as well as a tutorial covering the main features of Tornado.
- The *Tornado User's Guide* provides information on configuring and connecting the host and target environments, building your VxWorks application, booting VxWorks, and running Tornado.

For either host, *8. Configuration and Build* in this manual provides information on using Tornado 1.0.1-style manual methods for VxWorks configuration.

For a complete overview of Tornado documentation, see the documentation guide in the *Tornado User's Guide*.

1.3 VxWorks: A Partner in the Real-time Development Cycle

UNIX and Windows hosts are excellent systems for program development and for many interactive applications. However, they are not appropriate for real-time applications. On the other hand, traditional real-time operating systems provide poor environments for application development or for non-real-time components of an application, such as graphical user interfaces (GUIs).

Rather than trying to create a single operating system that "does it all," the Wind River philosophy is to utilize two complementary and cooperating operating systems (VxWorks and UNIX, or VxWorks and Windows) and let each do what it does best. VxWorks handles the critical real-time chores, while the host machine is used for program development and for applications that are not time-critical.

You can scale VxWorks to include exactly the feature combinations your application requires. During development, you can include additional features to speed your work (such as the networking facilities), then exclude them to save resources in the final version of your application.

You can use the cross-development host machine to edit, compile, link, and store real-time code, but then run and debug that real-time code on VxWorks. The resulting VxWorks application can run standalone—either in ROM or disk-based—with no further need for the network or the host system.

However, the host machine and VxWorks can also work together in a hybrid application, with the host machine using VxWorks systems as real-time "servers" in a networked environment. For instance, a VxWorks system controlling a robot might itself be controlled by a host machine that runs an expert system, or several VxWorks systems running factory equipment might be connected to host machines that track inventory or generate reports.

1.4 VxWorks Facilities: An Overview

This section provides a summary of VxWorks facilities; they are described in more detail in the following subsections. For details on any of these facilities, see the appropriate chapters in this manual.

- **High-Performance Real-time Kernel Facilities**

  The VxWorks kernel, *wind*, includes multitasking with preemptive priority scheduling, intertask synchronization and communications facilities, interrupt handling support, watchdog timers, and memory management.

- **POSIX Compatibility**

  VxWorks provides most interfaces specified by the 1003.1b standard (formerly the 1003.4 standard), simplifying your ports from other conforming systems.

- **I/O System**

  VxWorks provides a fast and flexible ANSI C-compatible I/O system, including UNIX standard buffered I/O and POSIX standard asynchronous I/O. VxWorks includes the following drivers:

Network driver	–	for network devices (Ethernet, shared memory)
Pipe driver	–	for intertask communication
RAM "disk" driver	–	for memory-resident files
SCSI driver	–	for SCSI hard disks, diskettes, and tape drives
Keyboard driver	–	for PC x86 keyboards (x86 BSP only)
Display driver	–	for PC x86 VGA displays (x86 BSP only)

Disk driver	–	for IDE and floppy disk drives (x86 BSP only)
Parallel port driver	–	for PC-style target hardware

- **Local File Systems**

  VxWorks provides fast file systems tailored to real-time applications. One file system is compatible with the MS-DOS® file system, another with the RT-11 file system, a third is a "raw disk" file system, a fourth supports SCSI tape devices, and a fifth supports CD-ROM devices.

- **C++ Development Support**

  In addition to general C++ support including the iostream library and the standard template library, the optional component Wind Foundation Classes adds the following C++ object libraries:

  – VxWorks Wrapper Class library
  – Tools.h++ library from Rogue Wave

- **Shared-Memory Objects (VxMP Option)**

  The VxMP option provides facilities for sharing semaphores, message queues, and memory regions between tasks on different processors.

- **Virtual Memory (Including VxVMI Option)**

  VxWorks provides both bundled and unbundled (VxVMI) virtual memory support for boards with an MMU, including the ability to make portions of memory noncacheable or read-only, as well as a set of routines for virtual-memory management.

- **Target-resident Tools**

  In the Tornado development system, the development tools reside on the host system; see the *Tornado User's Guide* for details. However, a target-resident shell, module loader and unloader, and symbol table can be configured into the VxWorks system if necessary.

- **Utility Libraries**

  VxWorks provides an extensive set of utility routines, including interrupt handling, watchdog timers, message logging, memory allocation, string formatting and scanning, linear and ring buffer manipulations, linked-list manipulations, and ANSI C libraries.

- **Performance Evaluation Tools**

  VxWorks performance evaluation tools include an execution timer for timing a routine or group of routines, and utilities to show CPU utilization percentage by task.

- **Target Agent**

  The target agent allows a VxWorks application to be remotely debugged using the Tornado development tools.

- **Board Support Packages**

  Board Support Packages (BSPs) are available for a variety of boards and provide routines for hardware initialization, interrupt setup, timers, memory mapping, and so on.

- **VxWorks Simulator (VxSim) and Logic Analyzer (WindView)**

  Tornado comes with an integrated simulator and software logic analyzer on all host platforms. VxSim simulates a VxWorks target for use as a prototyping and testing environment. WindView provides advanced debugging tools for the simulator environment.

  The optional product VxSim provides networking capability and the ability to run multiple simulators. The optional product WindView provides software logic analyzer support for all WRS BSPs.

- **Network Facilities**

  VxWorks provides "transparent" access to other VxWorks and TCP/IP-networked systems, a MUX interface (supporting advanced features such as multicasting, polled-mode Ethernet, and zero-copy transmission), a BSD[1] Sockets-compliant programming interface, remote procedure calls (RPC), SNMP (optional), remote file access (including NFS client and server facilities and a non-NFS facility utilizing RSH, FTP, or TFTP), BOOTP, proxy ARP, DHCP, DNS, OSPF (optional), and RIP. All VxWorks network facilities comply with standard Internet protocols, both loosely coupled over serial lines or standard Ethernet connections and tightly coupled over a backplane bus using shared memory.

  For information on VxWorks network support, see the *VxWorks Network Programmer's Guide*.

1. *BSD* stands for Berkeley Software Distribution, and refers to a version of UNIX.

Multitasking and Intertask Communications

Modern real-time systems are based on the complementary concepts of multitasking and intertask communications. A multitasking environment allows real-time applications to be constructed as a set of independent tasks, each with a separate thread of execution and its own set of system resources. The intertask communication facilities allow these tasks to synchronize and coordinate their activity.

The VxWorks multitasking kernel, *wind*, uses interrupt-driven, priority-based task scheduling. It features fast context switch times and low interrupt latency. Under VxWorks, any subroutine can be *spawned* as a separate task, with its own context and stack. Other basic task control facilities allow tasks to be suspended, resumed, deleted, delayed, and moved in priority. See *2.3 Tasks*, p.20 and the reference entry for **taskLib**.

The *wind* kernel supplies semaphores as the basic task synchronization and mutual-exclusion mechanism. There are several kinds of semaphores in *wind*, specialized for different application needs: binary semaphores, counting semaphores, mutual-exclusion semaphores, and POSIX semaphores. All of these semaphore types are fast and efficient. In addition to being available to application developers, they have also been used extensively in building higher-level facilities in VxWorks.

For intertask communications, the *wind* kernel also supplies message queues, pipes, sockets, and signals. The optional component VxMP provides shared-memory objects as a communication mechanism for tasks executing on different CPUs. For information on all these facilities, see *6. Shared-Memory Objects* and *2.4 Intertask Communications*, p.45. In addition, semaphores are described in the **semLib** and **semPxLib** reference entries; message queues are described in the **msgQLib** and **mqPxLib** reference entries; pipes are described in the **pipeDrv** reference entry and *2.4.5 Pipes*, p.79; sockets are described in the **sockLib** reference entry and *2.4.6 Network Intertask Communication*, p.80; and signals are described in the **sigLib** reference entry and *2.4.7 Signals*, p.81.

POSIX Interfaces

POSIX (the Portable Operating System Interface) is a set of standards under development by representatives of the software community, working under an ISO/IEEE charter. The purpose of this effort is to support application portability at the source level across operating systems. This effort has yielded a set of interfaces (POSIX standard 1003.1b, formerly called 1003.4) for real-time operating system services. Using these interfaces makes it easier to move applications from one operating system to another.

For a list of POSIX facilities, look under **POSIX** in the keyword index in the *VxWorks Reference Manual* or in the *Tornado Online Manuals*. Nearly all POSIX 1003.1b interfaces are available in VxWorks, including POSIX interfaces for:

– asynchronous I/O
– semaphores
– message queues
– memory management
– queued signals
– scheduling
– clocks and timers

In addition, several interfaces from the traditional POSIX 1003.1 standard are also supported.

I/O System

The VxWorks I/O system provides uniform device-independent access to many kinds of devices. You can call seven basic I/O routines: ***creat*( )**, ***remove*( )**, ***open*( )**, ***close*( )**, ***read*( )**, ***write*( )**, and ***ioctl*( )**. Higher-level I/O routines (such as ANSI C-compatible ***printf*( )** and ***scanf*( )** routines) are also provided.

VxWorks also provides a standard buffered I/O package (*stdio*) that includes ANSI C-compatible routines such as ***fopen*( )**, ***fclose*( )**, ***fread*( )**, ***fwrite*( )**, ***getc*( )**, and ***putc*( )**. These routines increase I/O performance in many cases.

The VxWorks I/O system also includes POSIX-compliant asynchronous I/O: a library of routines that perform input and output operations concurrently with a task's other activities.

VxWorks includes device drivers for serial communication, disks, RAM disks, SCSI tape devices, intertask communication devices (called *pipes*), and devices on a network. Application developers can easily write additional drivers, if needed. VxWorks allows dynamic installation and removal of drivers without rebooting the system.

Internally, the VxWorks I/O system allows individual drivers complete control over how the user requests are serviced. Drivers can easily implement different protocols, unique device-specific routines, and even different file systems, without interference from the I/O system itself. VxWorks also supplies several high-level packages that make it easy for drivers to implement common device protocols and file systems.

For a detailed discussion of the I/O system, see *3. I/O System*. Relevant reference entries include **ioLib** for basic I/O routines available to tasks, **fioLib** and **ansiStdio** for various format-driven I/O routines, **aioPxLib** for asynchronous I/O, and **iosLib** and **tyLib** for routines available to driver writers. Also see the reference entries for the supplied drivers.

Local File Systems

VxWorks includes several local file systems for use with block devices (disks). These devices all use a standard interface so that file systems can be freely mixed with device drivers. Local file systems for SCSI tape devices and CD-ROM devices are also included. The VxWorks I/O architecture makes it possible to have several different file systems on a single VxWorks system, even at the same time.

MS-DOS Compatible File System: dosFs

VxWorks provides the *dosFs* file system, which is compatible with the MS-DOS file system (for MS-DOS versions up to and including 6.2). The capabilities of dosFs offer considerable flexibility appropriate to the varying demands of real-time applications. Major features include:

- A hierarchical arrangement of files and directories, allowing efficient organization and permitting an arbitrary number of files to be created on a volume.
- The ability to specify contiguous file allocation on a per-file basis. Contiguous files offer enhanced performance, while non-contiguous files result in more efficient use of disk space.
- Compatibility with widely available storage and retrieval media. Diskettes created with dosFs and on MS-DOS personal computers can be freely interchanged and hard drives created with MS-DOS can be read by dosFs if it is correctly configured.
- Optional case-sensitive file names, with name lengths not restricted to the MS-DOS eight-character + extension convention.

Services for file-oriented device drivers using dosFs are implemented in **dosFsLib**.

RT-11 Compatible File System: rt11Fs

VxWorks provides the *rt11Fs* file system, which is compatible with that of the RT-11 operating system. This file system has been used for real-time applications because all files are contiguous. However, rt11Fs does have some drawbacks. It lacks a hierarchical file organization that is particularly useful on large disks. Also, the rigid contiguous allocation scheme may result in fragmented disk space. For these reasons, dosFs is preferable to rt11Fs.

The VxWorks implementation of the RT-11 file system includes byte-addressable random access (seeking) to all files. Each open file has a block buffer for optimized reading and writing.

Services for file-oriented device drivers using rt11Fs are implemented in **rt11FsLib**.

Raw Disk File System: rawFs

VxWorks provides *rawFs*, a simple "raw disk file system" for use with disk devices. rawFs treats the entire disk much like a single large file. The rawFs file system permits reading and writing portions of the disk, specified by byte offset, and it performs simple buffering. When only simple, low-level disk I/O is required, rawFs has the advantages of size and speed.

Services for file-oriented device drivers using rawFs are implemented in **rawFsLib**.

SCSI Sequential File System: tapeFs

VxWorks provides a file system for tape devices that do not use a standard file or directory structure on tape. The tape volume is treated much like a raw device where the entire volume is a large file. Any data organization on this large file is the responsibility of a higher-level layer.

Services for SCSI sequential device drivers using tapeFs are implemented in **tapeFsLib**.

cdRomFs

VxWorks provides the *cdromFs* file system which lets applications read any CD-ROM that is formatted in accordance with ISO 9660 file system standards. After initializing cdRomFs and mounting it on a CD-ROM block device, you can access data on that device using the standard POSIX I/O calls.

Alternative File Systems

In VxWorks, the file system is not tied to the device or its driver. A device can be associated with any file system. Alternatively, you can supply your own file systems that use standard drivers in the same way, by following the same standard interfaces between the file system, the driver, and the VxWorks I/O system.

Virtual Memory (Including VxVMI Option)

Virtual memory support is provided for boards with Memory Management Units (MMU). Bundled virtual memory support provides the ability to mark buffers noncacheable. This is useful for multiprocessor environments where memory is shared across processors or where DMA transfers take place. For information on bundled virtual memory support, see *7. Virtual Memory Interface* and the reference entries for **vmBaseLib** and **cacheLib**.

Unbundled virtual memory support is available as the optional component VxVMI. VxVMI provides the ability to make text segments and the exception vector table read-only, and includes a set of routines for developers to manage their own virtual memory contexts. For information on VxVMI, see *7. Virtual Memory Interface* and the reference entry for **vmLib**.

Shared-Memory Objects (VxMP Option)

The following shared-memory objects (available with VxWorks as the optional component, VxMP) are used for communication and synchronization between tasks on different CPUs:

- Shared semaphores can be used to synchronize tasks on different CPUs as well as provide mutual exclusion to shared data structures.
- Shared message queues allow tasks on multiple processors to exchange messages.
- Shared memory management is available to allocate common data buffers for tasks on different processors.

For information on VxMP, see *6. Shared-Memory Objects* and the reference entries for **smObjLib**, **smObjShow**, **semSmLib**, **msgQSmLib**, **smMemLib**, and **smNameLib**.

Target-Resident Tools

In the Tornado development system, a full suite of development tools reside and execute on the host machine; see the *Tornado User's Guide* for details. However, a target-resident shell, symbol table, and module loader/unloader can be configured into the VxWorks system if necessary, for example, to create a dynamically configured run-time system.

For information on these target-resident tools, see *9. Target Shell* and the reference entries for **shellLib**, **usrLib**, **dbgLib**, **loadLib**, **unldLib**, and **symLib**.

C++ Development (including Wind Foundation Classes Option)

VxWorks supports C++ development. The GNU C++ compiler is shipped with Tornado. The Tornado compiler provides support for multi-thread-safe exception handling. Tornado includes a new version of the **iostream** library and the SGI implementation of the Standard Template Library. The standard Tornado interactive development tools such as the debugger, the shell, and the incremental loader include C++ support.

In addition, you can order the Wind Foundation Classes optional component to add the following libraries:

– VxWorks Wrapper Class library
– Tools.h++ library from Rogue Wave

For more information on these libraries, see *5. C++ Development*.

Utility Libraries

VxWorks supplies many subroutines of general utility to application developers. These routines are organized as a set of subroutine libraries, which are described below. We urge you to use these libraries wherever possible. Using library utilities reduces both development time and memory requirements for the application.

Interrupt Handling Support

VxWorks supplies routines for handling hardware interrupts and software traps without having to resort to assembly language coding. Routines are provided to connect C routines to hardware interrupt vectors, and to manipulate the processor interrupt level.

For information on interrupt handling, see the **intLib** and **intArchLib** reference entries. Also see *2. Basic OS* for information about the context where interrupt-level code runs and for special restrictions that apply to interrupt service routines.

Watchdog Timers

A watchdog facility allows callers to schedule execution of their own routines after specified time delays. As soon as the specified number of ticks have elapsed, the specified "timeout" routine is called at the interrupt level of the system clock, unless the watchdog is canceled first. This mechanism is entirely different from the kernel's task delay facility. For information on watchdog timers, see *2.6 Watchdog Timers*, p. 90 and the reference entry for **wdLib**.

Message Logging

A simple message logging facility allows applications to send error or status messages to a logging task, which then formats and outputs the messages to a system-wide logging device (such as the system console, disk, or accessible memory). The message logging facility can be used from either interrupt level or task level. For information on this facility, see *3.5.3 Message Logging*, p. 109 and the reference entry for **logLib**.

Memory Allocation

VxWorks supplies a memory management facility useful for dynamically allocating, freeing, and reallocating blocks of memory from a memory pool. Blocks of arbitrary size can be allocated, and you can specify the size of the memory pool. This memory scheme is built on a much more general mechanism that allows VxWorks to manage several separate memory pools.

String Formatting and Scanning

VxWorks includes a complete set of ANSI C library string formatting and scanning subroutines that implement ***printf*( )**/***scanf*( )** format-driven encoding and decoding and associated routines. See the reference entries for **fioLib** and **ansiStdio**.

Linear and Ring Buffer Manipulations

The library **bLib** contains buffer manipulation routines such as copying, filling, comparing, and so on, that have been optimized for speed. The library **rngLib** provides a set of general ring buffer routines that manage first-in-first-out (FIFO) circular buffers. Additionally, these ring buffers have the property that a single writer and a single reader can access a ring buffer "simultaneously" without being required to interlock their accesses explicitly.

Linked-List Manipulations

The library **lstLib** contains a complete set of routines for creating and manipulating doubly-linked lists.

ANSI C Libraries

VxWorks provides all C libraries specified by ANSI X3.159-1989. The ANSI C specification includes the following libraries: **assert**, **ctype**, **errno**, **float**, **limits**, **locale**, **math**, **setjmp**, **signal**, **stdarg**, **stdio**, **stddef**, **stdlib**, **string**, and **time**.

The header files **float.h**, **limits.h**, **errno.h**, and **stddef.h** provide ANSI-specified definitions and declarations. The more commonly used libraries are described in the following reference entries:

ansiCtype	routines for character manipulation
ansiMath	trigonometric, exponential, and logarithmic routines
ansiSetjmp	routines for implementing a non-local goto
ansiStdarg	routines for traversing a variable-length argument list
ansiStdio	routines for manipulating streams for input/output
ansiStdlib	a variety of routines, including those for type translation, memory allocation, and random number generation
sigLib	signal-manipulation routines

Performance Evaluation

To understand and optimize the performance of a real-time system, it can be useful to time some of the VxWorks or application routines. VxWorks provides various timing facilities to help with this task.

The VxWorks execution timer can time any subroutine or group of subroutines. Because the system clock is too slow to provide the resolution necessary to time especially fast routines, the timer can also repeatedly execute a group of routines until the time of a single iteration is known to a reasonable accuracy. For information on the execution timer, see the **timexLib** reference entry.

VxWorks also provides the *spy* utility, which provides CPU utilization information for each task: the CPU time consumed, the time spent at interrupt level, and the amount of idle time. Time is displayed in ticks and in percentages. For information on this utility, see the **spyLib** reference entry.[2]

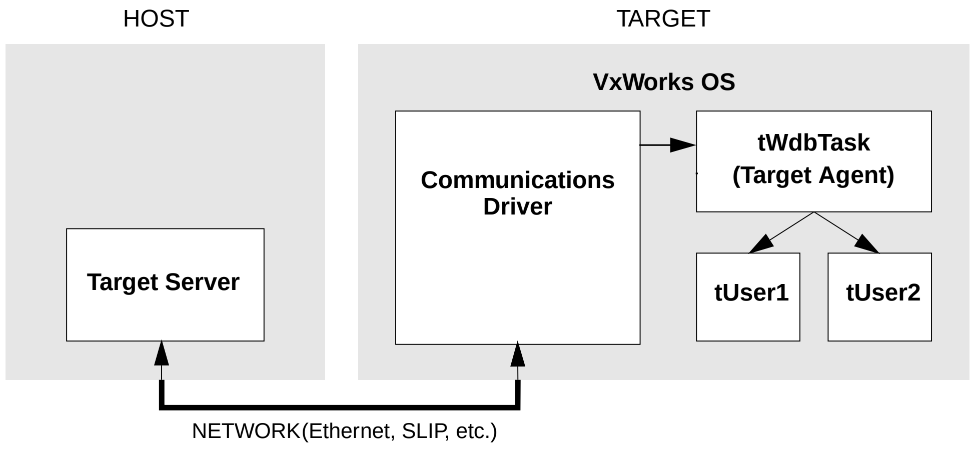
Even more powerful monitoring of the VxWorks system is available using the optional product WindView; for more information, see the *WindView User's Guide*.

Target Agent

The *target agent* follows the WDB (Wind DeBug) protocol, allowing a VxWorks target to be connected to the Tornado development tools. In the target agent's default configuration, shown in Figure 1-1, the agent runs as the VxWorks task **tWdbTask**. The Tornado target server sends debugging requests to the target agent. The debugging requests often result in the target agent controlling or manipulating other tasks in the system.

By default, the target server and agent communicate using the network. However, you can use alternative communication paths. For more information on the default configuration or alternative configurations of the target agent, see *Tornado Getting Started.* For information on the Tornado target server, see the *Tornado User's Guide: Overview.*

Figure 1-1 **Interaction Between Target Server and Target Agent**



2. You can also use this utility through the Tornado browser; see the *Tornado User's Guide: Browser* for details.

Board Support Packages (BSPs)

Two target-specific libraries, **sysLib** and **sysALib**, are included with each port of VxWorks. These libraries are the heart of VxWorks portability; they provide an identical software interface to the hardware functions of all boards. They include facilities for hardware initialization, interrupt handling and generation, hardware clock and timer management, mapping of local and bus memory spaces, memory sizing, and so on.

Each BSP also includes a boot ROM or other boot mechanism. Many of these import the run-time image from the development host. For information on boot ROMs and other booting mechanisms see *Tornado Getting Started* and *8.9 Creating Bootable Applications*, p.364.

For information on target-specific libraries, see *8.2 The Board Support Package (BSP)*, p.310 and the target-specific reference entries for your board type.

VxWorks Simulator

VxSim, the VxWorks simulator, is a program that simulates a VxWorks target for use as a prototyping and testing environment. The integrated version of the simulator allows a single simulator to be run. The VxSim optional product adds networking facilities, allowing the simulator to obtain an Internet address and communicate with the host (or other nodes on the network) using the VxWorks networking tools.

VxSim is essentially a port of VxWorks. In most regards, its capabilities are identical to a true VxWorks system running on remote target hardware. You can link in an application and rebuild the VxWorks image exactly the same way as in any other VxWorks cross-development environment. All Tornado development tools can be used with VxSim.

The difference between VxSim and a remote VxWorks target environment is that in VxSim, the image executes on the host machine itself as a host process. There is no emulation of instructions, because the code is in the host's own CPU architecture. Because target hardware interaction is not possible, device-driver development may not be suitable for simulation. However, the VxWorks scheduler is implemented in the VxSim process, maintaining true tasking interaction with respect to priorities and preemption. This means that any application that is written in a portable style and with minimal hardware interaction should be portable between VxSim and VxWorks.

For more information on VxSim, see *H. VxSim*.

1.5 Customer Services

A full range of support services is available from Wind River Systems to ensure that you have the opportunity to make optimal use of the extensive features of VxWorks.

This section summarizes the major services available. For more detailed information, consult the *Tornado User's Guide: Customer Service*.

Training

In the United States, Wind River Systems holds regularly scheduled classes on Tornado and VxWorks. Customers can also arrange to have Tornado classes held at their facility. The easiest way to learn about WRS training services, schedules, and prices is through the World Wide Web. Point your site's Web browser at the following URL:

```
http://www.wrs.com/training
```

You can contact the Training Department at:

Phone:	510/749-2148
	800/545–WIND
Fax:	510/749–2378
E-mail:	training@wrs.com

Outside of the United States, call your local distributor or nearest Wind River Systems office for training information. See the back cover of this manual for a list of Wind River Systems offices.

Customer Support

Direct contact with a staff of software engineers experienced in VxWorks is available through the Wind River Systems Customer Support program. For information on how to contact WRS Customer Support, see the copyright page at the front of this manual.

1.6 Documentation Conventions

Typographical Conventions

VxWorks documentation uses the conventions shown in Table 1-1 to differentiate various elements. Parentheses are always included to indicate a subroutine name, as in ***printf*( )**.

Table 1-1 **Font Usage for Special Terms**

Term	Example
files, pathnames	**/etc/hosts**
libraries, drivers	**memLib**, **nfsDrv**
host tools	**more**, **chkdsk**
subroutines	***semTake*( )**
boot commands	**p**
code display	`main ();`
keyboard input	`make CPU=MC68040 ...`
display output	`value = 0`
user-supplied parameters	*name*
constants	**INCLUDE_NFS**
C keywords, **cpp** directives	**#define**
named key on keyboard	**RETURN**
control characters	**CTRL+C**
lower-case acronyms	*fd*

Cross-References

Cross-references in this guide to a *reference entry* for a tool or module refer to an entry in the *VxWorks Reference Manual* (for target libraries or subroutines) or to the reference appendix in the *Tornado User's Guide* (for host tools). These references are also provided in the *Tornado Online Manuals*. For more information about how to access online documentation, see the *Tornado User's Guide: Documentation Guide*.

Other references from one book to another are always at the chapter level, and take the form *Book Title: Chapter Name*.

Pathnames

The top-level Tornado directory structure includes three major directories (see the *Tornado User's Guide: Directories and Files*). Although all VxWorks files reside in the **target** directory, in order to maintain consistency with other Tornado manuals this manual uses pathnames of the following form: *installDir***/target**. For example, if you install Tornado in **/group/wind** on a UNIX host or in **C:\Tornado** on a Windows host, the full pathname for the file shown as *installDir***/target/config/all/configAll.h** is **/group/wind/target/config/all/configAll.h** (which is also **$WIND_BASE/target/config/all/configAll.h**) on UNIX or **C:\Tornado\target\config\all\configAll.h** on Windows.

NOTE: In this manual, forward slashes are used as pathname delimiters for both UNIX and Windows file names since this is the default for VxWorks.

2
Basic OS

2.1 Introduction

Modern real-time systems are based on the complementary concepts of multitasking and intertask communications. A multitasking environment allows a real-time application to be constructed as a set of independent tasks, each with its own thread of execution and set of system resources. The intertask communication facilities allow these tasks to synchronize and communicate in order to coordinate their activity. In VxWorks, the intertask communication facilities range from fast semaphores to message queues and pipes to network-transparent sockets.

Another key facility in real-time systems is hardware interrupt handling, because interrupts are the usual mechanism to inform a system of external events. To get the fastest possible response to interrupts, *interrupt service routines (ISRs)* in VxWorks run in a special context of their own, outside of any task's context.

This chapter discusses the multitasking kernel, tasking facilities, intertask communication, and interrupt handling facilities, which are at the heart of the VxWorks run-time environment.

2.2 Wind Features and POSIX Features

The POSIX standard for real-time extensions (1003.1b) specifies a set of interfaces to kernel facilities. To improve application portability, the VxWorks kernel, *wind*, includes both POSIX interfaces and interfaces designed specifically for VxWorks.

This manual (especially in this chapter) uses the qualifier "Wind" to identify facilities designed expressly for use with the VxWorks *wind* kernel. For example, you can find a discussion of Wind semaphores contrasted to POSIX semaphores in *Comparison of POSIX and Wind Semaphores*, p.59.

2.3 Tasks

It is often essential to organize applications into independent, though cooperating, programs. Each of these programs, while executing, is called a *task*. In VxWorks, tasks have immediate, shared access to most system resources, while also maintaining enough separate context to maintain individual threads of control.

2.3.1 Multitasking

Multitasking provides the fundamental mechanism for an application to control and react to multiple, discrete real-world events. The VxWorks real-time kernel, *wind*, provides the basic multitasking environment. Multitasking creates the appearance of many threads of execution running concurrently when, in fact, the kernel interleaves their execution on the basis of a scheduling algorithm. Each apparently independent program is called a *task*. Each task has its own *context*, which is the CPU environment and system resources that the task sees each time it is scheduled to run by the kernel. On a context switch, a task's context is saved in the task control block (TCB). A task's context includes:

– a thread of execution, that is, the task's program counter
– the CPU registers and (optionally) floating-point registers
– a stack for dynamic variables and function calls
– I/O assignments for standard input, output, and error
– a delay timer
– a timeslice timer
– kernel control structures

– signal handlers
– debugging and performance monitoring values

In VxWorks, one important resource that is *not* part of a task's context is memory address space: all code executes in a single common address space. Giving each task its own memory space requires virtual-to-physical memory mapping, which is available only with the optional product VxVMI; for more information, see *7. Virtual Memory Interface*.

2.3.2 Task State Transition

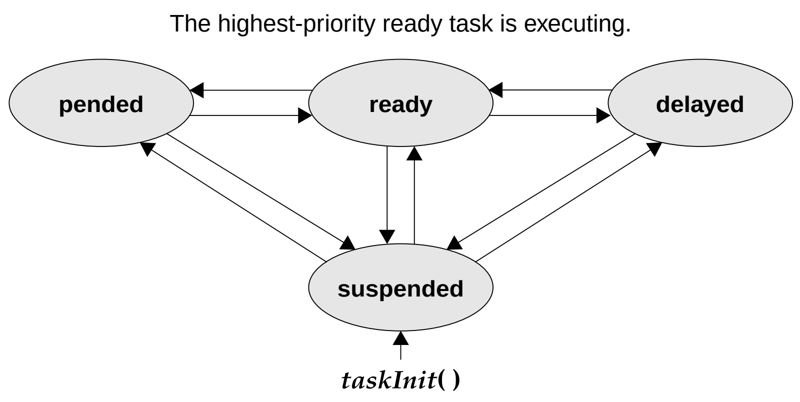
The kernel maintains the current state of each task in the system. A task changes from one state to another as the result of kernel function calls made by the application. When created, tasks enter the *suspended* state. Activation is necessary for a created task to enter the *ready* state. The activation phase is extremely fast, enabling applications to pre-create tasks and activate them in a timely manner. An alternative is the *spawning* primitive, which allows a task to be created and activated with a single function. Tasks can be deleted from any state.

The *wind* kernel states are shown in the state transition diagram in Figure 2-1, and a summary of the corresponding *state symbols* you will see when working with Tornado development tools is shown in Table 2-1.

Table 2-1 **Task State Transitions**

State Symbol	Description
READY	The state of a task that is not waiting for any resource other than the CPU.
PEND	The state of a task that is blocked due to the unavailability of some resource.
DELAY	The state of a task that is asleep for some duration.
SUSPEND	The state of a task that is unavailable for execution. This state is used primarily for debugging. Suspension does not inhibit state transition, only task execution. Thus *pended-suspended* tasks can still unblock and *delayed-suspended* tasks can still awaken.
DELAY + S	The state of a task that is both delayed and suspended.
PEND + S	The state of a task that is both pended and suspended.
PEND + T	The state of a task that is pended with a timeout value.
PEND + S + T	The state of a task that is both pended with a timeout value and suspended.
state **+ I**	The state of task specified by *state*, plus an inherited priority.

Figure 2-1 **Task State Transitions**



ready	→	**pended**	*semTake*( ) / *msgQReceive*( )
ready	→	**delayed**	*taskDelay*( )
ready	→	**suspended**	*taskSuspend*( )
pended	→	**ready**	*semGive*( ) / *msgQSend*( )
pended	→	**suspended**	*taskSuspend*( )
delayed	→	**ready**	expired delay
delayed	→	**suspended**	*taskSuspend*( )
suspended	→	**ready**	*taskResume*( ) / *taskActivate*( )
suspended	→	**pended**	*taskResume*( )
suspended	→	**delayed**	*taskResume*( )

2.3.3 Wind Task Scheduling

Multitasking requires a scheduling algorithm to allocate the CPU to ready tasks. Priority-based preemptive scheduling is the default algorithm in *wind*, but you can select round-robin scheduling for your applications as well. The routines listed in Table 2-2 control task scheduling.

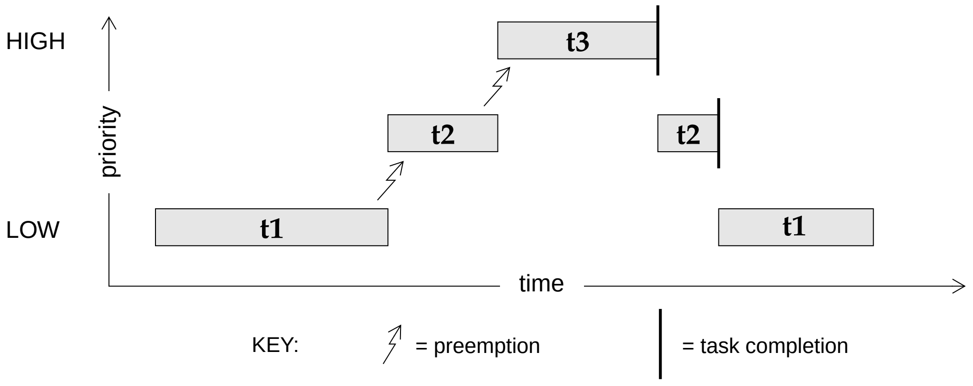
Table 2-2 **Task Scheduler Control Routines**

Call	Description
kernelTimeSlice( )	Control round-robin scheduling.
taskPrioritySet( )	Change the priority of a task.
taskLock( )	Disable task rescheduling.
taskUnlock( )	Enable task rescheduling.

Preemptive Priority Scheduling

With a preemptive priority-based scheduler, each task has a priority and the kernel ensures that the CPU is allocated to the highest priority task that is ready to run. This scheduling method is *preemptive* in that if a task that has higher priority than the current task becomes ready to run, the kernel immediately saves the current task's context and switches to the context of the higher priority task. In Figure 2-2, task **t1** is preempted by higher-priority task **t2**, which in turn is preempted by **t3**. When **t3** completes, **t2** continues executing. When **t2** completes execution, **t1** continues executing.

Figure 2-2 **Priority Preemption**



The *wind* kernel has 256 priority levels, numbered 0 through 255. Priority 0 is the highest and priority 255 is the lowest. Tasks are assigned a priority when created; however, while executing, a task can change its priority using ***taskPrioritySet*( )**. The ability to change task priorities dynamically allows applications to track precedence changes in the real world.

Round-Robin Scheduling

Preemptive priority scheduling can be augmented with round-robin scheduling. A round-robin scheduling algorithm attempts to share the CPU fairly among all ready tasks of the *same priority*. Without round-robin scheduling, when multiple tasks of equal priority must share the processor, a single task can usurp the processor by never blocking, thus never giving other equal-priority tasks a chance to run.

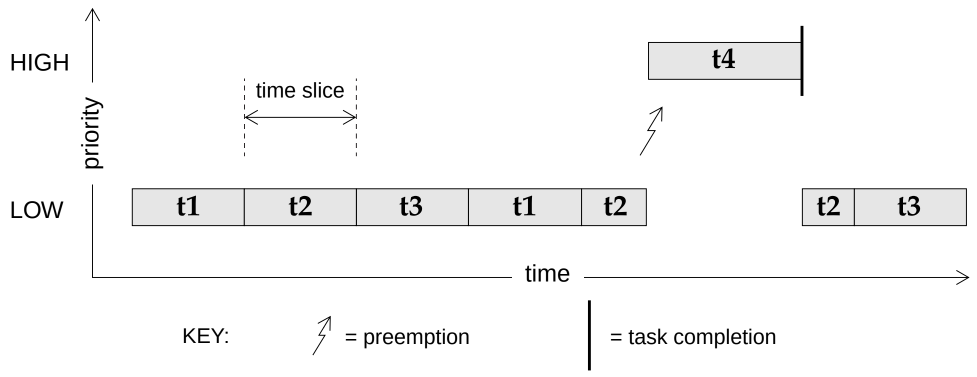
Round-robin scheduling achieves fair allocation of the CPU to tasks of the same priority by an approach known as *time slicing.* Each task of a group of tasks executes for a defined interval, or *time slice*; then another task executes for an equal interval, in rotation. The allocation is fair in that no task of a priority group gets a second slice of time before the other tasks of a group are given a slice.

Round-robin scheduling can be enabled with the routine ***kernelTimeSlice( )***, which takes a parameter for a time slice, or interval. This interval is the amount of time each task is allowed to run before relinquishing the processor to another equal-priority task.

More precisely, a run-time counter is kept for each task and incremented on every clock tick. When the specified time-slice interval is completed, the counter is cleared and the task is placed at the tail of the queue of tasks at its priority. New tasks joining a priority group are placed at the tail of the group with a run-time counter initialized to zero.

If a task is preempted by a higher priority task during its interval, its run-time count is saved and then restored when the task is again eligible for execution. Figure 2-3 shows round-robin scheduling for three tasks of the same priority: **t1**, **t2**, and **t3**. Task **t2** is preempted by a higher priority task **t4** but resumes at the count where it left off when **t4** is finished.

Figure 2-3 **Round-Robin Scheduling**



Preemption Locks

The *wind* scheduler can be explicitly disabled and enabled on a per-task basis with the routines ***taskLock*( )** and ***taskUnlock*( )**. When a task disables the scheduler by calling ***taskLock*( )**, no priority-based preemption can take place while that task is running.

However, if the task explicitly blocks or suspends, the scheduler selects the next highest-priority eligible task to execute. When the preemption-locked task unblocks and begins running again, preemption is again disabled.

Note that preemption locks prevent task context switching but do not lock out interrupt handling.

Preemption locks can be used to achieve mutual exclusion; however, keep the duration of preemption locking to a minimum. For more information, see *2.4.2 Mutual Exclusion*, p.46.

2.3.4 Tasking Control

The following sections give an overview of the basic VxWorks tasking routines, which are found in the VxWorks library **taskLib**. These routines provide the means for task creation, control, and information. See the reference entry for **taskLib** for further discussion. For interactive use, you can control VxWorks tasks from the host-resident shell; see the *Tornado User's Guide: Shell*.

Task Creation and Activation

The routines listed in Table 2-3 are used to create tasks.

Table 2-3 **Task Creation Routines**

Call	**Description**
***taskSpawn*( )**	Spawn (create and activate) a new task.
***taskInit*( )**	Initialize a new task.
***taskActivate*( )**	Activate an initialized task.

The arguments to ***taskSpawn*( )** are the new task's name (an ASCII string), priority, an "options" word, stack size, main routine address, and 10 arguments to be passed to the main routine as startup parameters:

```
id = taskSpawn ( name, priority, options, stacksize, main, arg1, …arg10 );
```

The ***taskSpawn*( )** routine creates the new task context, which includes allocating the stack and setting up the task environment to call the main routine (an ordinary subroutine) with the specified arguments. The new task begins execution at the entry to the specified routine.

The ***taskSpawn*( )** routine embodies the lower-level steps of allocation, initialization, and activation. The initialization and activation functions are provided by the routines ***taskInit*( )** and ***taskActivate*( )**; however, we recommend you use these routines only when you need greater control over allocation or activation.

Task Names and IDs

When a task is spawned, you can specify an ASCII string of any length to be the task name. VxWorks returns a task ID, which is a 4-byte handle to the task's data structures. Most VxWorks task routines take a task ID as the argument specifying a task. VxWorks uses a convention that a task ID of 0 (zero) always implies the calling task.

A task name should not conflict with any existing task name. Furthermore, to use the Tornado development tools to their best advantage, task names should not conflict with globally visible routine or variable names. To avoid name conflicts, VxWorks uses a convention of prefixing all task names started from the target with the letter *t* and task names started from the host with the letter *u*.

You may not want to name some or all of your application's tasks. If a NULL pointer is supplied for the *name* argument of ***taskSpawn*( )**, then VxWorks assigns a unique name. The name is of the form **t***N*, where *N* is a decimal integer that increases by one for each unnamed task that is spawned.

NOTE: In the shell, task names are resolved to their corresponding task IDs to simplify interaction with existing tasks; see the *Tornado User's Guide: Shell*.

The **taskLib** routines listed in Table 2-4 manage task IDs and names.

Table 2-4 **Task Name and ID Routines**

Call	Description
***taskName*( )**	Get the task name associated with a task ID.
***taskNameToId*( )**	Look up the task ID associated with a task name.
***taskIdSelf*( )**	Get the calling task's ID.
***taskIdVerify*( )**	Verify the existence of a specified task.

Task Options

When a task is spawned, an option parameter is specified by performing a logical OR operation on the desired options, listed in the following table. Note that **VX_FP_TASK** must be specified if the task performs any floating-point operations.

Table 2-5 **Task Options**

Name	Hex Value	Description
VX_FP_TASK	0x8	Execute with the floating-point coprocessor.
VX_NO_STACK_FILL	0x100	Do not fill stack with 0xee.
VX_PRIVATE_ENV	0x80	Execute task with a private environment.
VX_UNBREAKABLE	0x2	Disable breakpoints for the task.

To create a task that includes floating-point operations, use:

```
tid = taskSpawn ("tMyTask", 90, VX_FP_TASK, 20000, myFunc, 2387, 0, 0,
                 0, 0, 0, 0, 0, 0, 0);
```

Task options can also be examined and altered after a task is spawned by means of the routines listed in Table 2-6. Currently, only the **VX_UNBREAKABLE** option can be altered.

Table 2-6 **Task Option Routines**

Call	Description
***taskOptionsGet*( )**	Examine task options.
***taskOptionsSet*( )**	Set task options.

Task Information

The routines listed in Table 2-7 get information about a task by taking a snapshot of a task's context when called. The state of a task is dynamic, and the information may not be current unless the task is known to be dormant (that is, suspended).

Table 2-7 **Task Information Routines**

Call	Description
***taskIdListGet*( )**	Fill an array with the IDs of all active tasks.
***taskInfoGet*( )**	Get information about a task.
***taskPriorityGet*( )**	Examine the priority of a task.
***taskRegsGet*( )**	Examine a task's registers.
***taskRegsSet*( )**	Set a task's registers.
***taskIsSuspended*( )**	Check if a task is suspended.
***taskIsReady*( )**	Check if a task is ready to run.
***taskTcb*( )**	Get a pointer to task's control block.

Task Deletion and Deletion Safety

Tasks can be dynamically deleted from the system. VxWorks includes the routines listed in Table 2-8 to delete tasks and protect tasks from unexpected deletion.

WARNING: Make sure that tasks are not deleted at inappropriate times: a task must release all shared resources it holds before an application deletes the task.

Tasks implicitly call ***exit*( )** if the entry routine specified during task creation returns. Alternatively, a task can explicitly call ***exit*( )** at any point to kill itself. A task can kill another task by calling ***taskDelete*( )**.

When a task is deleted, no other task is notified of this deletion. The routines ***taskSafe*( )** and ***taskUnsafe*( )** address problems that stem from unexpected deletion of tasks. The routine ***taskSafe*( )** protects a task from deletion by other tasks. This protection is often needed when a task executes in a critical region or engages a critical resource.

Table 2-8 **Task-Deletion Routines**

Call	Description
***exit*( )**	Terminate the calling task and free memory (task stacks and task control blocks only).*
***taskDelete*( )**	Terminate a specified task and free memory (task stacks and task control blocks only).*
***taskSafe*( )**	Protect the calling task from deletion.
***taskUnsafe*( )**	Undo a ***taskSafe*( )** (make the calling task available for deletion).

* Memory that is allocated by the task during its execution is *not* freed when the task is terminated.

For example, a task might take a semaphore for exclusive access to some data structure. While executing inside the critical region, the task might be deleted by another task. Because the task is unable to complete the critical region, the data structure might be left in a corrupt or inconsistent state. Furthermore, because the semaphore can never be released by the task, the critical resource is now unavailable for use by any other task and is essentially frozen.

Using ***taskSafe*( )** to protect the task that took the semaphore prevents such an outcome. Any task that tries to delete a task protected with ***taskSafe*( )** is blocked. When finished with its critical resource, the protected task can make itself available for deletion by calling ***taskUnsafe*( )**, which readies any deleting task. To support nested deletion-safe regions, a count is kept of the number of times ***taskSafe*( )** and ***taskUnsafe*( )** are called. Deletion is allowed only when the count is zero, that is, there are as many "unsafes" as "safes." Protection operates only on the calling task. A task cannot make another task safe or unsafe from deletion.

The following code fragment shows how to use ***taskSafe*( )** and ***taskUnsafe*( )** to protect a critical region of code:

```
taskSafe ();
semTake (semId, WAIT_FOREVER);  /* Block until semaphore available */
.
.    critical region
.
semGive (semId);                /* Release semaphore */
taskUnsafe ();
```

Deletion safety is often coupled closely with mutual exclusion, as in this example. For convenience and efficiency, a special kind of semaphore, the *mutual-exclusion semaphore*, offers an option for deletion safety. For more information, see *Mutual-Exclusion Semaphores*, p.52.

Task Control

The routines listed in Table 2-9 provide direct control over a task's execution.

Table 2-9 **Task Control Routines**

Call	Description
***taskSuspend*( )**	Suspend a task.
***taskResume*( )**	Resume a task.
***taskRestart*( )**	Restart a task.
***taskDelay*( )**	Delay a task; delay units are ticks.
***nanosleep*( )**	Delay a task; delay units are nanoseconds.

VxWorks debugging facilities require routines for suspending and resuming a task. They are used to freeze a task's state for examination.

Tasks may require restarting during execution in response to some catastrophic error. The restart mechanism, ***taskRestart*( )**, recreates a task with the original creation arguments. The Tornado shell also uses this mechanism to restart itself in response to a task-abort request; for information, see the *Tornado User's Guide: Shell*.

Delay operations provide a simple mechanism for a task to sleep for a fixed duration. Task delays are often used for polling applications. For example, to delay a task for half a second without making assumptions about the clock rate, call:

```
taskDelay (sysClkRateGet ( ) / 2);
```

The routine ***sysClkRateGet*( )** returns the speed of the system clock in ticks per second. Instead of ***taskDelay*( )**, you can use the POSIX routine ***nanosleep*( )** to specify a delay directly in time units. Only the units are different; the resolution of both delay routines is the same, and depends on the system clock. For details, see *2.7 POSIX Clocks and Timers*, p.92.

As a side effect, ***taskDelay*( )** moves the calling task to the end of the ready queue for tasks of the same priority. In particular, you can yield the CPU to any other tasks of the same priority by "delaying" for zero clock ticks:

```
taskDelay (NO_WAIT); /* allow other tasks of same priority to run */
```

A "delay" of zero duration is only possible with ***taskDelay*( )**; ***nanosleep*( )** considers it an error.

2.3.5 Tasking Extensions

To allow additional task-related facilities to be added to the system without modifying the kernel, *wind* provides *task create*, *switch*, and *delete hooks*, which allow additional routines to be invoked whenever a task is created, a task context switch occurs, or a task is deleted. There are spare fields in the task control block (TCB) available for application extension of a task's context. These hook routines are listed in Table 2-10; for more information, see the reference entry for **taskHookLib**.

Table 2-10 **Task Create, Switch, and Delete Hooks**

Call	Description
***taskCreateHookAdd*( )**	Add a routine to be called at every task create.
***taskCreateHookDelete*( )**	Delete a previously added task create routine.
***taskSwitchHookAdd*( )**	Add a routine to be called at every task switch.
***taskSwitchHookDelete*( )**	Delete a previously added task switch routine.
***taskDeleteHookAdd*( )**	Add a routine to be called at every task delete.
***taskDeleteHookDelete*( )**	Delete a previously added task delete routine.

User-installed switch hooks are called within the kernel context. Thus, switch hooks do not have access to all VxWorks facilities. Table 2-11 summarizes the routines that can be called from a task switch hook; in general, any routine that does not involve the kernel can be called.

Table 2-11 **Routines that Can Be Called by Task Switch Hooks**

Library	Routines
bLib	All routines
fppArchLib	***fppSave*( )**, ***fppRestore*( )**
intLib	***intContext*( )**, ***intCount*( )**, ***intVecSet*( )**, ***intVecGet*( )**, ***intLock*( )**, ***intUnlock*( )**
lstLib	All routines except ***lstFree*( )**
mathALib	All are callable if ***fppSave*( )**/***fppRestore*( )** are used
rngLib	All routines except ***rngCreate*( )** and ***roundlet*( )**
taskLib	***taskIdVerify*( )**, ***taskIdDefault*( )**, ***taskIsReady*( )**, ***taskIsSuspended*( )**, ***taskTcb*( )**
vxLib	***vxTas*( )**

2.3.6 POSIX Scheduling Interface

The POSIX 1003.1b scheduling routines, provided by **schedPxLib**, are shown in Table 2-12. These routines let you use a portable interface to get and set task priority, get the scheduling policy, get the maximum and minimum priority for tasks, and if round-robin scheduling is in effect, get the length of a time slice. To understand how to use the routines in this alternative interface, be aware of the minor differences between the POSIX and Wind methods of scheduling.

Differences Between POSIX and Wind Scheduling

POSIX and Wind scheduling routines differ in the following ways:

- POSIX scheduling is based on *processes*, while Wind scheduling is based on *tasks*. Tasks and processes differ in several ways. Most notably, tasks can address memory directly while processes cannot; and processes inherit only some specific attributes from their parent process, while tasks operate in exactly the same environment as the parent task.

  Tasks and processes are alike in that they can be scheduled independently.

- VxWorks documentation uses the term *preemptive priority* scheduling, while the POSIX standard uses the term *FIFO*. This difference is purely one of nomenclature: both describe the same priority-based policy.

- The POSIX scheduling algorithms are applied on a process-by-process basis. The Wind methodology, on the other hand, applies scheduling algorithms on a system-wide basis—either all tasks use a round-robin scheme, or all use a preemptive priority scheme.

- The POSIX priority numbering scheme is the inverse of the Wind scheme. In POSIX, the higher the number, the higher the priority; in the Wind scheme, the *lower* the number, the higher the priority, where 0 is the highest priority. Accordingly, the priority numbers used with the POSIX scheduling library (**schedPxLib**) do not match those used and reported by all other components of VxWorks. You can override this default by setting the global variable **posixPriorityNumbering** to FALSE. If you do this, the Wind numbering scheme (smaller number = higher priority) is used by **schedPxLib**, and its priority numbers match those used by the other components of VxWorks.

The POSIX scheduling routines are included when **INCLUDE_POSIX_SCHED** is selected for inclusion in the project facility VxWorks view; see *Tornado User's Guide: Projects* for information on configuring VxWorks.

Table 2-12 **POSIX Scheduling Calls**

Call	Description
sched_setparam( )	Set a task's priority.
sched_getparam( )	Get the scheduling parameters for a specified task.
sched_setscheduler( )	Set scheduling policy and parameters for a task.
sched_yield( )	Relinquish the CPU.
sched_getscheduler( )	Get the current scheduling policy.
sched_get_priority_max( )	Get the maximum priority.
sched_get_priority_min( )	Get the minimum priority.
sched_rr_get_interval( )	If round-robin scheduling, get the time slice length.

Getting and Setting POSIX Task Priorities

The routines *sched_setparam*( ) and *sched_getparam*( ) set and get a task's priority, respectively. Both routines take a task ID and a **sched_param** structure (defined in *installDir*/**target/h/sched.h**). A task ID of 0 sets or gets the priority for the calling task. The **sched_priority** member of the **sched_param** structure specifies the new task priority when *sched_setparam*( ) is called. The routine *sched_getparam*( ) fills in the **sched_priority** with the specified task's current priority.

Example 2-1 **Getting and Setting POSIX Task Priorities**

```
/* This example sets the calling task's priority to 150, then verifies
 * that priority. To run from the shell, spawn as a task:
 *   -> sp priorityTest
 */

/* includes */
#include "vxWorks.h"
#include "sched.h"

/* defines */
#define PX_NEW_PRIORITY 150

STATUS priorityTest (void)
    {
    struct sched_param myParam;

    /* initialize param structure to desired priority */
    myParam.sched_priority = PX_NEW_PRIORITY;
    if (sched_setparam (0, &myParam) == ERROR)
        {
        printf ("error setting priority\n");
        return (ERROR);
        }

    /* demonstrate getting a task priority as a sanity check; ensure it
     * is the same value that we just set.
     */

    if (sched_getparam (0, &myParam) == ERROR)
        {
        printf ("error getting priority\n");
        return (ERROR);
        }

    if (myParam.sched_priority != PX_NEW_PRIORITY)
        {
        printf ("error - priorities do not match\n");
        return (ERROR);
        }
    else
        printf ("task priority = %d\n", myParam.sched_priority);

    return (OK);
    }
```

The routine ***sched_setscheduler*( )** is designed to set both scheduling policy and priority for a single POSIX process (which corresponds in most other cases to a single Wind task). In the VxWorks kernel, ***sched_setscheduler*( )** controls only task priority, because the kernel does not allow tasks to have scheduling policies that differ from one another. If its policy specification matches the current system-wide scheduling policy, ***sched_setscheduler*( )** sets only the priority, thus acting like ***sched_setparam*( )**. If its policy specification does not match the current one, ***sched_setscheduler*( )** returns an error.

The only way to change the scheduling policy is to change it for all tasks; there is no POSIX routine for this purpose. To set a system-wide scheduling policy, use the Wind function ***kernelTimeSlice*( )** described in *Round-Robin Scheduling*, p.23.

Getting and Displaying the Current Scheduling Policy

The POSIX routine ***sched_getscheduler*( )** returns the current scheduling policy. There are two valid scheduling policies in VxWorks: preemptive priority scheduling (in POSIX terms, **SCHED_FIFO**) and round-robin scheduling by priority (**SCHED_RR**).

Example 2-2 **Getting POSIX Scheduling Policy**

```
/* This example gets the scheduling policy and displays it. */

/* includes */

#include "vxWorks.h"
#include "sched.h"

STATUS schedulerTest (void)
    {
    int policy;

    if ((policy = sched_getscheduler (0)) == ERROR)
        {
        printf ("getting scheduler failed\n");
        return (ERROR);
        }

    /* sched_getscheduler returns either SCHED_FIFO or SCHED_RR */

    if (policy == SCHED_FIFO)
        printf ("current scheduling policy is FIFO\n");
    else
        printf ("current scheduling policy is round robin\n");

    return (OK);
    }
```

Getting Scheduling Parameters: Priority Limits and Time Slice

The routines *sched_get_priority_max*( ) and *sched_get_priority_min*( ) return the maximum and minimum possible POSIX priority values, respectively.

If round-robin scheduling is enabled, you can use *sched_rr_get_interval*( ) to determine the length of the current time-slice interval. This routine takes as an argument a pointer to a **timespec** structure (defined in **time.h**), and writes the number of seconds and nanoseconds per time slice to the appropriate elements of that structure.

Example 2-3 **Getting the POSIX Round-Robin Time Slice**

```
/* The following example checks that round-robin scheduling is enabled,
 * gets the length of the time slice, and then displays the time slice.
 */

/* includes */

#include "vxWorks.h"
#include "sched.h"
```

```
STATUS rrgetintervalTest (void)
    {
    struct timespec slice;

    /* turn on round robin */

    kernelTimeSlice (30);

    if (sched_rr_get_interval (0, &slice) == ERROR)
        {
        printf ("get-interval test failed\n");
        return (ERROR);
        }

    printf ("time slice is %l seconds and %l nanoseconds\n",
            slice.tv_sec, slice.tv_nsec);
    return (OK);
    }
```

2.3.7 Task Error Status: errno

By convention, C library functions set a single global integer variable **errno** to an appropriate error number whenever the function encounters an error. This convention is specified as part of the ANSI C standard.

Layered Definitions of errno

In VxWorks, **errno** is simultaneously defined in two different ways. There is, as in ANSI C, an underlying global variable called **errno**, which you can display by name using Tornado development tools; see the *Tornado User's Guide*. However, **errno** is also defined as a macro in **errno.h**; this is the definition visible to all of VxWorks except for one function. The macro is defined as a call to a function ***__errno*( )** that returns the address of the global variable, **errno** (as you might guess, this is the single function that does not itself use the macro definition for **errno**). This subterfuge yields a useful feature: because ***__errno*( )** is a function, you can place breakpoints on it while debugging, to determine where a particular error occurs. Nevertheless, because the result of the macro **errno** is the address of the global variable **errno**, C programs can set the value of **errno** in the standard way:

```
    errno = someErrorNumber;
```

As with any other **errno** implementation, take care not to have a local variable of the same name.

A Separate errno *Value for Each Task*

In VxWorks, the underlying global **errno** is a single predefined global variable that can be referenced directly by application code that is linked with VxWorks (either statically on the host or dynamically at load time). However, for **errno** to be useful in the multitasking environment of VxWorks, each task must see its own version of **errno**. Therefore **errno** is saved and restored by the kernel as part of each task's context every time a context switch occurs. Similarly, *interrupt service routines (ISRs)* see their own versions of **errno**.

This is accomplished by saving and restoring **errno** on the interrupt stack as part of the interrupt enter and exit code provided automatically by the kernel (see *2.5.1 Connecting Application Code to Interrupts*, p.85). Thus, regardless of the VxWorks context, an error code can be stored or consulted with direct manipulation of the global variable **errno**.

Error Return Convention

Almost all VxWorks functions follow a convention that indicates simple success or failure of their operation by the actual return value of the function. Many functions return only the status values **OK** (0) or **ERROR** (-1). Some functions that normally return a nonnegative number (for example, ***open*( )** returns a file descriptor) also return **ERROR** to indicate an error. Functions that return a pointer usually return **NULL** (0) to indicate an error. In most cases, a function returning such an error indication also sets **errno** to the specific error code.

The global variable **errno** is never cleared by VxWorks routines. Thus, its value always indicates the last error status set. When a VxWorks subroutine gets an error indication from a call to another routine, it usually returns its own error indication without modifying **errno**. Thus, the value of **errno** that is set in the lower-level routine remains available as the indication of error type.

For example, the VxWorks routine ***intConnect*( )**, which connects a user routine to a hardware interrupt, allocates memory by calling ***malloc*( )** and builds the interrupt driver in this allocated memory. If ***malloc*( )** fails because insufficient memory remains in the pool, it sets **errno** to a code indicating an insufficient-memory error was encountered in the memory allocation library, **memLib**. The ***malloc*( )** routine then returns **NULL** to indicate the failure. The ***intConnect*( )** routine, receiving the **NULL** from ***malloc*( )**, then returns its own error indication of **ERROR**. However, it does not alter **errno**, leaving it at the "insufficient memory" code set by ***malloc*( )**. For example:

```
if ((pNew = malloc (CHUNK_SIZE)) == NULL)
        return (ERROR);
```

We recommend that you use this mechanism in your own subroutines, setting and examining **errno** as a debugging technique. A string constant associated with **errno** can be displayed using ***printErrno*( )** if the **errno** value has a corresponding string entered in the error-status symbol table, **statSymTbl**. See the reference entry **errnoLib** for details on error-status values and building **statSymTbl**.

Assignment of Error Status Values

VxWorks **errno** values encode the module that issues an error, in the most significant two bytes, and use the least significant two bytes for individual error numbers. All VxWorks module numbers are in the range 1–500; **errno** values with a "module" number of zero are used for source compatibility.

All other **errno** values (that is, positive values greater than or equal to **501<<16**, and all negative values) are available for application use.

See the reference entry on **errnoLib** for more information about defining and decoding **errno** values with this convention.

2.3.8 Task Exception Handling

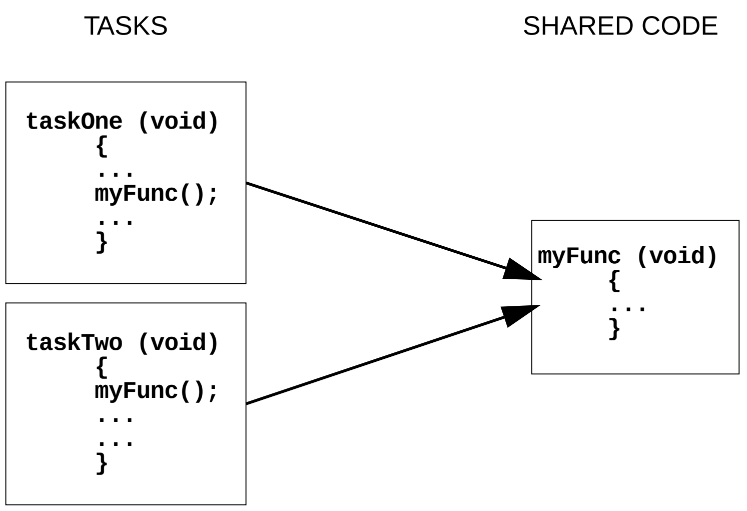
Errors in program code or data can cause hardware exception conditions such as illegal instructions, bus or address errors, divide by zero, and so forth. The VxWorks exception handling package takes care of all such exceptions. The default exception handler suspends the task that caused the exception, and saves the state of the task at the point of the exception. The kernel and other tasks continue uninterrupted. A description of the exception is transmitted to the Tornado development tools, which can be used to examine the suspended task; see the *Tornado User's Guide: Shell* for details.

Tasks can also attach their own handlers for certain hardware exceptions through the *signal* facility. If a task has supplied a signal handler for an exception, the default exception handling described above is not performed. Signals are also used for signaling software exceptions as well as hardware exceptions. They are described in more detail in *2.4.7 Signals*, p.81 and in the reference entry for **sigLib**.

2.3.9 Shared Code and Reentrancy

In VxWorks, it is common for a single copy of a subroutine or subroutine library to be invoked by many different tasks. For example, many tasks may call ***printf*( )**, but there is only a single copy of the subroutine in the system. A single copy of code executed by multiple tasks is called *shared code*. VxWorks dynamic linking facilities make this particularly easy. Shared code also makes the system more efficient and easier to maintain; see Figure 2-4.

Figure 2-4 **Shared Code**



Shared code must be *reentrant*. A subroutine is reentrant if a single copy of the routine can be called from several task contexts simultaneously without conflict. Such conflict typically occurs when a subroutine modifies global or static variables, because there is only a single copy of the data and code. A routine's references to such variables can overlap and interfere in invocations from different task contexts.

Most routines in VxWorks are reentrant. However, all routines which have a corresponding *name_**r***( ) routine should be assumed non-reentrant. For example, because ***ldiv*( )** has a corresponding routine ***ldiv_r*( )**, you can assume that ***ldiv*( )** is not reentrant.

VxWorks I/O and driver routines are reentrant, but require careful application design. For buffered I/O, we recommend using file-pointer buffers on a per-task basis. At the driver level, it is possible to load buffers with streams from different tasks, due to the global file descriptor table in VxWorks. This may or may not be desirable, depending on the nature of the application. For example, a packet driver can mix streams from different tasks because the packet header identifies the destination of each packet.

The majority of VxWorks routines use the following reentrancy techniques:

– dynamic stack variables
– global and static variables guarded by semaphores
– task variables

We recommend applying these same techniques when writing application code that can be called from several task contexts simultaneously.

Dynamic Stack Variables

Many subroutines are *pure* code, having no data of their own except dynamic stack variables. They work exclusively on data provided by the caller as parameters. The linked-list library, **lstLib**, is a good example of this. Its routines operate on lists and nodes provided by the caller in each subroutine call.

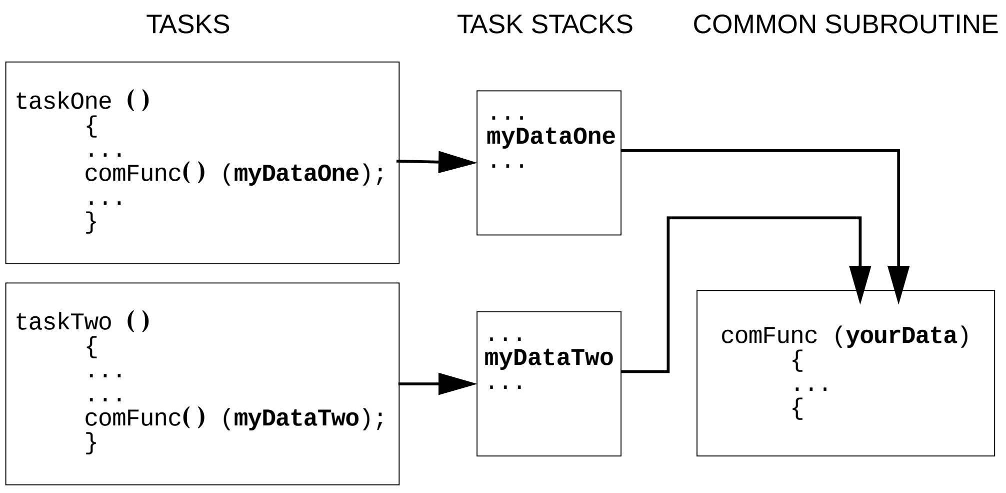
Subroutines of this kind are inherently reentrant. Multiple tasks can use such routines simultaneously without interfering with each other, because each task does indeed have its own stack. See Figure 2-5.

Guarded Global and Static Variables

Some libraries encapsulate access to common data. One example is the memory allocation library, **memLib**, which manages pools of memory to be used by many tasks. This library declares and uses its own static data variables to keep track of pool allocation.

This kind of library requires some caution because the routines are not inherently reentrant. Multiple tasks simultaneously invoking the routines in the library might interfere with access to common variables. Such libraries must be made explicitly reentrant by providing a *mutual-exclusion* mechanism to prohibit tasks from simultaneously executing critical sections of code. The usual mutual-exclusion mechanism is the semaphore facility provided by **semLib** and described in *2.4.3 Semaphores*, p.47.

Figure 2-5 **Stack Variables and Shared Code**



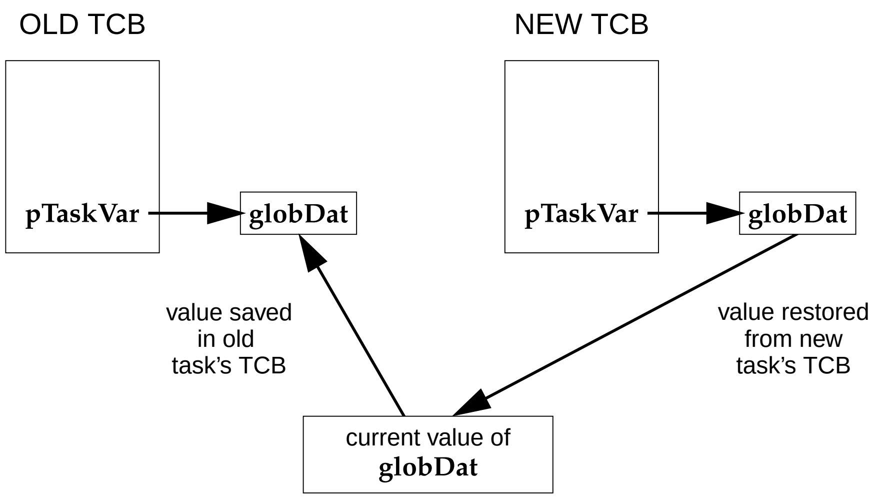
Task Variables

Some routines that can be called by multiple tasks simultaneously may require global or static variables with a distinct value for each calling task. For example, several tasks may reference a private buffer of memory and yet refer to it with the same global variable.

To accommodate this, VxWorks provides a facility called *task variables* that allows 4-byte variables to be added to a task's context, so that the value of such a variable is switched every time a task switch occurs to or from its owner task. Typically, several tasks declare the same variable (4-byte memory location) as a task variable. Each of those tasks can then treat that single memory location as its own private variable; see Figure 2-6. This facility is provided by the routines ***taskVarAdd*( )**, ***taskVarDelete*( )**, ***taskVarSet*( )**, and ***taskVarGet*( )**, which are described in the reference entry for **taskVarLib**.

Use this mechanism sparingly. Each task variable adds a few microseconds to the context switching time for its task, because the value of the variable must be saved and restored as part of the task's context. Consider collecting all of a module's task variables into a single dynamically allocated structure, and then making all accesses to that structure indirectly through a single pointer. This pointer can then be the task variable for all tasks using that module.

Figure 2-6 **Task Variables and Context Switches**



Multiple Tasks with the Same Main Routine

With VxWorks, it is possible to spawn several tasks with the same main routine. Each spawn creates a new task with its own stack and context. Each spawn can also pass the main routine different parameters to the new task. In this case, the same rules of reentrancy described in *Task Variables*, p.41 apply to the entire task.

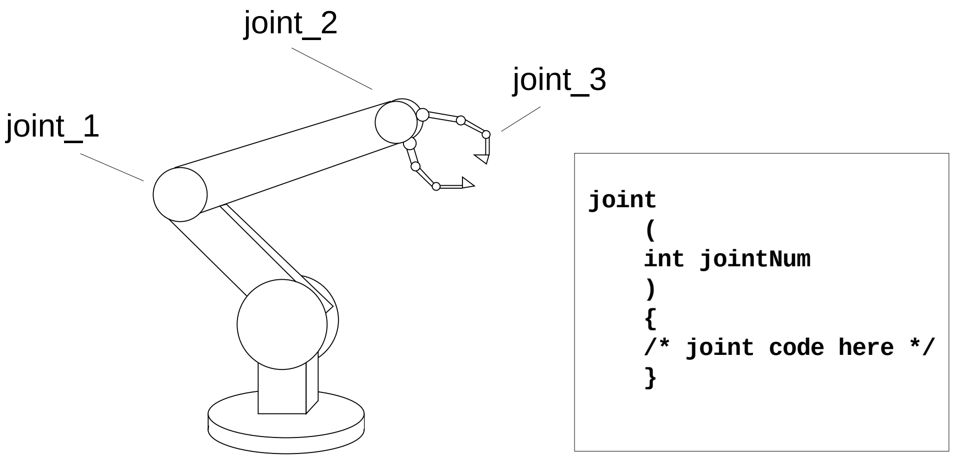
This is useful when the same function needs to be performed concurrently with different sets of parameters. For example, a routine that monitors a particular kind of equipment might be spawned several times to monitor several different pieces of that equipment. The arguments to the main routine could indicate which particular piece of equipment the task is to monitor.

In Figure 2-7, multiple joints of the mechanical arm use the same code. The tasks manipulating the joints invoke ***joint( )***. The joint number (**jointNum**) is used to indicate which joint on the arm to manipulate.

2.3.10 VxWorks System Tasks

VxWorks includes several system tasks, described below.

Figure 2-7 **Multiple Tasks Utilizing Same Code**



```
joint
    (
    int jointNum
    )
    {
    /* joint code here */
    }
```

The Root Task: tUsrRoot

The root task, **tUsrRoot**, is the first task executed by the kernel. The entry point of the root task is ***usrRoot*( )** in *installDir***/target/config/all/usrConfig.c** and initializes most VxWorks facilities. It spawns such tasks as the logging task, the exception task, the network task, and the **tRlogind** daemon. Normally, the root task terminates and is deleted after all initialization has occurred. You are free to add any necessary initialization to the root task. For more information, see *8.5 Configuring VxWorks*, p.337.

The Logging Task: tLogTask

The log task, **tLogTask**, is used by VxWorks modules to log system messages without having to perform I/O in the current task context. For more information, see *3.5.3 Message Logging*, p.109 and the reference entry for **logLib**.

The Exception Task: tExcTask

The exception task, **tExcTask**, supports the VxWorks exception handling package by performing functions that cannot occur at interrupt level. It must have the highest priority in the system. Do not suspend, delete, or change the priority of this task. For more information, see the reference entry for **excLib**.

The Network Task: tNetTask

The **tNetTask** daemon handles the task-level functions required by the VxWorks network.

The Target Agent Task: tWdbTask

The target agent task, **tWdbTask**, is created if the target agent is set to run in task mode; see *8.6.1 Scaling Down VxWorks*, p. 344. It services requests from the Tornado target server; for information on this server, see the *Tornado User's Guide: Overview.*

Tasks for Optional Components

The following VxWorks system tasks are created if their associated configuration constants are defined; for more information, see *8.5 Configuring VxWorks*, p. 337.

tShell
If you have included the target shell in the VxWorks configuration, it is spawned as this task. Any routine or task that is invoked from the target shell, rather than spawned, runs in the **tShell** context. For more information, see *9. Target Shell*.

tRlogind
If you have included the target shell and the **rlogin** facility in the VxWorks configuration, this daemon allows remote users to log in to VxWorks. It accepts a remote login request from another VxWorks or host system and spawns **tRlogInTask** and **tRlogOutTask**. These tasks exist as long as the remote user is logged on. During the remote session, the shell's (and any other task's) input and output are redirected to the remote user. A *tty*-like interface is provided to the remote user through the use of the VxWorks pseudo-terminal driver, **ptyDrv**. For more information, see *3.7.1 Serial I/O Devices (Terminal and Pseudo-Terminal Devices)*, p. 118 and the reference entry for **ptyDrv**.

tTelnetd
If you have included the target shell and the **telnet** facility in the VxWorks configuration, this daemon allows remote users to log in to VxWorks with **telnet**. It accepts a remote login request from another VxWorks or host system and spawns the input task **tTelnetInTask** and output task **tTelnetOutTask**. These tasks exist as long as the remote user is logged on. During the remote session, the shell's (and any other task's) input and output are redirected to the remote user. A *tty*-like interface is provided to the remote user through the use of the VxWorks pseudo-terminal driver, **ptyDrv**. See *3.7.1 Serial I/O Devices (Terminal and Pseudo-Terminal Devices)*, p. 118 and the reference entry for **ptyDrv** for further explanation.

tPortmapd
If you have included the RPC facility in the VxWorks configuration, this daemon is an RPC server that acts as a central registrar for RPC servers running on the same machine. RPC clients query the **tPortmapd** daemon to find out how to contact the various servers.

2.4 Intertask Communications

The complement to the multitasking routines described in the *2.3 Tasks*, p.20 is the intertask communication facilities. These facilities permit independent tasks to coordinate their actions.

VxWorks supplies a rich set of intertask communication mechanisms, including:

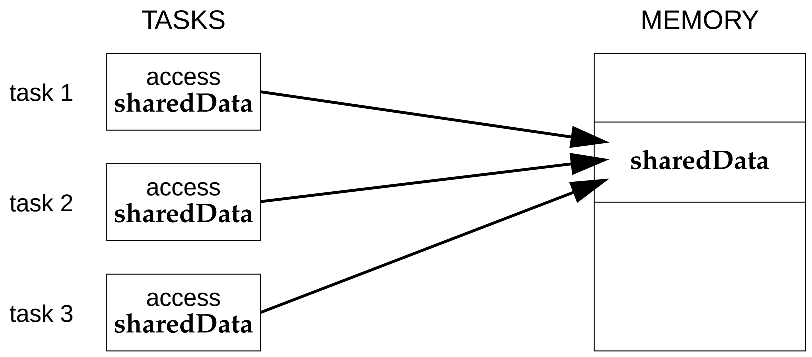
- *Shared memory*, for simple sharing of data.
- *Semaphores*, for basic mutual exclusion and synchronization.
- *Message queues* and *pipes*, for intertask message passing within a CPU.
- *Sockets* and *remote procedure calls*, for network-transparent intertask communication.
- *Signals*, for exception handling.

The optional product, VxMP, provides intertask communication over the backplane for tasks running on different CPUs. This includes shared semaphores, shared message queues, shared memory, and the shared name database.

2.4.1 Shared Data Structures

The most obvious way for tasks to communicate is by accessing shared data structures. Because all tasks in VxWorks exist in a single linear address space, sharing data structures between tasks is trivial; see Figure 2-8. Global variables, linear buffers, ring buffers, linked lists, and pointers can be referenced directly by code running in different contexts.

Figure 2-8 **Shared Data Structures**



2.4.2 Mutual Exclusion

While a shared address space simplifies exchange of data, interlocking access to memory is crucial to avoid contention. Many methods exist for obtaining exclusive access to resources, and vary only in the scope of the exclusion. Such methods include disabling interrupts, disabling preemption, and resource locking with semaphores.

Interrupt Locks and Latency

The most powerful method available for mutual exclusion is the disabling of interrupts. Such a lock guarantees exclusive access to the CPU:

```
funcA ()
    {
    int lock = intLock();
    .
    .   critical region that cannot be interrupted
    .
    intUnlock (lock);
    }
```

While this solves problems involving mutual exclusion with ISRs, it is inappropriate as a general-purpose mutual-exclusion method for most real-time systems, because it prevents the system from responding to external events for the duration of these locks. Interrupt latency is unacceptable whenever an immediate response to an external event is required. However, interrupt locking can sometimes be necessary where mutual exclusion involves ISRs. In any situation, keep the duration of interrupt lockouts short.

Preemptive Locks and Latency

Disabling preemption offers a somewhat less restrictive form of mutual exclusion. While no other task is allowed to preempt the current executing task, ISRs are able to execute:

```
funcA ()
    {
    taskLock ();
    .
    .   critical region that cannot be interrupted
    .
    taskUnlock ();
    }
```

However, this method can lead to unacceptable real-time response. Tasks of higher priority are unable to execute until the locking task leaves the critical region, even though the higher-priority task is not itself involved with the critical region. While this kind of mutual exclusion is simple, if you use it, make sure to keep the duration short. A better mechanism is provided by semaphores, discussed in *2.4.3 Semaphores*, p.47.

2.4.3 Semaphores

VxWorks semaphores are highly optimized and provide the fastest intertask communication mechanism in VxWorks. Semaphores are the primary means for addressing the requirements of both mutual exclusion and task synchronization:

- For *mutual exclusion*, semaphores interlock access to shared resources. They provide mutual exclusion with finer granularity than either interrupt disabling or preemptive locks, discussed in *2.4.2 Mutual Exclusion*, p.46.
- For *synchronization*, semaphores coordinate a task's execution with external events.

There are three types of Wind semaphores, optimized to address different classes of problems:

binary
: The fastest, most general-purpose semaphore. Optimized for synchronization or mutual exclusion.

mutual exclusion
A special binary semaphore optimized for problems inherent in mutual exclusion: priority inheritance, deletion safety, and recursion.

counting
Like the binary semaphore, but keeps track of the number of times a semaphore is given. Optimized for guarding multiple instances of a resource.

VxWorks provides not only the Wind semaphores, designed expressly for VxWorks, but also POSIX semaphores, designed for portability. An alternate semaphore library provides the POSIX-compatible semaphore interface; see *POSIX Semaphores*, p.57.

The semaphores described here are for use on a single CPU. The optional product VxMP provides semaphores that can be used across processors; see *6. Shared-Memory Objects*.

Semaphore Control

Instead of defining a full set of semaphore control routines for each type of semaphore, the Wind semaphores provide a single uniform interface for semaphore control. Only the creation routines are specific to the semaphore type. Table 2-13 lists the semaphore control routines.

Table 2-13 **Semaphore Control Routines**

Call	Description
***semBCreate*( )**	Allocate and initialize a binary semaphore.
***semMCreate*( )**	Allocate and initialize a mutual-exclusion semaphore.
***semCCreate*( )**	Allocate and initialize a counting semaphore.
***semDelete*( )**	Terminate and free a semaphore.
***semTake*( )**	Take a semaphore.
***semGive*( )**	Give a semaphore.
***semFlush*( )**	Unblock all tasks that are waiting for a semaphore.

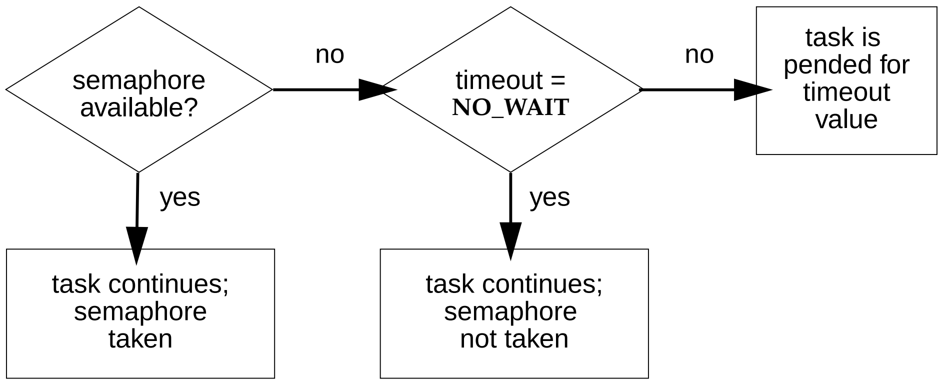
The ***semBCreate*( )**, ***semMCreate*( )**, and ***semCCreate*( )** routines return a semaphore ID that serves as a handle on the semaphore during subsequent use by the other semaphore-control routines. When a semaphore is created, the queue type is specified. Tasks pending on a semaphore can be queued in priority order (**SEM_Q_PRIORITY**) or in first-in first-out order (**SEM_Q_FIFO**).

WARNING: The ***semDelete*( )** call terminates a semaphore and deallocates any associated memory. Take care when deleting semaphores, particularly those used for mutual exclusion, to avoid deleting a semaphore that another task still requires. Do not delete a semaphore unless the same task first succeeds in taking it.

Binary Semaphores

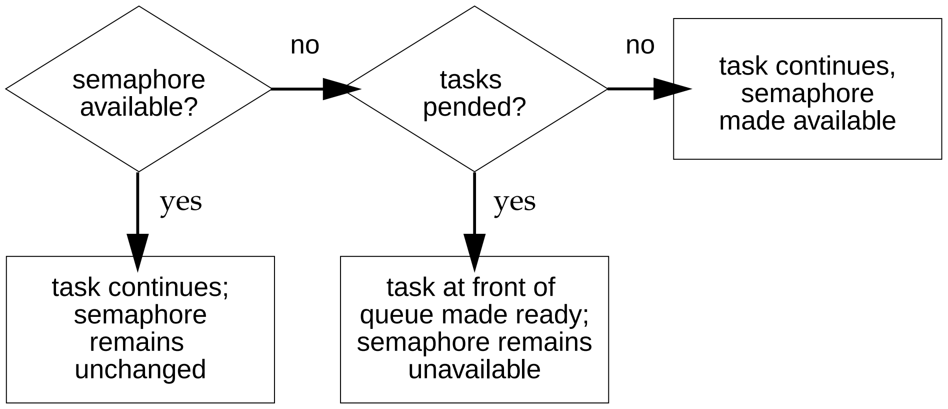
The general-purpose binary semaphore is capable of addressing the requirements of both forms of task coordination: mutual exclusion and synchronization. The binary semaphore has the least overhead associated with it, making it particularly applicable to high-performance requirements. The mutual-exclusion semaphore described in *Mutual-Exclusion Semaphores*, p.52 is also a binary semaphore, but it has been optimized to address problems inherent to mutual exclusion. Alternatively, the binary semaphore can be used for mutual exclusion if the advanced features of the mutual-exclusion semaphore are deemed unnecessary.

Figure 2-9 **Taking a Semaphore**


semaphore available?
no
timeout = NO_WAIT
no
task is pended for timeout value
yes
yes
task continues; semaphore taken
task continues; semaphore not taken

A binary semaphore can be viewed as a flag that is available (full) or unavailable (empty). When a task takes a binary semaphore, with ***semTake*( )**, the outcome depends on whether the semaphore is available (full) or unavailable (empty) at the time of the call; see Figure 2-9. If the semaphore is available (full), the semaphore

Figure 2-10 **Giving a Semaphore**


semaphore available?
no
tasks pended?
no
task continues, semaphore made available
yes
yes
task continues; semaphore remains unchanged
task at front of queue made ready; semaphore remains unavailable

becomes unavailable (empty) and the task continues executing immediately. If the semaphore is unavailable (empty), the task is put on a queue of blocked tasks and enters a state of pending on the availability of the semaphore.

When a task gives a binary semaphore, using ***semGive*( )**, the outcome also depends on whether the semaphore is available (full) or unavailable (empty) at the time of the call; see Figure 2-10. If the semaphore is already available (full), giving the semaphore has no effect at all. If the semaphore is unavailable (empty) and no task is waiting to take it, then the semaphore becomes available (full). If the semaphore is unavailable (empty) and one or more tasks are pending on its availability, then the first task in the queue of blocked tasks is unblocked, and the semaphore is left unavailable (empty).

Mutual Exclusion

Binary semaphores interlock access to a shared resource efficiently. Unlike disabling interrupts or preemptive locks, binary semaphores limit the scope of the mutual exclusion to only the associated resource. In this technique, a semaphore is created to guard the resource. Initially the semaphore is available (full).

```
/* includes */
#include "vxWorks.h"
#include "semLib.h"

SEM_ID semMutex;

/* Create a binary semaphore that is initially full. Tasks *
```

```
 * blocked on semaphore wait in priority order.             */

semMutex = semBCreate (SEM_Q_PRIORITY, SEM_FULL);
```

When a task wants to access the resource, it must first take that semaphore. As long as the task keeps the semaphore, all other tasks seeking access to the resource are blocked from execution. When the task is finished with the resource, it gives back the semaphore, allowing another task to use the resource.

Thus all accesses to a resource requiring mutual exclusion are bracketed with ***semTake*( )** and ***semGive*( )** pairs:

```
semTake (semMutex, WAIT_FOREVER);
.
.   critical region, only accessible by a single task at a time
.
semGive (semMutex);
```

Synchronization

When used for task synchronization, a semaphore can represent a condition or event that a task is waiting for. Initially the semaphore is unavailable (empty). A task or ISR signals the occurrence of the event by giving the semaphore (see *2.5 Interrupt Service Code*, p.85 for a complete discussion of ISRs). Another task waits for the semaphore by calling ***semTake*( )**. The waiting task blocks until the event occurs and the semaphore is given.

Note the difference in sequence between semaphores used for mutual exclusion and those used for synchronization. For mutual exclusion, the semaphore is initially full, and each task first takes, then gives back the semaphore. For synchronization, the semaphore is initially empty, and one task waits to take the semaphore given by another task.

In Example 2-4, the ***init*( )** routine creates the binary semaphore, attaches an ISR to an event, and spawns a task to process the event. The routine ***task1*( )** runs until it calls ***semTake*( )**. It remains blocked at that point until an event causes the ISR to call ***semGive*( )**. When the ISR completes, ***task1*( )** executes to process the event. There is an advantage of handling event processing within the context of a dedicated task: less processing takes place at interrupt level, thereby reducing interrupt latency. This model of event processing is recommended for real-time applications.

Example 2-4 **Using Semaphores for Task Synchronization**

```
/* This example shows the use of semaphores for task synchronization. */

/* includes */
```

```
#include "vxWorks.h"
#include "semLib.h"
#include "arch/arch/ivarch.h" /* replace arch with architecture type */

SEM_ID syncSem;        /* ID of sync semaphore */

init (
    int someIntNum
    )
    {
    /* connect interrupt service routine */
    intConnect (INUM_TO_IVEC (someIntNum), eventInterruptSvcRout, 0);

    /* create semaphore */
    syncSem = semBCreate (SEM_Q_FIFO, SEM_EMPTY);

    /* spawn task used for synchronization. */
    taskSpawn ("sample", 100, 0, 20000, task1, 0,0,0,0,0,0,0,0,0,0);
    }

task1 (void)
    {
    ...
    semTake (syncSem, WAIT_FOREVER); /* wait for event to occur */
    printf ("task 1 got the semaphore\n");
    ... /* process event */
    }

eventInterruptSvcRout (void)
    {
    ...
    semGive (syncSem);   /* let task 1 process event */
    ...
    }
```

Broadcast synchronization allows all processes that are blocked on the same semaphore to be unblocked atomically. Correct application behavior often requires a set of tasks to process an event before any task of the set has the opportunity to process further events. The routine ***semFlush*( )** addresses this class of synchronization problem by unblocking all tasks pended on a semaphore.

Mutual-Exclusion Semaphores

The mutual-exclusion semaphore is a specialized binary semaphore designed to address issues inherent in mutual exclusion, including priority inversion, deletion safety, and recursive access to resources.

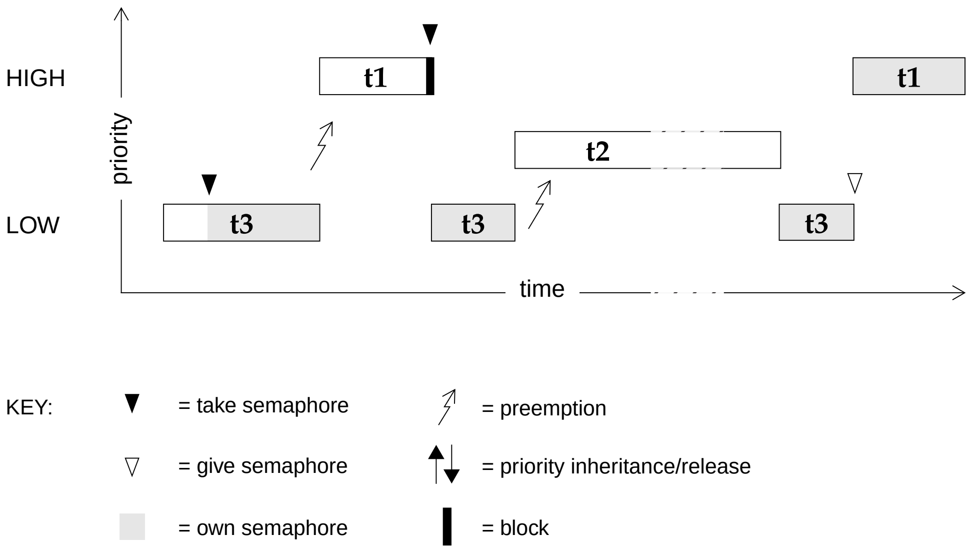
The fundamental behavior of the mutual-exclusion semaphore is identical to the binary semaphore, with the following exceptions:

- It can be used only for mutual exclusion.
- It can be given only by the task that took it.
- It cannot be given from an ISR.
- The ***semFlush*( )** operation is illegal.

Priority Inversion

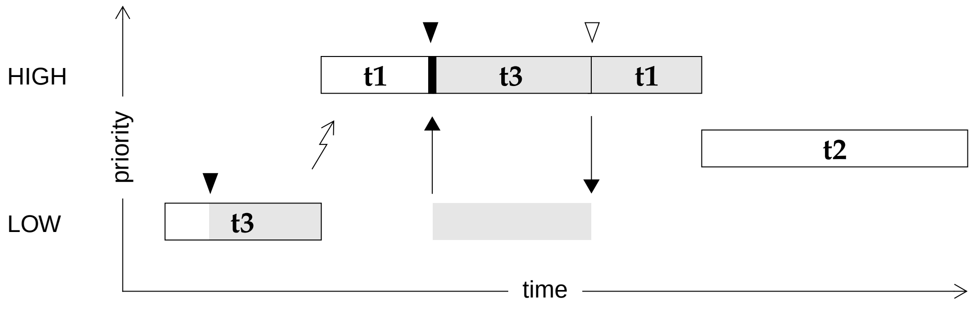
Priority inversion arises when a higher-priority task is forced to wait an indefinite period of time for a lower-priority task to complete. Consider the scenario in Figure 2-11: **t1**, **t2**, and **t3** are tasks of high, medium, and low priority, respectively. **t3** has acquired some resource by taking its associated binary guard semaphore. When **t1** preempts **t3** and contends for the resource by taking the same semaphore, it becomes blocked. If we could be assured that **t1** would be blocked no longer than the time it normally takes **t3** to finish with the resource, there would be no problem because the resource cannot be preempted. However, the low-priority task is vulnerable to preemption by medium-priority tasks (like **t2**), which could inhibit **t3** from relinquishing the resource. This condition could persist, blocking **t1** for an indefinite period of time.

Figure 2-11 **Priority Inversion**



The mutual-exclusion semaphore has the option **SEM_INVERSION_SAFE**, which enables a *priority-inheritance* algorithm. The priority-inheritance protocol assures that a task that owns a resource executes at the priority of the highest-priority task blocked on that resource. Once the task priority has been elevated, it remains at the higher level until all mutual-exclusion semaphores that the task owns are released; then the task returns to its normal, or standard, priority. Hence, the "inheriting" task is protected from preemption by any intermediate-priority tasks. This option must be used in conjunction with a priority queue (**SEM_Q_PRIORITY**).

Figure 2-12 **Priority Inheritance**



In Figure 2-12, priority inheritance solves the problem of priority inversion by elevating the priority of **t3** to the priority of **t1** during the time **t1** is blocked on the semaphore. This protects **t3**, and indirectly **t1**, from preemption by **t2**.

The following example creates a mutual-exclusion semaphore that uses the priority inheritance algorithm:

```
semId = semMCreate (SEM_Q_PRIORITY | SEM_INVERSION_SAFE);
```

Deletion Safety

Another problem of mutual exclusion involves task deletion. Within a critical region guarded by semaphores, it is often desirable to protect the executing task from unexpected deletion. Deleting a task executing in a critical region can be catastrophic. The resource might be left in a corrupted state and the semaphore guarding the resource left unavailable, effectively preventing all access to the resource.

The primitives ***taskSafe*( )** and ***taskUnsafe*( )** provide one solution to task deletion. However, the mutual-exclusion semaphore offers the option **SEM_DELETE_SAFE**, which enables an implicit ***taskSafe*( )** with each ***semTake*( )**, and a ***taskUnsafe*( )** with each ***semGive*( )**. In this way, a task can be protected from deletion while it has the semaphore. This option is more efficient than the primitives ***taskSafe*( )** and ***taskUnsafe*( )**, as the resulting code requires fewer entrances to the kernel.

```
    semId = semMCreate (SEM_Q_FIFO | SEM_DELETE_SAFE);
```

Recursive Resource Access

Mutual-exclusion semaphores can be taken *recursively*. This means that the semaphore can be taken more than once by the task that owns it before finally being released. Recursion is useful for a set of routines that must call each other but that also require mutually exclusive access to a resource. This is possible because the system keeps track of which task currently owns the mutual-exclusion semaphore.

Before being released, a mutual-exclusion semaphore taken recursively must be *given* the same number of times it is *taken*. This is tracked by a count that increments with each ***semTake*( )** and decrements with each ***semGive*( )**.

Example 2-5 **Recursive Use of a Mutual-Exclusion Semaphore**

```
/* Function A requires access to a resource which it acquires by taking
 * mySem; function A may also need to call function B, which also
 * requires mySem:
 */

/* includes */
#include "vxWorks.h"
#include "semLib.h"
SEM_ID mySem;

/* Create a mutual-exclusion semaphore. */

init ()
    {
    mySem = semMCreate (SEM_Q_PRIORITY);
    }
funcA ()
    {
    semTake (mySem, WAIT_FOREVER);
    printf ("funcA: Got mutual-exclusion semaphore\n");
    ...
    funcB ();
    ...
    semGive (mySem);
    printf ("funcA: Released mutual-exclusion semaphore\n");
    }
funcB ()
    {
    semTake (mySem, WAIT_FOREVER);
    printf ("funcB: Got mutual-exclusion semaphore\n");
    ...
    semGive (mySem);
    printf ("funcB: Releases mutual-exclusion semaphore\n");
    }
```

Counting Semaphores

Counting semaphores are another means to implement task synchronization and mutual exclusion. The counting semaphore works like the binary semaphore except that it keeps track of the number of times a semaphore is given. Every time a semaphore is given, the count is incremented; every time a semaphore is taken, the count is decremented. When the count reaches zero, a task that tries to take the semaphore is blocked. As with the binary semaphore, if a semaphore is given and a task is blocked, it becomes unblocked. However, unlike the binary semaphore, if a semaphore is given and no tasks are blocked, then the count is incremented. This means that a semaphore that is given twice can be taken twice without blocking. Table 2-14 shows an example time sequence of tasks taking and giving a counting semaphore that was initialized to a count of 3.

Table 2-14 **Counting Semaphore Example**

Semaphore Call	Count after Call	Resulting Behavior
***semCCreate*( )**	3	Semaphore initialized with initial count of 3.
***semTake*( )**	2	Semaphore taken.
***semTake*( )**	1	Semaphore taken.
***semTake*( )**	0	Semaphore taken.
***semTake*( )**	0	Task blocks waiting for semaphore to be available.
***semGive*( )**	0	Task waiting is given semaphore.
***semGive*( )**	1	No task waiting for semaphore; count incremented.

Counting semaphores are useful for guarding multiple copies of resources. For example, the use of five tape drives might be coordinated using a counting semaphore with an initial count of 5, or a ring buffer with 256 entries might be implemented using a counting semaphore with an initial count of 256. The initial count is specified as an argument to the ***semCCreate*( )** routine.

Special Semaphore Options

The uniform Wind semaphore interface includes two special options. These options are not available for the POSIX-compatible semaphores described in *POSIX Semaphores*, p.57.

Timeouts

Wind semaphores include the ability to time out from the pended state. This is controlled by a parameter to ***semTake*( )** that specifies the amount of time in ticks that the task is willing to wait in the pended state. If the task succeeds in taking the semaphore within the allotted time, ***semTake*( )** returns **OK**. The **errno** set when a ***semTake*( )** returns **ERROR** due to timing out before successfully taking the semaphore depends upon the timeout value passed. A ***semTake*( )** with **NO_WAIT** (0), which means *do not wait at all*, sets **errno** to **S_objLib_OBJ_UNAVAILABLE**. A ***semTake*( )** with a positive timeout value returns **S_objLib_OBJ_TIMEOUT**. A timeout value of **WAIT_FOREVER** (-1) means *wait indefinitely.*

Queues

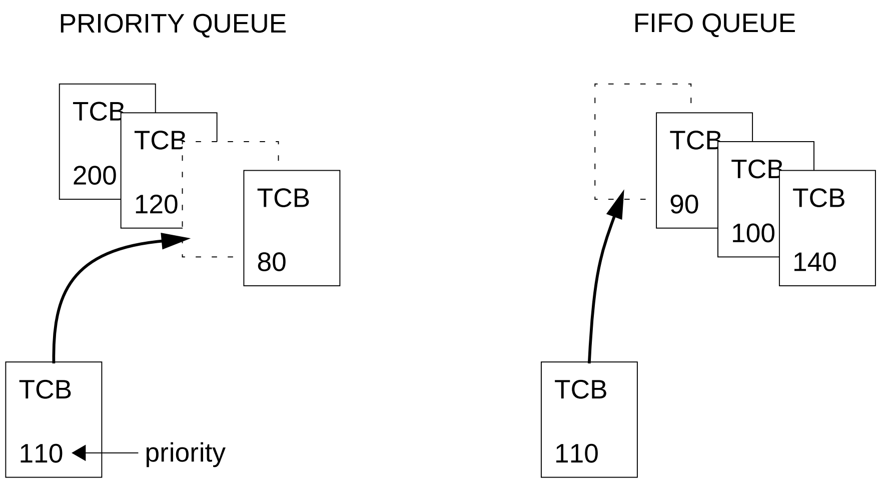
Wind semaphores include the ability to select the queuing mechanism employed for tasks blocked on a semaphore. They can be queued based on either of two criteria: first-in first-out (FIFO) order, or priority order; see Figure 2-13.

Priority ordering better preserves the intended priority structure of the system at the expense of some overhead in ***semTake*( )** in sorting the tasks by priority. A FIFO queue requires no priority sorting overhead and leads to constant-time performance. The selection of queue type is specified during semaphore creation with ***semBCreate*( )**, ***semMCreate*( )**, or ***semCCreate*( )**. Semaphores using the priority inheritance option (**SEM_INVERSION_SAFE**) must select priority-order queuing.

POSIX Semaphores

POSIX defines both *named* and *unnamed* semaphores, which have the same properties, but use slightly different interfaces. The POSIX semaphore library provides routines for creating, opening, and destroying both named and unnamed

Figure 2-13 **Task Queue Types**



semaphores. The POSIX semaphore routines provided by **semPxLib** are shown in Table 2-15.

With named semaphores, you assign a symbolic name[1] when opening the semaphore; the other named-semaphore routines accept this name as an argument.

The POSIX terms *wait* (or *lock*) and *post* (or *unlock*) correspond to the VxWorks terms *take* and *give*, respectively.

The initialization routine ***semPxLibInit*( )** is called by default when **INCLUDE_POSIX_SEM** is selected for inclusion in the project facility VxWorks view. The routines ***sem_open*( )**, ***sem_unlink*( )**, and ***sem_close*( )** are for opening and closing/destroying named semaphores only; ***sem_init*( )** and ***sem_destroy*( )** are for initializing and destroying unnamed semaphores only. The routines for locking, unlocking, and getting the value of semaphores are used for both named and unnamed semaphores.

1. Some host operating systems, such as UNIX, require symbolic names for objects that are to be shared among processes. This is because processes do not normally share memory in such operating systems. In VxWorks, there is no requirement for named semaphores, because all objects are located within a single address space, and reference to shared objects by memory location is standard practice.

Table 2-15 **POSIX Semaphore Routines**

Call	Description
***semPxLibInit*( )**	Initialize the POSIX semaphore library (non-POSIX).
***sem_init*( )**	Initialize an unnamed semaphore.
***sem_destroy*( )**	Destroy an unnamed semaphore.
***sem_open*( )**	Initialize/open a named semaphore.
***sem_close*( )**	Close a named semaphore.
***sem_unlink*( )**	Remove a named semaphore.
***sem_wait*( )**	Lock a semaphore.
***sem_trywait*( )**	Lock a semaphore only if it is not already locked.
***sem_post*( )**	Unlock a semaphore.
***sem_getvalue*( )**	Get the value of a semaphore.

WARNING: The ***sem_destroy*( )** call terminates an unnamed semaphore and deallocates any associated memory; the combination of ***sem_close*( )** and ***sem_unlink*( )** has the same effect for named semaphores. Take care when deleting semaphores, particularly mutual exclusion semaphores, to avoid deleting a semaphore still required by another task. Do not delete a semaphore unless the deleting task first succeeds in locking that semaphore. (Likewise, for named semaphores, close semaphores only from the same task that opens them.)

Comparison of POSIX and Wind Semaphores

POSIX semaphores are *counting* semaphores; that is, they keep track of the number of times they are given.

The Wind semaphore mechanism is similar to that specified by POSIX, except that Wind semaphores offer additional features: priority inheritance, task-deletion safety, the ability for a single task to take a semaphore multiple times, ownership of mutual-exclusion semaphores, semaphore timeouts, and the choice of queuing mechanism. When these features are important, Wind semaphores are preferable.

Using Unnamed Semaphores

In using unnamed semaphores, normally one task allocates memory for the semaphore and initializes it. A semaphore is represented with the data structure

sem_t, defined in **semaphore.h**. The semaphore initialization routine, ***sem_init*( )**, allows you to specify the initial value.

Once the semaphore is initialized, any task can use the semaphore by locking it with ***sem_wait*( )** (blocking) or ***sem_trywait*( )** (non-blocking), and unlocking it with ***sem_post*( )**.

As noted earlier, semaphores can be used for both synchronization and mutual exclusion. When a semaphore is used for synchronization, it is typically initialized to zero (locked). The task waiting to be synchronized blocks on a ***sem_wait*( )**. The task doing the synchronizing unlocks the semaphore using ***sem_post*( )**. If the task blocked on the semaphore is the only one waiting for that semaphore, the task unblocks and becomes ready to run. If other tasks are blocked on the semaphore, the task with the highest priority is unblocked.

When a semaphore is used for mutual exclusion, it is typically initialized to a value greater than zero (meaning that the resource is available). Therefore, the first task to lock the semaphore does so without blocking; subsequent tasks block (if the semaphore value was initialized to 1).

Example 2-6 **POSIX Unnamed Semaphores**

```
/* This example uses unnamed semaphores to synchronize an action between
 * the calling task and a task that it spawns (tSyncTask). To run from
 * the shell, spawn as a task:
 *   -> sp unnameSem
 */

/* includes */

#include "vxWorks.h"
#include "semaphore.h"

/* forward declarations */

void syncTask (sem_t * pSem);

void unnameSem (void)
    {
    sem_t * pSem;

    /* reserve memory for semaphore */

    pSem = (sem_t *) malloc (sizeof (sem_t));

    /* initialize semaphore to unavailable */

    if (sem_init (pSem, 0, 0) == -1)
        {
        printf ("unnameSem: sem_init failed\n");
        return;
        }

    /* create sync task */

    printf ("unnameSem: spawning task...\n");
    taskSpawn ("tSyncTask", 90, 0, 2000, syncTask, pSem);

    /* do something useful to synchronize with syncTask */

    /* unlock sem */

    printf ("unnameSem: posting semaphore - synchronizing action\n");
    if (sem_post (pSem) == -1)
        {
        printf ("unnameSem: posting semaphore failed\n");
        return;
        }

    /* all done - destroy semaphore */

    if (sem_destroy (pSem) == -1)
      {
      printf ("unnameSem: sem_destroy failed\n");
      return;
      }
    }

void syncTask
    (
    sem_t * pSem
    )
    {
    /* wait for synchronization from unnameSem */

    if (sem_wait (pSem) == -1)
        {
        printf ("syncTask: sem_wait failed \n");
        return;
        }
    else
        printf ("syncTask:sem locked; doing sync'ed action...\n");

    /* do something useful here */
    }
```

Using Named Semaphores

The ***sem_open*( )** routine either opens a named semaphore that already exists, or, as an option, creates a new semaphore. You can specify which of these possibilities you want by combining the following flag values:

O_CREAT	Create the semaphore if it does not already exist (if it exists, either fail or open the semaphore, depending on whether **O_EXCL** is specified).
O_EXCL	Open the semaphore only if newly created; fail if the semaphore exists.

The possible effects of a call to ***sem_open*( )**, depending on which flags are set and on whether the semaphore accessed already exists, are shown in Table 2-16. There is no entry for **O_EXCL** alone, because using that flag alone is not meaningful.

Table 2-16 **Possible Outcomes of Calling *sem_open*( )**

Flag Settings	Semaphore Exists	Semaphore Does Not Exist
None	Semaphore is opened	Routine fails
O_CREAT	Semaphore is opened	Semaphore is created
O_CREAT and **O_EXCL**	Routine fails	Semaphore is created

A POSIX named semaphore, once initialized, remains usable until explicitly destroyed. Tasks can explicitly mark a semaphore for destruction at any time, but the semaphore remains in the system until no task has the semaphore open.

If **INCLUDE_POSIX_SEM_SHOW** is selected for inclusion in the project facility VxWorks view (for details, see *Tornado User's Guide: Projects*), you can use ***show*( )** from the Tornado shell to display information about a POSIX semaphore:[2]

```
-> show semId
value = 0 = 0x0
```

The output is sent to the standard output device, and provides information about the POSIX semaphore **mySem** with two tasks blocked waiting for it:

```
Semaphore name        :mySem
sem_open() count       :3
Semaphore value       :0
No. of blocked tasks     :2
```

For a group of collaborating tasks to use a named semaphore, one of the tasks first creates and initializes the semaphore (by calling ***sem_open*( )** with the **O_CREAT** flag). Any task that needs to use the semaphore thereafter opens it by calling ***sem_open*( )** with the same name (but without setting **O_CREAT**). Any task that has opened the semaphore can use it by locking it with ***sem_wait*( )** (blocking) or ***sem_trywait*( )** (non-blocking) and unlocking it with ***sem_post*( )**.

2. This is not a POSIX routine, nor is it designed for use from programs; use it from the Tornado shell (see the *Tornado User's Guide: Shell* for details).

To remove a semaphore, all tasks using it must first close it with ***sem_close*( )**, and one of the tasks must also unlink it. Unlinking a semaphore with ***sem_unlink*( )** removes the semaphore name from the name table. After the name is removed from the name table, tasks that currently have the semaphore open can still use it, but no new tasks can open this semaphore. The next time a task tries to open the semaphore without the **O_CREAT** flag, the operation fails. The semaphore vanishes when the last task closes it.

Example 2-7 **POSIX Named Semaphores**

```
/* In this example, nameSem() creates a task for synchronization. The
 * new task, tSyncSemTask, blocks on the semaphore created in nameSem().
 * Once the synchronization takes place, both tasks close the semaphore,
 * and nameSem() unlinks it. To run this task from the shell, spawn
 * nameSem as a task:
 *   -> sp nameSem, "myTest"
 */

/* includes */
#include "vxWorks.h"
#include "semaphore.h"
#include "fcntl.h"

/* forward declaration */
int syncSemTask (char * name);

int nameSem
    (
    char * name
    )
    {
    sem_t * semId;

    /* create a named semaphore, initialize to 0*/
    printf ("nameSem: creating semaphore\n");
    if ((semId = sem_open (name, O_CREAT, 0, 0)) == (sem_t *) -1)
        {
        printf ("nameSem: sem_open failed\n");
        return;
        }

    printf ("nameSem: spawning sync task\n");

    taskSpawn ("tSyncSemTask", 90, 0, 2000, syncSemTask, name);

    /* do something useful to synchronize with syncSemTask */

    /* give semaphore */
    printf ("nameSem: posting semaphore - synchronizing action\n");
    if (sem_post (semId) == -1)
        {
```

```
        printf ("nameSem: sem_post failed\n");
        return;
        }

    /* all done */
    if (sem_close (semId) == -1)
        {
        printf ("nameSem: sem_close failed\n");
        return;
        }

    if (sem_unlink (name) == -1)
        {
        printf ("nameSem: sem_unlink failed\n");
        return;
        }

    printf ("nameSem: closed and unlinked semaphore\n");
    }

int syncSemTask
    (
    char * name
    )

    {
    sem_t * semId;

    /* open semaphore */
    printf ("syncSemTask: opening semaphore\n");
    if ((semId = sem_open (name, 0)) == (sem_t *) -1)
        {
        printf ("syncSemTask: sem_open failed\n");
        return;
        }

    /* block waiting for synchronization from nameSem */
    printf ("syncSemTask: attempting to take semaphore...\n");
    if (sem_wait (semId) == -1)
        {
        printf ("syncSemTask: taking sem failed\n");
        return;
        }

    printf ("syncSemTask: has semaphore, doing sync'ed action ...\n");

    /* do something useful here */

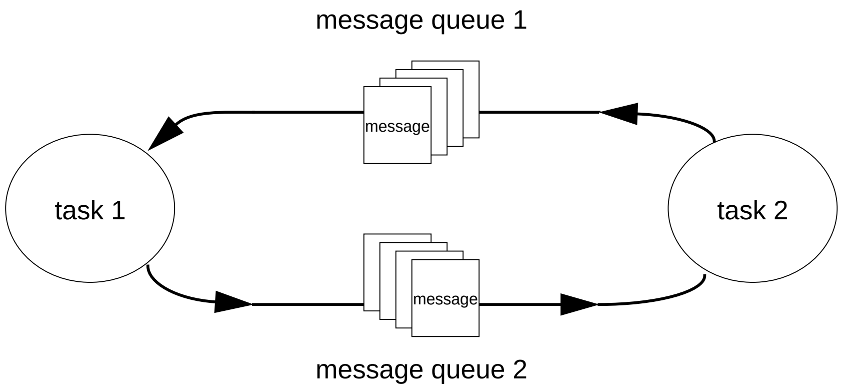
    if (sem_close (semId) == -1)
        {
        printf ("syncSemTask: sem_close failed\n");
        return;
        }
    }
```

2.4.4 Message Queues

Modern real-time applications are constructed as a set of independent but cooperating tasks. While semaphores provide a high-speed mechanism for the synchronization and interlocking of tasks, often a higher-level mechanism is necessary to allow cooperating tasks to communicate with each other. In VxWorks, the primary intertask communication mechanism within a single CPU is *message queues.* The optional product, VxMP, provides global message queues that can be used across processors; for more information, see *6. Shared-Memory Objects*.

Message queues allow a variable number of messages, each of variable length, to be queued. Any task or ISR can send messages to a message queue. Any task can receive messages from a message queue. Multiple tasks can send to and receive from the same message queue. Full-duplex communication between two tasks generally requires two message queues, one for each direction; see Figure 2-14.

Figure 2-14 **Full Duplex Communication Using Message Queues**



There are two message-queue subroutine libraries in VxWorks. The first of these, **msgQLib**, provides Wind message queues, designed expressly for VxWorks; the second, **mqPxLib**, is compatible with the POSIX standard (1003.1b) for real-time extensions. See *Comparison of POSIX and Wind Message Queues*, p.77 for a discussion of the differences between the two message-queue designs.

Wind Message Queues

Wind message queues are created and deleted with the routines shown in Table 2-17. This library provides messages that are queued in FIFO order, with a single exception: there are two priority levels, and messages marked as high priority are attached to the head of the queue.

Table 2-17 **Wind Message Queue Control**

Call	Description
***msgQCreate*( )**	Allocate and initialize a message queue.
***msgQDelete*( )**	Terminate and free a message queue.
***msgQSend*( )**	Send a message to a message queue.
***msgQReceive*( )**	Receive a message from a message queue.

A message queue is created with ***msgQCreate*( )**. Its parameters specify the maximum number of messages that can be queued in the message queue and the maximum length in bytes of each message. Enough buffer space is preallocated for the specified number and length of messages.

A task or ISR sends a message to a message queue with ***msgQSend*( )**. If no tasks are waiting for messages on that queue, the message is added to the queue's buffer of messages. If any tasks are already waiting for a message from that message queue, the message is immediately delivered to the first waiting task.

A task receives a message from a message queue with ***msgQReceive*( )**. If messages are already available in the message queue's buffer, the first message is immediately dequeued and returned to the caller. If no messages are available, then the calling task blocks and is added to a queue of tasks waiting for messages. This queue of waiting tasks can be ordered either by task priority or FIFO, as specified in an option parameter when the queue is created.

Timeouts

Both ***msgQSend*( )** and ***msgQReceive*( )** take timeout parameters. When sending a message, the timeout specifies how many ticks to wait for buffer space to become available, if no space is available to queue the message. When receiving a message, the timeout specifies how many ticks to wait for a message to become available, if no message is immediately available. As with semaphores, the value of the timeout parameter can have the special values of **NO_WAIT** (0), meaning always return immediately, or **WAIT_FOREVER** (-1), meaning never time out the routine.

Urgent Messages

The ***msgQSend*( )** function allows specification of the priority of the message as either normal (**MSG_PRI_NORMAL**) or urgent (**MSG_PRI_URGENT**). Normal priority messages are added to the tail of the list of queued messages, while urgent priority messages are added to the head of the list.

Example 2-8 **Wind Message Queues**

```
/* In this example, task t1 creates the message queue and sends a message
 * to task t2. Task t2 receives the message from the queue and simply
 * displays the message.
 */

/* includes */
#include "vxWorks.h"
#include "msgQLib.h"

/* defines */
#define MAX_MSGS (10)
#define MAX_MSG_LEN (100)

MSG_Q_ID myMsgQId;

task2 (void)
    {
    char msgBuf[MAX_MSG_LEN];

    /* get message from queue; if necessary wait until msg is available */
    if (msgQReceive(myMsgQId, msgBuf, MAX_MSG_LEN, WAIT_FOREVER) == ERROR)
        return (ERROR);

    /* display message */
    printf ("Message from task 1:\n%s\n", msgBuf);
    }

#define MESSAGE "Greetings from Task 1"
task1 (void)
    {
    /* create message queue */
    if ((myMsgQId = msgQCreate (MAX_MSGS, MAX_MSG_LEN, MSG_Q_PRIORITY))
        == NULL)
        return (ERROR);

    /* send a normal priority message, blocking if queue is full */
    if (msgQSend (myMsgQId, MESSAGE, sizeof (MESSAGE), WAIT_FOREVER,
                  MSG_PRI_NORMAL) == ERROR)
        return (ERROR);
    }
```

POSIX Message Queues

The POSIX message queue routines, provided by **mqPxLib**, are shown in Table 2-18. These routines are similar to Wind message queues, except that POSIX message queues provide named queues and messages with a range of priorities.

Table 2-18 **POSIX Message Queue Routines**

Call	Description
***mqPxLibInit*( )**	Initialize the POSIX message queue library (non-POSIX).
***mq_open*( )**	Open a message queue.
***mq_close*( )**	Close a message queue.
***mq_unlink*( )**	Remove a message queue.
***mq_send*( )**	Send a message to a queue.
***mq_receive*( )**	Get a message from a queue.
***mq_notify*( )**	Signal a task that a message is waiting on a queue.
***mq_setattr*( )**	Set a queue attribute.
***mq_getattr*( )**	Get a queue attribute.

The initialization routine ***mqPxLibInit*( )** makes the POSIX message queue routines available; the system initialization code must call it before any tasks use POSIX message queues. As shipped, ***usrInit*( )** calls ***mqPxLibInit*( )** when **INCLUDE_POSIX_MQ** is selected for inclusion in the project facility VxWorks view.

Before a set of tasks can communicate through a POSIX message queue, one of the tasks must create the message queue by calling ***mq_open*( )** with the **O_CREAT** flag set. Once a message queue is created, other tasks can open that queue by name to send and receive messages on it. Only the first task opens the queue with the **O_CREAT** flag; subsequent tasks can open the queue for receiving only (**O_RDONLY**), sending only (**O_WRONLY**), or both sending and receiving (**O_RDWR**).

To put messages on a queue, use ***mq_send*( )**. If a task attempts to put a message on the queue when the queue is full, the task blocks until some other task reads a message from the queue, making space available. To avoid blocking on ***mq_send*( )**, set **O_NONBLOCK** when you open the message queue. In that case, when the queue is full, ***mq_send*( )** returns -1 and sets **errno** to **EAGAIN** instead of pending, allowing you to try again or take other action as appropriate.

One of the arguments to ***mq_send*( )** specifies a message priority. Priorities range from 0 (lowest priority) to 31 (highest priority).

When a task receives a message using ***mq_receive*( )**, the task receives the highest-priority message currently on the queue. Among multiple messages with the same priority, the first message placed on the queue is the first received (FIFO order). If the queue is empty, the task blocks until a message is placed on the queue. To avoid pending on ***mq_receive*( )**, open the message queue with **O_NONBLOCK**; in that case, when a task attempts to read from an empty queue, ***mq_receive*( )** returns -1 and sets **errno** to **EAGAIN**.

To close a message queue, call ***mq_close*( )**. Closing the queue does not destroy it, but only asserts that your task is no longer using the queue. To request that the queue be destroyed, call ***mq_unlink*( )**. *Unlinking* a message queue does not destroy the queue immediately, but it does prevent any further tasks from opening that queue, by removing the queue name from the name table. Tasks that currently have the queue open can continue to use it. When the last task closes an unlinked queue, the queue is destroyed.

Example 2-9 **POSIX Message Queues**

```
/* In this example, the mqExInit() routine spawns two tasks that
 * communicate using the message queue.
 */

/* mqEx.h - message example header */

/* defines */
#define MQ_NAME "exampleMessageQueue"

/* forward declarations */
void receiveTask (void);
void sendTask (void);

/* testMQ.c - example using POSIX message queues */

/* includes */
#include "vxWorks.h"
#include "mqueue.h"
#include "fcntl.h"
#include "errno.h"
#include "mqEx.h"

/* defines */
#define HI_PRIO     31
#define MSG_SIZE    16
```

```
int mqExInit (void)
    {
    /* create two tasks */
    if (taskSpawn ("tRcvTask", 95, 0, 4000, receiveTask, 0, 0, 0, 0,
                 0, 0, 0, 0, 0, 0) == ERROR)
        {
        printf ("taskSpawn of tRcvTask failed\n");
        return (ERROR);
        }

    if (taskSpawn ("tSndTask", 100, 0, 4000, sendTask, 0, 0, 0, 0,
                 0, 0, 0, 0, 0, 0) == ERROR)
        {
        printf ("taskSpawn of tSendTask failed\n");
        return (ERROR);
        }
    }

void receiveTask (void)
    {
    mqd_t    mqPXId;          /* msg queue descriptor */
    char     msg[MSG_SIZE];   /* msg buffer */
    int      prio;            /* priority of message */

    /* open message queue using default attributes */
    if ((mqPXId = mq_open (MQ_NAME, O_RDWR | O_CREAT, 0, NULL))
        == (mqd_t) -1)
        {
        printf ("receiveTask: mq_open failed\n");
        return;
        }

    /* try reading from queue */
    if (mq_receive (mqPXId, msg, MSG_SIZE, &prio) == -1)
        {
        printf ("receiveTask: mq_receive failed\n");
        return;
        }
    else
        {
        printf ("receiveTask: Msg of priority %d received:\n\t\t%s\n",
                prio, msg);
        }
    }

/* sendTask.c - mq sending example */

/* includes */
#include "vxWorks.h"
#include "mqueue.h"
#include "fcntl.h"
#include "mqEx.h"

/* defines */
#define MSG   "greetings"
#define HI_PRIO 30
```

```
void sendTask (void)
    {
    mqd_t    mqPXId;          /* msg queue descriptor */

    /* open msg queue; should already exist with default attributes */
    if ((mqPXId = mq_open (MQ_NAME, O_RDWR, 0, NULL)) == (mqd_t) -1)
        {
        printf ("sendTask: mq_open failed\n");
        return;
        }

    /* try writing to queue */
    if (mq_send (mqPXId, MSG, sizeof (MSG), HI_PRIO) == -1)
        {
        printf ("sendTask: mq_send failed\n");
        return;
        }
    else
        printf ("sendTask: mq_send succeeded\n");
    }
```

Notifying a Task that a Message is Waiting

A task can use the ***mq_notify*( )** routine to request notification when a message for it arrives at an empty queue. The advantage of this is that a task can avoid blocking or polling to wait for a message.

The ***mq_notify*( )** call specifies a signal to be sent to the task when a message is placed on an empty queue. This mechanism uses the POSIX data-carrying extension to signaling, which allows you, for example, to carry a queue identifier with the signal (see *POSIX Queued Signals*, p.83).

The ***mq_notify*( )** mechanism is designed to alert the task only for new messages that are actually available. If the message queue already contains messages, no notification is sent when more messages arrive. If there is another task that is blocked on the queue with ***mq_receive*( )**, that other task unblocks, and no notification is sent to the task registered with ***mq_notify*( )**.

Notification is exclusive to a single task: each queue can register only one task for notification at a time. Once a queue has a task to notify, no attempts to register with ***mq_notify*( )** can succeed until the notification request is satisfied or cancelled.

Once a queue sends notification to a task, the notification request is satisfied, and the queue has no further special relationship with that particular task; that is, the queue sends a notification signal only once per ***mq_notify*( )** request. To arrange for one particular task to continue receiving notification signals, the best approach is to call ***mq_notify*( )** from the same signal handler that receives the notification signals. This reinstalls the notification request as soon as possible.

To cancel a notification request, specify **NULL** instead of a notification signal. Only the currently registered task can cancel its notification request.

Example 2-10 **Notifying a Task that a Message Queue is Waiting**

```
/* In this example, a task uses mq_notify() to discover when a message
 * is waiting for it on a previously empty queue.
 */

/* includes */
#include "vxWorks.h"
#include "signal.h"
#include "mqueue.h"
#include "fcntl.h"
#include "errno.h"

/* defines */
#define QNAM      "PxQ1"
#define MSG_SIZE    64       /* limit on message sizes */

/* forward declarations */
static void exNotificationHandle (int, siginfo_t *, void *);
static void exMqRead (mqd_t);

/***********************************************************************
* exMqNotify - example of how to use mq_notify()
*
* This routine illustrates the use of mq_notify() to request notification
* via signal of new messages in a queue. To simplify the example, a
* single task both sends and receives a message.
*/

int exMqNotify
    (
    char * pMess           /* text for message to self */
    )
    {
    struct mq_attr   attr;                  /* queue attribute structure */
    struct sigevent   sigNotify;            /* to attach notification */
    struct sigaction  mySigAction;          /* to attach signal handler */
    mqd_t        exMqId;                          /* id of message queue */

    /* Minor sanity check; avoid exceeding msg buffer */
    if (MSG_SIZE <= strlen (pMess))
        {
        printf ("exMqNotify: message too long\n");
        return (-1);
        }

    /* Install signal handler for the notify signal - fill in a
     * sigaction structure and pass it to sigaction(). Because the
     * handler needs the siginfo structure as an argument, the
     * SA_SIGINFO flag is set in sa_flags.
     */
```

```
mySigAction.sa_sigaction = exNotificationHandle;
mySigAction.sa_flags   = SA_SIGINFO;
sigemptyset (&mySigAction.sa_mask);

if (sigaction (SIGUSR1, &mySigAction, NULL) == -1)
    {
    printf ("sigaction failed\n");
    return (-1);
    }

/* Create a message queue - fill in a mq_attr structure with the
 * size and no. of messages required, and pass it to mq_open().
 */
attr.mq_flags  = O_NONBLOCK;    /* make nonblocking */
attr.mq_maxmsg = 2;
attr.mq_msgsize = MSG_SIZE;

if ( (exMqId = mq_open (QNAM, O_CREAT | O_RDWR, 0, &attr)) ==
     (mqd_t) - 1 )
    {
    printf ("mq_open failed\n");
    return (-1);
    }

/* Set up notification: fill in a sigevent structure and pass it
 * to mq_notify(). The queue ID is passed as an argument to the
 * signal handler.
 */
sigNotify.sigev_signo      = SIGUSR1;
sigNotify.sigev_notify     = SIGEV_SIGNAL;
sigNotify.sigev_value.sival_int = (int) exMqId;

if (mq_notify (exMqId, &sigNotify) == -1)
    {
    printf ("mq_notify failed\n");
    return (-1);
    }

/* We just created the message queue, but it may not be empty;
 * a higher-priority task may have placed a message there while
 * we were requesting notification. mq_notify() does nothing if
 * messages are already in the queue; therefore we try to
 * retrieve any messages already in the queue.
 */
exMqRead (exMqId);

/* Now we know the queue is empty, so we will receive a signal
 * the next time a message arrives.
 *
 * We send a message, which causes the notify handler to be
 * invoked. It is a little silly to have the task that gets the
 * notification be the one that puts the messages on the queue,
 * but we do it here to simplify the example.
 *
 * A real application would do other work instead at this point.
 */
```

```
    if (mq_send (exMqId, pMess, 1 + strlen (pMess), 0) == -1)
        {
        printf ("mq_send failed\n");
        return (-1);
        }

    /* Cleanup */
    if (mq_close (exMqId) == -1)
        {
        printf ("mq_close failed\n");
        return (-1);
        }

    /* More cleanup */
    if (mq_unlink (QNAM) == -1)
        {
        printf ("mq_unlink failed\n");
        return (-1);
        }

    return (0);
    }

/************************************************************************
* exNotificationHandle - handler to read in messages
*
* This routine is a signal handler; it reads in messages from a message
* queue.
*/

static void exNotificationHandle
    (
    int        sig,         /* signal number */
    siginfo_t * pInfo,          /* signal information */
    void *     pSigContext     /* unused (required by posix) */
    )
    {
    struct sigevent   sigNotify;
    mqd_t        exMqId;

    /* Get the ID of the message queue out of the siginfo structure. */
    exMqId = (mqd_t) pInfo->si_value.sival_int;

    /* Request notification again; it resets each time a notification
     * signal goes out.
     */
    sigNotify.sigev_signo = pInfo->si_signo;
    sigNotify.sigev_value = pInfo->si_value;
    sigNotify.sigev_notify = SIGEV_SIGNAL;

    if (mq_notify (exMqId, &sigNotify) == -1)
        {
        printf ("mq_notify failed\n");
        return;
        }
    /* Read in the messages */
    exMqRead (exMqId);
    }

/************************************************************************
* exMqRead - read in messages
*
* This small utility routine receives and displays all messages
* currently in a POSIX message queue; assumes queue has O_NONBLOCK.
*/

static void exMqRead
    (
    mqd_t        exMqId
    )
    {
    char        msg[MSG_SIZE];
    int         prio;

    /* Read in the messages - uses a loop to read in the messages
     * because a notification is sent ONLY when a message is sent on
     * an EMPTY message queue. There could be multiple msgs if, for
     * example, a higher-priority task was sending them. Because the
     * message queue was opened with the O_NONBLOCK flag, eventually
     * this loop exits with errno set to EAGAIN (meaning we did an
     * mq_receive() on an empty message queue).
     */
    while (mq_receive (exMqId, msg, MSG_SIZE, &prio) != -1)
        {
        printf ("exMqRead: received message: %s\n",msg);
        }

    if (errno != EAGAIN)
        {
        printf ("mq_receive: errno = %d\n", errno);
        }
    }
```

Message Queue Attributes

A POSIX message queue has the following attributes:

- an optional **O_NONBLOCK** flag
- the maximum number of messages in the message queue
- the maximum message size
- the number of messages currently on the queue

Tasks can set or clear the **O_NONBLOCK** flag (but not the other attributes) using *mq_setattr***( )**, and get the values of all the attributes using *mq_getattr***( )**.

Example 2-11 **Setting and Getting Message Queue Attributes**

```
/* This example sets the O_NONBLOCK flag, and examines message queue
 * attributes.
 */

/* includes */
#include "vxWorks.h"
#include "mqueue.h"
#include "fcntl.h"
#include "errno.h"

/* defines */
#define MSG_SIZE    16

int attrEx
    (
    char * name
    )
    {
    mqd_t           mqPXId;     /* mq descriptor */
    struct mq_attr  attr;       /* queue attribute structure */
    struct mq_attr  oldAttr;    /* old queue attributes */
    char            buffer[MSG_SIZE];
    int             prio;

    /* create read write queue that is blocking */
    attr.mq_flags = 0;
    attr.mq_maxmsg = 1;
    attr.mq_msgsize = 16;
    if ((mqPXId = mq_open (name, O_CREAT | O_RDWR , 0, &attr))
         == (mqd_t) -1)
        return (ERROR);
    else
        printf ("mq_open with non-block succeeded\n");

    /* change attributes on queue - turn on non-blocking */
    attr.mq_flags = O_NONBLOCK;
    if (mq_setattr (mqPXId, &attr, &oldAttr) == -1)
        return (ERROR);
    else
        {
        /* paranoia check - oldAttr should not include non-blocking. */
        if (oldAttr.mq_flags & O_NONBLOCK)
            return (ERROR);
        else
            printf ("mq_setattr turning on non-blocking succeeded\n");
        }

    /* try receiving - there are no messages but this shouldn't block */
    if (mq_receive (mqPXId, buffer, MSG_SIZE, &prio) == -1)
        {
        if (errno != EAGAIN)
            return (ERROR);
        else
```

```
            printf ("mq_receive with non-blocking didn’t block on empty queue\n");
        }
    else
        return (ERROR);

    /* use mq_getattr to verify success */
    if (mq_getattr (mqPXId, &oldAttr) == -1)
        return (ERROR);
    else
        {
        /* test that we got the values we think we should */
        if (!(oldAttr.mq_flags & O_NONBLOCK) || (oldAttr.mq_curmsgs != 0))
            return (ERROR);
        else
            printf ("queue attributes are:\n\tblocking is %s\n\t
                    message size is: %d\n\t
                    max messages in queue: %d\n\t
                    no. of current msgs in queue: %d\n",
                    oldAttr.mq_flags & O_NONBLOCK ? "on" : "off",
                    oldAttr.mq_msgsize, oldAttr.mq_maxmsg,
                    oldAttr.mq_curmsgs);
        }

    /* clean up - close and unlink mq */
    if (mq_unlink (name) == -1)
        return (ERROR);
    if (mq_close (mqPXId) == -1)
        return (ERROR);
    return (OK);
    }
```

Comparison of POSIX and Wind Message Queues

The two forms of message queues solve many of the same problems, but there are some significant differences. Table 2-19 summarizes the main differences between the two forms of message queues.

Table 2-19 **Message Queue Feature Comparison**

Feature	**Wind Message Queues**	**POSIX Message Queues**
Message Priority Levels	1	32
Blocked Task Queues	FIFO or priority-based	Priority-based
Receive with Timeout	Optional	Not available
Task Notification	Not available	Optional (one task)
Close/Unlink Semantics	No	Yes

Another feature of POSIX message queues is, of course, portability: if you are migrating to VxWorks from another 1003.1b-compliant system, using POSIX message queues enables you to leave that part of the code unchanged, reducing the porting effort.

Displaying Message Queue Attributes

The VxWorks ***show*( )** command produces a display of the key message queue attributes, for either kind of message queue[3]. For example, if **mqPXId** is a POSIX message queue:

```
-> show mqPXId
value = 0 = 0x0
```

The output is sent to the standard output device, and looks like the following:

```
Message queue name       : MyQueue
No. of messages in queue    : 1
Maximum no. of messages     : 16
Maximum message size      : 16
```

Compare this to the output when **myMsgQId** is a Wind message queue:[4]

```
-> show myMsgQId
Message Queue Id  : 0x3adaf0
Task Queuing    : FIFO
Message Byte Len  : 4
Messages Max    : 30
Messages Queued   : 14
Receivers Blocked  : 0
Send timeouts    : 0
Receive timeouts  : 0
```

Servers and Clients with Message Queues

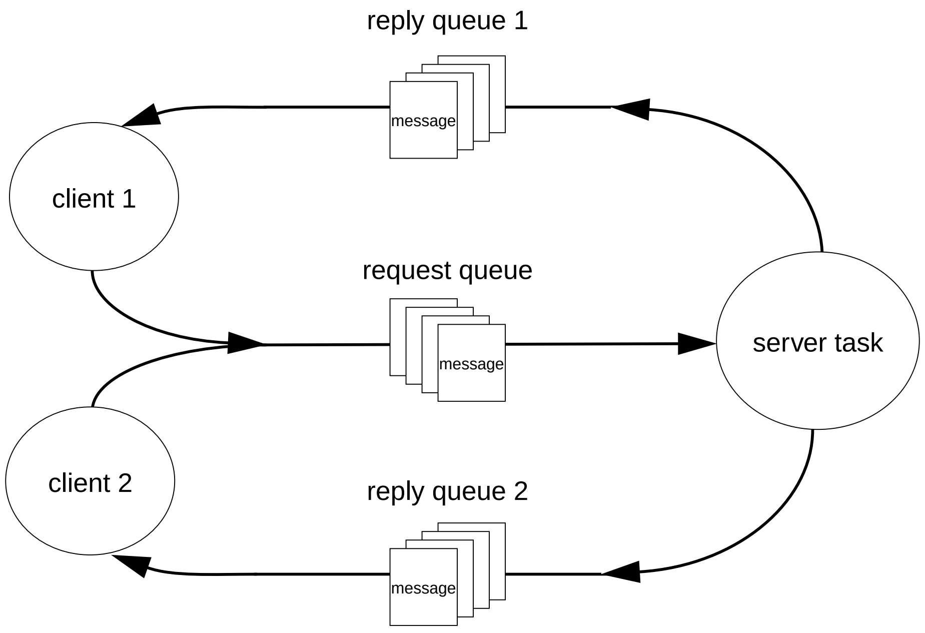
Real-time systems are often structured using a *client-server* model of tasks. In this model, server tasks accept requests from client tasks to perform some service, and usually return a reply. The requests and replies are usually made in the form of

3. However, to get information on POSIX message queues, **INCLUDE_POSIX_MQ_SHOW** must be defined in the VxWorks configuration; for information, see *Tornado User's Guide: Projects*.
4. The built-in ***show*( )** routine handles Wind message queues; see the *Tornado User's Guide: Shell* for information on built-in routines. You can also use the Tornado browser to get information on Wind message queues; see the *Tornado User's Guide: Browser* for details.

intertask messages. In VxWorks, message queues or pipes (see *2.4.5 Pipes*, p.79) are a natural way to implement this.

For example, client-server communications might be implemented as shown in Figure 2-15. Each server task creates a message queue to receive request messages from clients. Each client task creates a message queue to receive reply messages from servers. Each request message includes a field containing the **msgQId** of the client's reply message queue. A server task's "main loop" consists of reading request messages from its request message queue, performing the request, and sending a reply to the client's reply message queue.

Figure 2-15 **Client-Server Communications Using Message Queues**



The same architecture can be achieved with pipes instead of message queues, or by other means that are tailored to the needs of the particular application.

2.4.5 Pipes

Pipes provide an alternative interface to the message queue facility that goes through the VxWorks I/O system. Pipes are virtual I/O devices managed by the driver **pipeDrv**. The routine ***pipeDevCreate*( )** creates a pipe device and the underlying message queue associated with that pipe. The call specifies the name of the created pipe, the maximum number of messages that can be queued to it, and the maximum length of each message:

```
status = pipeDevCreate ("/pipe/name", max_msgs, max_length);
```

The created pipe is a normally named I/O device. Tasks can use the standard I/O routines to open, read, and write pipes, and invoke *ioctl* routines. As they do with other I/O devices, tasks block when they read from an empty pipe until data is available, and block when they write to a full pipe until there is space available. Like message queues, ISRs can write to a pipe, but cannot read from a pipe.

As I/O devices, pipes provide one important feature that message queues cannot—the ability to be used with ***select*( )**. This routine allows a task to wait for data to be available on any of a set of I/O devices. The ***select*( )** routine also works with other asynchronous I/O devices including network sockets and serial devices. Thus, by using ***select*( )**, a task can wait for data on a combination of several pipes, sockets, and serial devices; see *3.3.8 Pending on Multiple File Descriptors: The Select Facility*, p.104.

Pipes allow you to implement a client-server model of intertask communications; see *Servers and Clients with Message Queues*, p.78.

2.4.6 Network Intertask Communication

Sockets

In VxWorks, the basis of intertask communications across the network is *sockets*. A socket is an endpoint for communications between tasks; data is sent from one socket to another. When you create a socket, you specify the Internet communications protocol that is to transmit the data. VxWorks supports the Internet protocols TCP and UDP. VxWorks socket facilities are source compatible with BSD 4.4 UNIX.

TCP provides reliable, guaranteed, two-way transmission of data with *stream sockets*. In a stream-socket communication, two sockets are "connected," allowing a reliable byte-stream to flow between them in each direction as in a circuit. For this reason TCP is often referred to as a *virtual circuit* protocol.

UDP provides a simpler but less robust form of communication. In UDP communications, data is sent between sockets in separate, unconnected, individually addressed packets called *datagrams.* A process creates a datagram socket and binds it to a particular port. There is no notion of a UDP "connection." Any UDP socket, on any host in the network, can send messages to any other UDP socket by specifying its Internet address and port number.

One of the biggest advantages of socket communications is that it is "homogeneous." Socket communications among processes are exactly the same regardless of the location of the processes in the network, or the operating system under which they are running. Processes can communicate within a single CPU, across a backplane, across an Ethernet, or across any connected combination of networks. Socket communications can occur between VxWorks tasks and host system processes in any combination. In all cases, the communications look identical to the application, except, of course, for their speed.

For more information, see *VxWorks Network Programmer's Guide: Networking APIs* and the reference entry for **sockLib**.

Remote Procedure Calls (RPC)

Remote Procedure Calls (RPC) is a facility that allows a process on one machine to call a procedure that is executed by another process on either the same machine or a remote machine. Internally, RPC uses sockets as the underlying communication mechanism. Thus with RPC, VxWorks tasks and host system processes can invoke routines that execute on other VxWorks or host machines, in any combination.

As discussed in the previous sections on message queues and pipes, many real-time systems are structured with a client-server model of tasks. In this model, client tasks request services of server tasks, and then wait for their reply. RPC formalizes this model and provides a standard protocol for passing requests and returning replies. Also, RPC includes tools to help generate the client interface routines and the server skeleton.

For more information on RPC, see *VxWorks Network Programmer's Guide: RPC, Remote Procedure Calls*.

2.4.7 Signals

VxWorks supports a software signal facility. Signals asynchronously alter the control flow of a task. Any task or ISR can raise a signal for a particular task. The task being signaled immediately suspends its current thread of execution and executes the task-specified signal handler routine the next time it is scheduled to run. The signal handler executes in the receiving task's context and makes use of that task's stack. The signal handler is invoked even if the task is blocked.

Signals are more appropriate for error and exception handling than as a general-purpose intertask communication mechanism. In general, signal handlers should be treated like ISRs; no routine should be called from a signal handler that might cause the handler to block. Because signals are asynchronous, it is difficult to predict which resources might be unavailable when a particular signal is raised. To be perfectly safe, call only those routines that can safely be called from an ISR (see Table 2-23). Deviate from this practice only when you are sure your signal handler can not create a deadlock situation.

The *wind* kernel supports two types of signal interface: UNIX BSD-style signals and POSIX-compatible signals. The POSIX-compatible signal interface, in turn, includes both the fundamental signaling interface specified in the POSIX standard 1003.1, and the queued-signals extension from POSIX 1003.1b. For the sake of simplicity, we recommend that you use only one interface type in a given application, rather than mixing routines from different interfaces.

For more information on signals, see the reference entry for **sigLib**.

Basic Signal Routines

Table 2-20 shows the basic signal routines. To make these facilities available, the signal library initialization routine ***sigInit*( )** must be called, normally from ***usrInit*( )** in **usrConfig.c**, before interrupts are enabled.

The colorful name ***kill*( )** harks back to the origin of these interfaces in UNIX BSD. Although the interfaces vary, the functionality of BSD-style signals and basic POSIX signals is similar.

In many ways, signals are analogous to hardware interrupts. The basic signal facility provides a set of 31 distinct signals. A *signal handler* binds to a particular signal with ***sigvec*( )** or ***sigaction*( )** in much the same way that an ISR is connected to an interrupt vector with ***intConnect*( )**. A signal can be asserted by calling ***kill*( )**. This is analogous to the occurrence of an interrupt. The routines ***sigsetmask*( )** and ***sigblock*( )** or ***sigprocmask*( )** let signals be selectively inhibited.

Certain signals are associated with hardware exceptions. For example, bus errors, illegal instructions, and floating-point exceptions raise specific signals.

Table 2-20 **Basic Signal Calls (BSD and POSIX 1003.1b)**

POSIX 1003.1b Compatible Call	UNIX BSD Compatible Call	Description
***signal*( )**	***signal*( )**	Specify the handler associated with a signal.
***kill*( )**	***kill*( )**	Send a signal to a task.
***raise*( )**	N/A	Send a signal to yourself.
***sigaction*( )**	***sigvec*( )**	Examine or set the signal handler for a signal.
***sigsuspend*( )**	***pause*( )**	Suspend a task until a signal is delivered.
***sigpending*( )**	N/A	Retrieve a set of pending signals blocked from delivery.
***sigemptyset*( )** ***sigfillset*( )** ***sigaddset*( )** ***sigdelset*( )** ***sigismember*( )**	***sigsetmask*( )**	Manipulate a signal mask.
***sigprocmask*( )**	***sigsetmask*( )**	Set the mask of blocked signals.
***sigprocmask*( )**	***sigblock*( )**	Add to a set of blocked signals.

POSIX Queued Signals

The ***sigqueue*( )** routine provides an alternative to ***kill*( )** for sending signals to a task. The important differences between the two are:

- ***sigqueue*( )** includes an application-specified value that is sent as part of the signal. You can use this value to supply whatever context your signal handler finds useful. This value is of type **sigval** (defined in **signal.h**); the signal handler finds it in the **si_value** field of one of its arguments, a structure **siginfo_t**. An extension to the POSIX ***sigaction*( )** routine allows you to register signal handlers that accept this additional argument.
- ***sigqueue*( )** enables the queueing of multiple signals for any task. The ***kill*( )** routine, by contrast, delivers only a single signal, even if multiple signals arrive before the handler runs.

VxWorks includes seven signals reserved for application use, numbered consecutively from **SIGRTMIN**. The presence of these reserved signals is required by POSIX 1003.1b, but the specific signal values are not; for portability, specify these signals as offsets from **SIGRTMIN** (for example, write **SIGRTMIN**+2 to refer to the third reserved signal number). All signals delivered with ***sigqueue*( )** are queued by numeric order, with lower-numbered signals queuing ahead of higher-numbered signals.

POSIX 1003.1b also introduced an alternative means of receiving signals. The routine ***sigwaitinfo*( )** differs from ***sigsuspend*( )** or ***pause*( )** in that it allows your application to respond to a signal without going through the mechanism of a registered signal handler: when a signal is available, ***sigwaitinfo*( )** returns the value of that signal as a result, and does not invoke a signal handler even if one is registered. The routine ***sigtimedwait*( )** is similar, except that it can time out.

For detailed information on signals, see the reference entry for **sigLib**.

Table 2-21 **POSIX 1003.1b Queued Signal Calls**

Call	Description
***sigqueue*( )**	Send a queued signal.
***sigwaitinfo*( )**	Wait for a signal.
***sigtimedwait*( )**	Wait for a signal with a timeout.

Signal Configuration

The basic signal facility is included in VxWorks by default with **INCLUDE_SIGNALS** (located under kernel components in the project facility).

Before your application can use POSIX queued signals, they must be initialized separately with ***sigqueueInit*( )**. Like the basic signals initialization function ***sigInit*( )**, this function is normally called from ***usrInit*( )** in **usrConfig.c**, after ***sysInit*( )** runs.

To initialize the queued signal functionality, also define **INCLUDE_POSIX_SIGNALS** (located under POSIX components in the project facility): with that definition, ***sigqueueInit*( )** is called automatically.

The routine ***sigqueueInit*( )** allocates *nQueues* buffers for use by ***sigqueue*( )**, which requires a buffer for each currently queued signal (see the reference entry for ***sigqueueInit*( )**). A call to ***sigqueue*( )** fails if no buffer is available.

2.5 Interrupt Service Code

Hardware interrupt handling is of key significance in real-time systems, because it is usually through interrupts that the system is informed of external events. For the fastest possible response to interrupts, interrupt service routines (ISRs) in VxWorks run in a special context outside of any task's context. Thus, interrupt handling involves no task context switch. The interrupt routines, listed in Table 2-22, are provided in **intLib** and **intArchLib**.

Table 2-22 **Interrupt Routines**

Call	Description
***intConnect*( )**	Connect a C routine to an interrupt vector.
***intContext*( )**	Return TRUE if called from interrupt level.
***intCount*( )**	Get the current interrupt nesting depth.
***intLevelSet*( )**	Set the processor interrupt mask level.
***intLock*( )**	Disable interrupts.
***intUnlock*( )**	Re-enable interrupts.
***intVecBaseSet*( )**	Set the vector base address.
***intVecBaseGet*( )**	Get the vector base address.
***intVecSet*( )**	Set an exception vector.
***intVecGet*( )**	Get an exception vector.

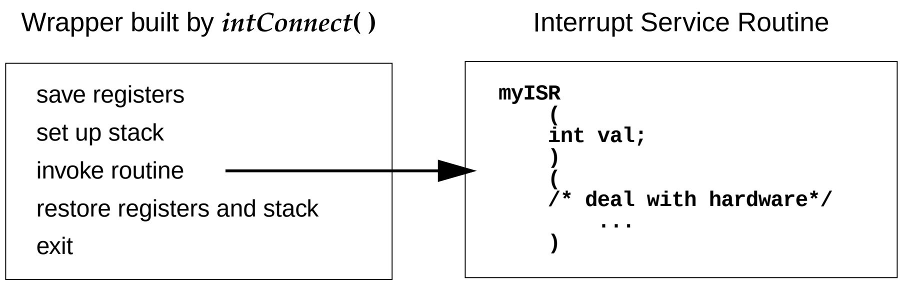
For boards with an MMU, the optional product VxVMI provides write protection for the interrupt vector table; see *7. Virtual Memory Interface*.

2.5.1 Connecting Application Code to Interrupts

You can use system hardware interrupts other than those used by VxWorks. VxWorks provides the routine ***intConnect*( )**, which allows C functions to be connected to any interrupt. The arguments to this routine are the byte offset of the interrupt vector to connect to, the address of the C function to be connected, and an argument to pass to the function. When an interrupt occurs with a vector established in this way, the connected C function is called at interrupt level with the specified argument. When the interrupt handling is finished, the connected function returns. A routine connected to an interrupt in this way is called an *interrupt service routine* (ISR).

Interrupts cannot actually vector directly to C functions. Instead, ***intConnect*( )** builds a small amount of code that saves the necessary registers, sets up a stack entry (either on a special interrupt stack, or on the current task's stack) with the argument to be passed, and calls the connected function. On return from the function it restores the registers and stack, and exits the interrupt; see Figure 2-16.

Figure 2-16 **Routine Built by *intConnect*( )**


Wrapper built by intConnect( )
Interrupt Service Routine
save registers
set up stack
invoke routine
restore registers and stack
exit

```
myISR
    (
    int val;
    )
    (
    /* deal with hardware*/
        ...
    )
```

```
intConnect (INUM_TO_IVEC (someIntNum), myISR, someVal);
```

For target boards with VME backplanes, the BSP provides two standard routines for controlling VME bus interrupts, ***sysIntEnable*( )** and ***sysIntDisable*( )**.

2.5.2 Interrupt Stack

Whenever the architecture allows it, all ISRs use the same *interrupt stack*. This stack is allocated and initialized by the system at start-up according to specified configuration parameters. It must be large enough to handle the worst possible combination of nested interrupts.

Some architectures, however, do not permit using a separate interrupt stack. On such architectures, ISRs use the stack of the interrupted task. If you have such an architecture, you must create tasks with enough stack space to handle the worst possible combination of nested interrupts *and* the worst possible combination of ordinary nested calls. See the reference entry for your BSP to determine whether your architecture supports a separate interrupt stack.

Use the ***checkStack*( )** facility during development to see how close your tasks and ISRs have come to exhausting the available stack space.

2.5.3 Special Limitations of ISRs

Many VxWorks facilities are available to ISRs, but there are some important limitations. These limitations stem from the fact that an ISR does not run in a regular task context: it has no task control block, for example, and all ISRs share a single stack.

Table 2-23 **Routines that Can Be Called by Interrupt Service Routines**

Library	Routines
bLib	All routines
errnoLib	***errnoGet*( )**, ***errnoSet*( )**
fppArchLib	***fppSave*( )**, ***fppRestore*( )**
intLib	***intContext*( )**, ***intCount*( )**, ***intVecSet*( )**, ***intVecGet*( )**
intArchLib	***intLock*( )**, ***intUnlock*( )**
logLib	***logMsg*( )**
lstLib	All routines except ***lstFree*( )**
mathALib	All routines, if ***fppSave*( )**/***fppRestore*( )** are used
msgQLib	***msgQSend*( )**
pipeDrv	***write*( )**
rngLib	All routines except ***rngCreate*( )** and ***rngDelete*( )**
selectLib	***selWakeup*( ), *selWakeupAll*( )**
semLib	***semGive*( )** except mutual-exclusion semaphores, ***semFlush*( )**
sigLib	***kill*( )**
taskLib	***taskSuspend*( )**, ***taskResume*( )**, ***taskPrioritySet*( )**, ***taskPriorityGet*( )**, ***taskIdVerify*( )**, ***taskIdDefault*( )**, ***taskIsReady*( )**, ***taskIsSuspended*( )**, ***taskTcb*( )**
tickLib	***tickAnnounce*( )**, ***tickSet*( )**, ***tickGet*( )**
tyLib	***tyIRd*( )**, ***tyITx*( )**
vxLib	***vxTas*( ), *vxMemProbe*( )**
wdLib	***wdStart*( )**, ***wdCancel*( )**

For this reason, the basic restriction on ISRs is that they must not invoke routines that might cause the caller to block. For example, they must not try to take a semaphore, because if the semaphore is unavailable, the kernel tries to switch the caller to the pended state. However, ISRs can give semaphores, releasing any tasks waiting on them.

Because the memory facilities ***malloc*( )** and ***free*( )** take a semaphore, they cannot be called by ISRs, and neither can routines that make calls to ***malloc*( )** and ***free*( )**. For example, ISRs cannot call any creation or deletion routines.

ISRs also must not perform I/O through VxWorks drivers. Although there are no inherent restrictions in the I/O system, most device drivers require a task context because they might block the caller to wait for the device. An important exception is the VxWorks pipe driver, which is designed to permit writes by ISRs.

VxWorks supplies a logging facility, in which a logging task prints text messages to the system console. This mechanism was specifically designed so that ISRs could use it, and is the most common way to print messages from ISRs. For more information, see the reference entry for **logLib**.

An ISR also must not call routines that use a floating-point coprocessor. In VxWorks, the interrupt driver code created by ***intConnect*( )** does not save and restore floating-point registers; thus, ISRs must not include floating-point instructions. If an ISR requires floating-point instructions, it must explicitly save and restore the registers of the floating-point coprocessor using routines in **fppArchLib**.

All VxWorks utility libraries, such as the linked-list and ring-buffer libraries, can be used by ISRs. As discussed earlier (*2.3.7 Task Error Status: errno*, p.36), the global variable **errno** is saved and restored as a part of the interrupt enter and exit code generated by the ***intConnect*( )** facility. Thus **errno** can be referenced and modified by ISRs as in any other code. Table 2-23 lists routines that can be called from ISRs.

2.5.4 Exceptions at Interrupt Level

When a task causes a hardware exception such as illegal instruction or bus error, the task is suspended and the rest of the system continues uninterrupted. However, when an ISR causes such an exception, there is no safe recourse for the system to handle the exception. The ISR has no context that can be suspended. Instead, VxWorks stores the description of the exception in a special location in low memory and executes a system restart.

The VxWorks boot ROMs test for the presence of the exception description in low memory and if it is detected, display it on the system console. The **e** command in the boot ROMs re-displays the exception description; see *Tornado User's Guide: Setup and Startup*.

One example of such an exception is the message:

```
workQPanic: Kernel work queue overflow.
```

This exception usually occurs when kernel calls are made from interrupt level at a very high rate. It generally indicates a problem with clearing the interrupt signal or a similar driver problem.

2.5.5 Reserving High Interrupt Levels

The VxWorks interrupt support described earlier in this section is acceptable for most applications. However, on occasion, low-level control is required for events such as critical motion control or system failure response. In such cases it is desirable to reserve the highest interrupt levels to ensure zero-latency response to these events. To achieve zero-latency response, VxWorks provides the routine ***intLockLevelSet*( )**, which sets the system-wide interrupt-lockout level to the specified level. If you do not specify a level, the default is the highest level supported by the processor architecture.

⚠ **CAUTION:** Some hardware prevents masking certain interrupt levels; check the hardware manufacturer's documentation. For example, on MC680*x*0 chips, interrupt level 7 is non-maskable. Because level 7 is also the highest interrupt level on this architecture, VxWorks uses 7 as the default lockout level—but this is in fact equivalent to a lockout level of 6, since the hardware prevents locking out level 7.

2.5.6 Additional Restrictions for ISRs at High Interrupt Levels

ISRs connected to interrupt levels that are not locked out (either an interrupt level higher than that set by ***intLockLevelSet*( )**, or an interrupt level defined in hardware as non-maskable) have special restrictions:

- The ISR can be connected only with ***intVecSet*( )**.
- The ISR cannot use any VxWorks operating system facilities that depend on interrupt locks for correct operation.

2.5.7 Interrupt-to-Task Communication

While it is important that VxWorks support direct connection of ISRs that run at interrupt level, interrupt events usually propagate to task-level code. Many VxWorks facilities are not available to interrupt-level code, including I/O to any device other than pipes. The following techniques can be used to communicate from ISRs to task-level code:

- **Shared Memory and Ring Buffers.** ISRs can share variables, buffers, and ring buffers with task-level code.
- **Semaphores.** ISRs can give semaphores (except for mutual-exclusion semaphores and VxMP shared semaphores) that tasks can take and wait for.
- **Message Queues.** ISRs can send messages to message queues for tasks to receive (except for shared message queues using VxMP). If the queue is full, the message is discarded.
- **Pipes.** ISRs can write messages to pipes that tasks can read. Tasks and ISRs can write to the same pipes. However, if the pipe is full, the message written is discarded because the ISR cannot block. ISRs must not invoke any I/O routine on pipes other than ***write*( )**.
- **Signals.** ISRs can "signal" tasks, causing asynchronous scheduling of their signal handlers.

2.6 Watchdog Timers

VxWorks includes a watchdog-timer mechanism that allows any C function to be connected to a specified time delay. Watchdog timers are maintained as part of the system clock ISR. Normally, functions invoked by watchdog timers execute as interrupt service code at the interrupt level of the system clock. However, if the kernel is unable to execute the function immediately for any reason (such as a previous interrupt or kernel state), the function is placed on the **tExcTask** work queue. Functions on the **tExcTask** work queue execute at the priority level of the **tExcTask** (usually 0). Restrictions on ISRs apply to routines connected to watchdog timers. The functions in Table 2-24 are provided by the **wdLib** library.

A watchdog timer is first created by calling ***wdCreate*( )**. Then the timer can be started by calling ***wdStart*( )**, which takes as arguments the number of ticks to delay, the C function to call, and an argument to be passed to that function. After

Table 2-24 **Watchdog Timer Calls**

Call	Description
wdCreate( )	Allocate and initialize a watchdog timer.
wdDelete( )	Terminate and deallocate a watchdog timer.
wdStart( )	Start a watchdog timer.
wdCancel( )	Cancel a currently counting watchdog timer.

the specified number of ticks have elapsed, the function is called with the specified argument. The watchdog timer can be canceled any time before the delay has elapsed by calling ***wdCancel*( )**.

Example 2-12 **Watchdog Timers**

```
/* This example creates a watchdog timer and sets it to go off in
 * 3 seconds.
 */

/* includes */
#include "vxWorks.h"
#include "logLib.h"
#include "wdLib.h"

/* defines */
#define  SECONDS (3)

WDOG_ID myWatchDogId;
task (void)
    {
    /* Create watchdog */

    if ((myWatchDogId = wdCreate( )) == NULL)
        return (ERROR);

    /* Set timer to go off in SECONDS - printing a message to stdout */

    if (wdStart (myWatchDogId, sysClkRateGet( ) * SECONDS, logMsg,
                 "Watchdog timer just expired\n") == ERROR)
        return (ERROR);

    /* ... */
    }
```

2.7 POSIX Clocks and Timers

A *clock* is a software construct (**struct timespec**, defined in **time.h**) that keeps time in seconds and nanoseconds. The software clock is updated by system-clock ticks. VxWorks provides a POSIX 1003.1b standard clock and timer interface.

The POSIX standard provides for identifying multiple virtual clocks, but only one clock is required—the system-wide real-time clock, identified in the clock and timer routines as **CLOCK_REALTIME** (also defined in **time.h**). VxWorks provides routines to access the system-wide real-time clock; see the reference entry for **clockLib**. (No virtual clocks are supported in VxWorks.)

The POSIX timer facility provides routines for tasks to signal themselves at some time in the future. Routines are provided to create, set, and delete a timer; see the reference entry for **timerLib**. When a timer goes off, the default signal (**SIGALRM**) is sent to the task. Use ***sigaction*( )** to install a signal handler that executes when the timer expires (see *2.4.7 Signals*, p.81).

Example 2-13 **POSIX Timers**

```
/* This example creates a new timer and stores it in timerid. */

/* includes */
#include "vxWorks.h"
#include "time.h"

int createTimer (void)
    {
    timer_t timerid;

    /* create timer */

    if (timer_create (CLOCK_REALTIME, NULL, &timerid) == ERROR)
        {
        printf ("create FAILED\n");
        return (ERROR);
        }

    return (OK);
    }
```

An additional POSIX function, ***nanosleep*( )**, allows specification of sleep or delay time in units of seconds and nanoseconds, as opposed to the ticks used by the Wind ***taskDelay*( )** function. Only the units are different, however, not the precision: both delay routines have the same precision, determined by the system clock rate.

2.8 POSIX Memory-Locking Interface

Many operating systems perform memory *paging* and *swapping*. These techniques allow the use of more virtual memory than there is physical memory on a system, by copying blocks of memory out to disk and back. These techniques impose severe and unpredictable delays in execution time; they are therefore undesirable in real-time systems.

Because the *wind* kernel is designed specifically for real-time applications, it never performs paging or swapping. However, the POSIX 1003.1b standard for real-time extensions also covers operating systems that perform paging or swapping. On such systems, applications that attempt real-time performance can use the POSIX *page-locking* facilities to declare that certain blocks of memory must not be paged or swapped.

To help maximize portability, VxWorks includes the POSIX page-locking routines. Executing these routines makes no difference in VxWorks, because all memory is, in effect, always locked. They are included only to make it easier to port programs between other POSIX-conforming systems and VxWorks.

The POSIX page-locking routines are in **mmanPxLib** (the name reflects the fact that these routines are part of the POSIX "memory-management" routines). Because in VxWorks all pages are always kept in memory, the routines listed in Table 2-25 always return a value of **OK** (0), and have no further effect.

The **mmanPxLib** library is included automatically when the configuration constant **INCLUDE_POSIX_MEM** is selected for inclusion in the project facility VxWorks view.

Table 2-25 **POSIX Memory Management Calls**

Call	Purpose on Systems with Paging or Swapping
***mlockall*( )**	Lock into memory all pages used by a task.
***munlockall*( )**	Unlock all pages used by a task.
***mlock*( )**	Lock a specified page.
***munlock*( )**	Unlock a specified page.

3
I/O System

3.1 Introduction

The VxWorks I/O system is designed to present a simple, uniform, device-independent interface to any kind of device, including:

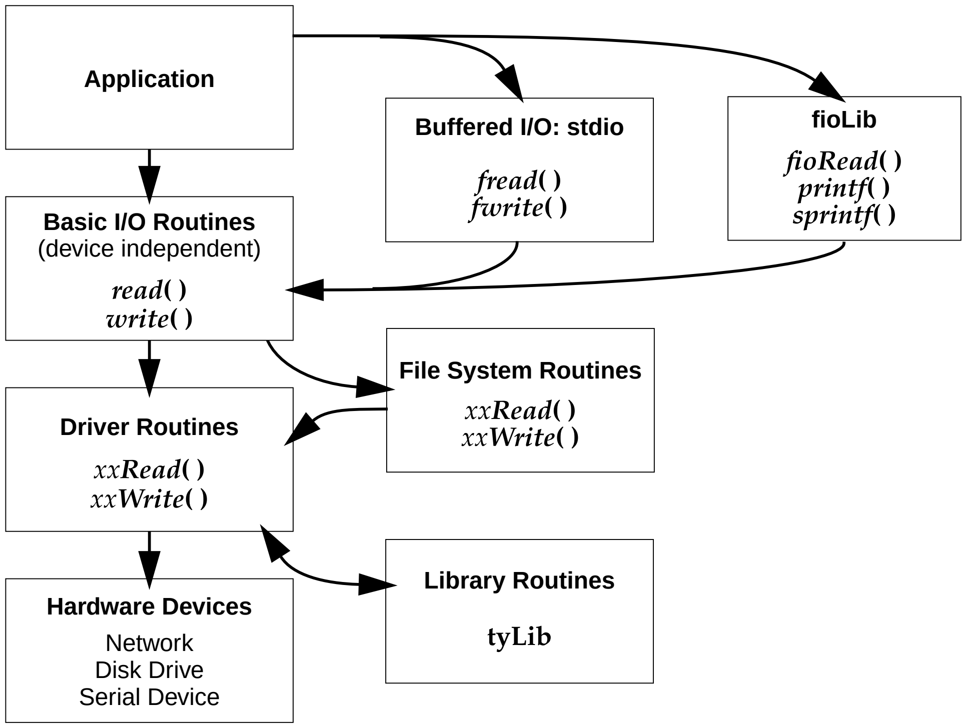
– character-oriented devices such as terminals or communications lines
– random-access block devices such as disks
– virtual devices such as intertask *pipes* and *sockets*
– monitor and control devices such as digital/analog I/O devices
– network devices that give access to remote devices

The VxWorks I/O system provides standard C libraries for both basic and buffered I/O. The basic I/O libraries are UNIX-compatible; the buffered I/O libraries are ANSI C-compatible. Internally, the VxWorks I/O system has a unique design that makes it faster and more flexible than most other I/O systems. These are important attributes in a real-time system.

This chapter first describes the nature of *files* and *devices*, and the user view of basic and buffered I/O. The middle section discusses the details of some specific devices. The final section is a detailed discussion of the internal structure of the VxWorks I/O system.

Figure 3-1 diagrams the relationships between the different pieces of the VxWorks I/O system. All the elements of the I/O system are discussed in this chapter, except for file system routines, which are presented in *4. Local File Systems* in this manual.

Figure 3-1 **Overview of the VxWorks I/O System**



3.2 Files, Devices, and Drivers

In VxWorks, applications access I/O devices by opening named *files*. A *file* can refer to one of two things:

- An unstructured *"raw" device* such as a serial communications channel or an intertask pipe.
- A *logical file* on a structured, random-access device containing a file system.

Consider the following named files:

/usr/myfile **/pipe/mypipe** **/tyCo/0**

The first refers to a file called **myfile**, on a disk device called **/usr**. The second is a named pipe (by convention, pipe names begin with **/pipe**). The third refers to a physical serial channel. However, I/O can be done to or from any of these in the same way. Within VxWorks, they are all called *files*, even though they refer to very different physical objects.

Devices are handled by program modules called *drivers*. In general, using the I/O system does not require any further understanding of the implementation of devices and drivers. Note, however, that the VxWorks I/O system gives drivers considerable flexibility in the way they handle each specific device. Drivers strive to follow the conventional user view presented here, but can differ in the specifics. See *3.7 Devices in VxWorks*, p. 118.

Although all I/O is directed at named files, it can be done at two different levels: *basic* and *buffered*. The two differ in the way data is buffered and in the types of calls that can be made. These two levels are discussed in later sections.

3.2.1 File Names and the Default Device

A file name is specified as a character string. An unstructured device is specified with the device name. In the case of file system devices, the device name is followed by a file name. Thus the name **/tyCo/0** might name a particular serial I/O channel, and the name **DEV1:/file1** probably indicates the file **file1** on the **DEV1:** device.

When a file name is specified in an I/O call, the I/O system searches for a device with a name that matches at least an initial substring of the file name. The I/O function is then directed at this device.

If a matching device name cannot be found, then the I/O function is directed at a *default device*. You can set this default device to be any device in the system, including no device at all, in which case failure to match a device name returns an error.

Non-block devices are named when they are added to the I/O system, usually at system initialization time. Block devices are named when they are initialized for use with a specific file system. The VxWorks I/O system imposes no restrictions on the names given to devices. The I/O system does not interpret device or file names in any way, other than during the search for matching device and file names.

It is useful to adopt some naming conventions for device and file names: most device names begin with a slash (**/**), except non-NFS network devices and VxWorks DOS devices (dosFs).

By convention, NFS-based network devices are *mounted* with names that begin with a slash. For example:

```
/usr
```

Non-NFS network devices are named with the remote machine name followed by a colon. For example:

```
host:
```

The remainder of the name is the file name in the remote directory on the remote system.

File system devices using dosFs are often named with uppercase letters and/or digits followed by a colon. For example:

```
DEV1:
```

NOTE: File names and directory names on dosFs devices are often separated by backslashes (\). These can be used interchangeably with forward slashes (**/**).

CAUTION: Because device names are recognized by the I/O system using simple substring matching, a slash (**/**) should not be used alone as a device name.

3.3 Basic I/O

Basic I/O is the lowest level of I/O in VxWorks. The basic I/O interface is source-compatible with the I/O primitives in the standard C library. There are seven basic I/O calls, shown in the following table.

Table 3-1 **Basic I/O Routines**

Call	Description
***creat*( )**	Create a file.
***remove*( )**	Remove a file.
***open*( )**	Open a file. (Optionally, create a file.)
***close*( )**	Close a file.

Table 3-1 **Basic I/O Routines**

Call	Description
***read*( )**	Read a previously created or opened file.
***write*( )**	Write a previously created or opened file.
***ioctl*( )**	Perform special control functions on files or devices.

3.3.1 File Descriptors

At the basic I/O level, files are referred to by a *file descriptor*, or *fd*. An *fd* is a small integer returned by a call to ***open*( )** or ***creat*( )**. The other basic I/O calls take an *fd* as a parameter to specify the intended file. An *fd* has no meaning discernible to the user; it is only a handle for the I/O system.

When a file is opened, an *fd* is allocated and returned. When the file is closed, the *fd* is deallocated. There are a finite number of *fd*s available in VxWorks. To avoid exceeding the system limit, it is important to close *fd*s that are no longer in use. The number of available *fd*s is specified in the initialization of the I/O system.

3.3.2 Standard Input, Standard Output, and Standard Error

Three file descriptors are reserved and have special meanings:

0 = standard input
1 = standard output
2 = standard error output

These *fd*s are never returned as the result of an ***open*( )** or ***creat*( )**, but serve rather as indirect references that can be redirected to any other open *fd*.

These standard *fd*s are used to make tasks and modules independent of their actual I/O assignments. If a module sends its output to standard output (*fd* = 1), then its output can be redirected to any file or device, without altering the module.

VxWorks allows two levels of redirection. First, there is a global assignment of the three standard *fd*s. Second, individual tasks can override the global assignment of these *fd*s with their own assignments that apply only to that task.

Global Redirection

When VxWorks is initialized, the global assignments of the standard *fd*s are directed, by default, to the system console. When tasks are spawned, they initially have no task-specific *fd* assignments; instead, they use the global assignments.

The global assignments can be redirected using ***ioGlobalStdSet*( )**. The parameters to this routine are the global standard *fd* to be redirected, and the *fd* to direct it to.

For example, the following call sets global standard output (*fd* = 1) to be the open file with a file descriptor of **fileFd**:

```
ioGlobalStdSet (1, fileFd);
```

All tasks in the system that do not have their own task-specific redirection write standard output to that file thereafter. For example, the task **tRlogind** calls ***ioGlobalStdSet*( )** to redirect I/O across the network during an **rlogin** session.

Task-Specific Redirection

The assignments for a specific task can be redirected using the routine ***ioTaskStdSet*( )**. The parameters to this routine are the task ID (0 = self) of the task with the assignments to be redirected, the standard *fd* to be redirected, and the *fd* to direct it to. For example, a task can make the following call to write standard output to **fileFd**:

```
ioTaskStdSet (0, 1, fileFd);
```

All other tasks are unaffected by this redirection, and subsequent global redirections of standard output do not affect this task.

3.3.3 Open and Close

Before I/O can be performed to a device, an *fd* must be opened to that device by invoking the ***open*( )** routine (or ***creat*( )**, as discussed in the next section). The arguments to ***open*( )** are the file name, the type of access, and, when necessary, the mode:

```
fd = open ("name", flags, mode);
```

The possible access flags are shown in Table 3-2.

Table 3-2 **File Access Flags**

Flag	Hex Value	Description
O_RDONLY	0	Open for reading only.
O_WRONLY	1	Open for writing only.
O_RDWR	2	Open for reading and writing.
O_CREAT	200	Create a new file.
O_TRUNC	400	Truncate the file.

The *mode* parameter is used in the following special cases to specify the mode (permission bits) of a file or to create subdirectories:

- In general, you can open only preexisting devices and files with ***open*( )**. However, with NFS network, dosFs, and rt11Fs devices, you can also create files with ***open*( )** by or'ing **O_CREAT** with one of the access flags. In the case of NFS devices, ***open*( )** requires the third parameter specifying the mode of the file:

  ```
  fd = open ("name", O_CREAT | O_RDWR, 0644);
  ```

- With both dosFs and NFS devices, you can use the **O_CREAT** option to create a subdirectory by setting *mode* to **FSTAT_DIR**. Other uses of the mode parameter with dosFs devices are ignored.

The ***open*( )** routine, if successful, returns an *fd* (a small integer). This *fd* is then used in subsequent I/O calls to specify that file. The *fd* is a *global* identifier that is *not* task specific. One task can open a file, and then any other tasks can use the resulting *fd* (for example, pipes). The *fd* remains valid until ***close*( )** is invoked with that *fd*:

```
close (fd);
```

At that point, I/O to the file is flushed (completely written out) and the *fd* can no longer be used by any task. However, the same *fd* number can again be assigned by the I/O system in any subsequent ***open*( )**.

When a task exits or is deleted, the files opened by that task are not automatically closed, because *fd*s are not task specific. Thus, it is recommended that tasks explicitly close all files when they are no longer required. As stated previously, there is a limit to the number of files that can be open at one time.

3.3.4 Create and Remove

File-oriented devices must be able to create and remove files as well as open existing files. The ***creat*( )** routine directs a file-oriented device to make a new file on the device and return a file descriptor for it. The arguments to ***creat*( )** are similar to those of ***open*( )** except that the file name specifies the name of the new file rather than an existing one; the ***creat*( )** routine returns an *fd* identifying the new file.

```
fd = creat ("name", flag);
```

The ***remove*( )** routine removes a named file on a file-oriented device:

```
remove ("name");
```

Do not remove files while they are open.

With non-file-system oriented device names, ***creat*( )** acts exactly like ***open*( )**; however, ***remove*( )** has no effect.

3.3.5 Read and Write

After an *fd* is obtained by invoking ***open*( )** or ***creat*( )**, tasks can read bytes from a file with ***read*( )** and write bytes to a file with ***write*( )**. The arguments to ***read*( )** are the *fd*, the address of the buffer to receive input, and the maximum number of bytes to read:

```
nBytes = read (fd, &buffer, maxBytes);
```

The ***read*( )** routine waits for input to be available from the specified file, and returns the number of bytes actually read. For file-system devices, if the number of bytes read is less than the number requested, a subsequent ***read*( )** returns 0 (zero), indicating end-of-file. For non-file-system devices, the number of bytes read can be less than the number requested even if more bytes are available; a subsequent ***read*( )** may or may not return 0. In the case of serial devices and TCP sockets, repeated calls to ***read*( )** are sometimes necessary to read a specific number of bytes. (See the reference entry for ***fioRead*( )** in **fioLib**). A return value of **ERROR** (-1) indicates an unsuccessful read.

The arguments to ***write*( )** are the *fd*, the address of the buffer that contains the data to be output, and the number of bytes to be written:

```
actualBytes = write (fd, &buffer, nBytes);
```

The ***write*( )** routine ensures that all specified data is at least queued for output before returning to the caller, though the data may not yet have been written to the device (this is driver dependent). ***write*( )** returns the number of bytes written; if the number returned is not equal to the number requested, an error has occurred.

3.3.6 File Truncation

It is sometimes convenient to discard part of the data in a file. After a file is open for writing, you can use the ***ftruncate*( )** routine to truncate a file to a specified size. Its arguments are an *fd* and the desired length of the file:

```
status = ftruncate (fd, length);
```

If it succeeds in truncating the file, ***ftruncate*( )** returns **OK**. If the size specified is larger than the actual size of the file, or if the *fd* refers to a device that cannot be truncated, ***ftruncate*( )** returns **ERROR**, and sets **errno** to **EINVAL**.

The ***ftruncate*( )** routine is part of the POSIX 1003.1b standard, but this implementation is only partially POSIX-compliant: creation and modification times are not updated. This call is supported only by **dosFsLib**, the DOS-compatible file system library.

3.3.7 I/O Control

The ***ioctl*( )** routine is an open-ended mechanism for performing any I/O functions that do not fit the other basic I/O calls. Examples include determining how many bytes are currently available for input, setting device-specific options, obtaining information about a file system, and positioning random-access files to specific byte positions. The arguments to the ***ioctl*( )** routine are the *fd*, a code that identifies the control function requested, and an optional function-dependent argument:

```
result = ioctl (fd, function, arg);
```

For example, the following call uses the **FIOBAUDRATE** function to set the baud rate of a *tty* device to 9600:

```
status = ioctl (fd, FIOBAUDRATE, 9600);
```

The discussion of specific devices in *3.7 Devices in VxWorks*, p. 118 summarizes the ***ioctl*( )** functions available for each device. The ***ioctl*( )** control codes are defined in **ioLib.h**. For more information, see the reference entries for specific device drivers.

3.3.8 Pending on Multiple File Descriptors: The Select Facility

The VxWorks *select* facility provides a UNIX- and Windows-compatible method for pending on multiple file descriptors. The library **selectLib** provides both task-level support, allowing tasks to wait for multiple devices to become active, and device driver support, giving drivers the ability to detect tasks that are pended while waiting for I/O on the device. To use this facility, the header file **selectLib.h** must be included in your application code.

Task-level support not only gives tasks the ability to simultaneously wait for I/O on multiple devices, but it also allows tasks to specify the maximum time to wait for I/O to become available. For an example of using the select facility to pend on multiple file descriptors, consider a client-server model in which the server is servicing both local and remote clients. The server task uses a pipe to communicate with local clients and a socket to communicate with remote clients. The server task must respond to clients as quickly as possible. If the server blocks waiting for a request on only one of the communication streams, it cannot service requests that come in on the other stream until it gets a request on the first stream. For example, if the server blocks waiting for a request to arrive in the socket, it cannot service requests that arrive in the pipe until a request arrives in the socket to unblock it. This can delay local tasks waiting to get their requests serviced. The select facility solves this problem by giving the server task the ability to monitor both the socket and the pipe and service requests as they come in, regardless of the communication stream used.

Tasks can block until data becomes available or the device is ready for writing. The ***select*( )** routine returns when one or more file descriptors are ready or a timeout has occurred. Using the ***select*( )** routine, a task specifies the file descriptors on which to wait for activity. Bit fields are used in the ***select*( )** call to specify the read and write file descriptors of interest. When ***select*( )** returns, the bit fields are modified to reflect the file descriptors that have become available. The macros for building and manipulating these bit fields are listed in Table 3-3.

Table 3-3 **Select Macros**

Macro	**Function**
FD_ZERO	Zeros all bits.
FD_SET	Sets bit corresponding to a specified file descriptor.
FD_CLR	Clears a specified bit.
FD_ISSET	Returns 1 if specified bit is set, otherwise returns 0.

Applications can use ***select*( )** with any character I/O devices that provide support for this facility (for example, pipes, serial devices, and sockets). For information on writing a device driver that supports ***select*( )**, see *Implementing select( )*, p.152.

Example 3-1 **The Select Facility**

```
/* selServer.c - select example
 * In this example, a server task uses two pipes: one for normal-priority
 * requests, the other for high-priority requests. The server opens both
 * pipes and blocks while waiting for data to be available in at least one
 * of the pipes.
 */

#include "vxWorks.h"
#include "selectLib.h"
#include "fcntl.h"

#define MAX_FDS 2
#define MAX_DATA 1024
#define PIPEHI  "/pipe/highPriority"
#define PIPENORM "/pipe/normalPriority"

/************************************************************************
* selServer - reads data as it becomes available from two different pipes
*
* Opens two pipe fds, reading from whichever becomes available. The
* server code assumes the pipes have been created from either another
* task or the shell. To test this code from the shell do the following:
*  -> ld < selServer.o
*  -> pipeDevCreate ("/pipe/highPriority", 5, 1024)
*  -> pipeDevCreate ("/pipe/normalPriority", 5, 1024)
*  -> fdHi = open ("/pipe/highPriority", 1, 0)
*  -> fdNorm = open ("/pipe/normalPriority", 1, 0)
*  -> iosFdShow
*  -> sp selServer
*  -> i
* At this point you should see selServer’s state as pended. You can now
* write to either pipe to make the selServer display your message.
*  -> write fdNorm, "Howdy", 6
*  -> write fdHi, "Urgent", 7
*/

STATUS selServer (void)
  {
  struct fd_set readFds;      /* bit mask of fds to read from */
  int      fds[MAX_FDS];      /* array of fds on which to pend */
  int      width;            /* number of fds on which to pend */
  int      i;                /* index for fd array */
  char     buffer[MAX_DATA]; /* buffer for data that is read */
/* open file descriptors */
  if ((fds[0] = open (PIPEHI, O_RDONLY, 0)) == ERROR)
    return (ERROR);
  if ((fds[1] = open (PIPENORM, O_RDONLY, 0)) == ERROR)
    return (ERROR);

/* loop forever reading data and servicing clients */
  FOREVER
    {
    /* clear bits in read bit mask */
    FD_ZERO (&readFds);

/* initialize bit mask */
    FD_SET (fds[0], &readFds);
    FD_SET (fds[1], &readFds);
    width = (fds[0] > fds[1]) ? fds[0] : fds[1];
    width++;

/* pend, waiting for one or more fds to become ready */
    if (select (width, &readFds, NULL, NULL, NULL) == ERROR)
      return (ERROR);

/* step through array and read from fds that are ready */
    for (i=0; i< MAX_FDS; i++)
      {
      /* check if this fd has data to read */
      if (FD_ISSET (fds[i], &readFds))
        {
        /* typically read from fd now that it is ready */
        read (fds[i], buffer, MAX_DATA);
        /* normally service request, for this example print it */
        printf ("SELSERVER Reading from %s: %s\n",
            (i == 0) ? PIPEHI : PIPENORM, buffer);
        }
      }
    }
  }
```

3.4 Buffered I/O: Stdio

The VxWorks I/O library provides a buffered I/O package that is compatible with the UNIX and Windows *stdio* package and provides full ANSI C support. To include the *stdio* package in the VxWorks system, select **INCLUDE_ANSI_STDIO** for inclusion in the project facility VxWorks view; see *Tornado User’s Guide: Projects* for information on configuring VxWorks.

Note that the implementation of ***printf*( )**, ***sprintf*( )**, and ***sscanf*( )**, traditionally considered part of the *stdio* package, is part of a different package in VxWorks. These routines are discussed in *3.5 Other Formatted I/O*, p.108.

3.4.1 Using Stdio

Although the VxWorks I/O system is efficient, some overhead is associated with each low-level call. First, the I/O system must dispatch from the device-independent user call (***read*( )**, ***write*( )**, and so on) to the driver-specific routine for that function. Second, most drivers invoke a mutual exclusion or queuing mechanism to prevent simultaneous requests by multiple users from interfering with each other.

Because the VxWorks primitives are fast, this overhead is quite small. However, an application processing a single character at a time from a file incurs that overhead for each character if it reads each character with a separate ***read*( )** call:

```
n = read (fd, &char, 1);
```

To make this type of I/O more efficient and flexible, the *stdio* package implements a buffering scheme in which data is read and written in large chunks and buffered privately. This buffering is transparent to the application; it is handled automatically by the *stdio* routines and macros. To access a file with *stdio*, a file is opened with ***fopen*( )** instead of ***open*( )** (many *stdio* calls begin with the letter *f*):

```
fp = fopen ("/usr/foo", "r");
```

The returned value, a *file pointer* (or *fp*) is a handle for the opened file and its associated buffers and pointers. An *fp* is actually a pointer to the associated data structure of type **FILE** (that is, it is declared as **FILE ***). By contrast, the low-level I/O routines identify a file with a *file descriptor* (*fd*), which is a small integer. In fact, the **FILE** structure pointed to by the *fp* contains the underlying *fd* of the open file.

An already open *fd* can be associated belatedly with a **FILE** buffer by calling ***fdopen*( )**:

```
fp = fdopen (fd, "r");
```

After a file is opened with ***fopen*( )**, data can be read with ***fread*( )**, or a character at a time with ***getc*( )**, and data can be written with ***fwrite*( )**, or a character at a time with ***putc*( )**.

The routines and macros to get data into or out of a file are extremely efficient. They access the buffer with direct pointers that are incremented as data is read or written by the user. They pause to call the low-level read or write routines only when a read buffer is empty or a write buffer is full.

WARNING: The *stdio* buffers and pointers are *private* to a particular task. They are *not* interlocked with semaphores or any other mutual exclusion mechanism, because this defeats the point of an efficient private buffering scheme. Therefore, multiple tasks must not perform I/O to the same *stdio* **FILE** pointer at the same time.

The **FILE** buffer is deallocated when ***fclose*( )** is called.

3.4.2 Standard Input, Standard Output, and Standard Error

As discussed earlier in *3.3 Basic I/O*, p.98, there are three special file descriptors (0, 1, and 2) reserved for standard input, standard output, and standard error. Three corresponding *stdio* **FILE** buffers are automatically created when a task uses the standard file descriptors, *stdin*, *stdout*, and *stderr,* to do buffered I/O to the standard *fd*s. Each task using the standard I/O *fds* has its own *stdio* **FILE** buffers. The **FILE** buffers are deallocated when the task exits.

3.5 Other Formatted I/O

3.5.1 Special Cases: *printf*( ), *sprintf*( ), and *sscanf*( )

The routines ***printf*( )**, ***sprintf*( )**, and ***sscanf*( )** are generally considered to be part of the standard *stdio* package. However, the VxWorks implementation of these routines, while functionally the same, does not use the *stdio* package. Instead, it uses a self-contained, formatted, non-buffered interface to the I/O system in the library **fioLib**. Note that these routines provide the functionality specified by ANSI; however, ***printf*( )** is not buffered.

Because these routines are implemented in this way, the full *stdio* package, which is optional, can be omitted from a VxWorks configuration without sacrificing their availability. Applications requiring *printf*-style output that is buffered can still accomplish this by calling ***fprintf*( )** explicitly to *stdout*.

While ***sscanf*( )** is implemented in **fioLib** and can be used even if *stdio* is omitted, the same is not true of ***scanf*( )**, which is implemented in the usual way in *stdio*.

3.5.2 Additional Routines: *printErr*( ) and *fdprintf*( )

Additional routines in **fioLib** provide formatted but unbuffered output. The routine ***printErr*( )** is analogous to ***printf*( )** but outputs formatted strings to the standard error *fd* (2). The routine ***fdprintf*( )** outputs formatted strings to a specified *fd*.

3.5.3 Message Logging

Another higher-level I/O facility is provided by the library **logLib**, which allows formatted messages to be logged without having to do I/O in the current task's context, or when there is no task context. The message format and parameters are sent on a message queue to a logging task, which then formats and outputs the message. This is useful when messages must be logged from interrupt level, or when it is desirable not to delay the current task for I/O or use the current task's stack for message formatting (which can take up significant stack space). The message is displayed on the console unless otherwise redirected at system startup using ***logInit*( )** or dynamically using ***logFdSet*( )**.

3.6 Asynchronous Input/Output

Asynchronous Input/Output (AIO) is the ability to perform input and output operations concurrently with ordinary internal processing. AIO enables you to decouple I/O operations from the activities of a particular task when these are logically independent.

The benefit of AIO is greater processing efficiency: it permits I/O operations to take place whenever resources are available, rather than making them await arbitrary events such as the completion of independent operations. AIO eliminates some of the unnecessary blocking of tasks that is caused by ordinary synchronous I/O; this decreases contention for resources between input/output and internal processing, and expedites throughput.

The VxWorks AIO implementation meets the specification in the POSIX 1003.1b standard. To include AIO in your VxWorks configuration, select **INCLUDE_POSIX_AIO** and **INCLUDE_POSIX_AIO_SYSDRV** in the project facility VxWorks view; see *Tornado User's Guide: Projects* for information on configuring VxWorks. The second configuration constant enables the auxiliary AIO system driver, required for asynchronous I/O on all current VxWorks devices.

3.6.1 The POSIX AIO Routines

The VxWorks library **aioPxLib** provides the POSIX AIO routines. To access a file asynchronously, open it with the ***open*( )** routine, like any other file. Thereafter, use the file descriptor returned by ***open*( )** in calls to the AIO routines. The POSIX AIO routines (and two associated non-POSIX routines) are listed in Table 3-4.

Table 3-4 **Asynchronous Input/Output Routines**

Function	**Description**
***aioPxLibInit*( )**	Initialize the AIO library (non-POSIX).
***aioShow*( )**	Display the outstanding AIO requests (non-POSIX).*
***aio_read*( )**	Initiate an asynchronous read operation.
***aio_write*( )**	Initiate an asynchronous write operation.
***aio_listio*( )**	Initiate a list of up to **LIO_MAX** asynchronous I/O requests.
***aio_error*( )**	Retrieve the error status of an AIO operation.
***aio_return*( )**	Retrieve the return status of a completed AIO operation.
***aio_cancel*( )**	Cancel a previously submitted AIO operation.
***aio_suspend*( )**	Wait until an AIO operation is done, interrupted, or timed out.

* This function is not built into the Tornado shell. To use it from the Tornado shell, you must select **INCLUDE_POSIX_AIO_SHOW** for inclusion in the project facility VxWorks view. When you invoke the function, its output is sent to the standard output device.

The default VxWorks initialization code calls ***aioPxLibInit*( )** automatically when **INCLUDE_POSIX_AIO** is selected for inclusion in the project facility VxWorks view. This routine takes one parameter, the maximum number of ***lio_listio*( )** calls that can be outstanding at one time. By default this parameter is **MAX_LIO_CALLS** (which can be seen on the Params tab of the properties window to be 0 by default). When the parameter is 0, the value is taken from **AIO_CLUST_MAX** (defined in *installDir***/target/h/private/aioPxLibP.h**).

The AIO system driver, **aioSysDrv**, is initialized by default with the routine ***aioSysInit*( )** when both **INCLUDE_POSIX_AIO** and **INCLUDE_POSIX_AIO_SYSDRV** are included. The purpose of **aioSysDrv** is to provide request queues independent of any particular device driver, so that you can use any VxWorks device driver with AIO.

The routine ***aioSysInit*( )** takes three parameters: the number of AIO system tasks to spawn, and the priority and stack size for these system tasks. The number of AIO system tasks spawned equals the number of AIO requests that can be handled in parallel. The default initialization call uses three constants, all defined in **configAll.h**:

```
aioSysInit( MAX_AIO_SYS_TASKS, AIO_TASK_PRIORITY, AIO_TASK_STACK_SIZE )
```

When any of the parameters passed to ***aioSysInit*( )** is 0, the corresponding value is taken from **AIO_IO_TASKS_DFLT**, **AIO_IO_PRIO_DFLT**, and **AIO_IO_STACK_DFLT** (all defined in *installDir***/target/h/aioSysDrv.h**).

Table 3-5 lists the names of the constants called from **usrConfig.c** and their default values (which can be seen on the Params tab of the properties window). It also shows the constants used within initialization routines when the parameters are left at their default values of 0, and where these constants are defined.

Table 3-5 **AIO Initialization Functions and Related Constants**

Initialization Function	configAll.h Constant	Def. Value	Header File Constant used when arg = 0	Def. Value	Header File (all in *installDir*/target
***aioPxLibInit*( )**	**MAX_LIO_CALLS**	0	**AIO_CLUST_MAX**	100	**h/private/aioPxLibP.h**
***aioSysInit*( )**	**MAX_AIO_SYS_TASKS**	0	**AIO_IO_TASKS_DFLT**	2	**h/aioSysDrv.h**
	AIO_TASK_PRIORITY	0	**AIO_IO_PRIO_DFLT**	50	**h/aioSysDrv.h**
	AIO_TASK_STACK_SIZE	0	**AIO_IO_STACK_DFLT**	0x7000	**h/aioSysDrv.h**

3.6.2 AIO Control Block

Each of the AIO calls takes an AIO control block (**aiocb**) as an argument to describe the AIO operation. The calling routine must allocate space for the control block, which is associated with a single AIO operation. No two concurrent AIO operations can use the same control block; an attempt to do so yields undefined results.

The **aiocb** and the data buffers it references are used by the system while performing the associated request. Therefore, after you request an AIO operation, you must not modify the corresponding **aiocb** before calling ***aio_return*( )**; this function frees the **aiocb** for modification or reuse.

⚠ **CAUTION:** If a routine allocates stack space for the **aiocb**, that routine must call ***aio_return*( )** to free the **aiocb** before returning.

The **aiocb** structure is defined in **aio.h**. It contains the following fields:

aio_fildes
file descriptor for I/O

aio_offset
offset from the beginning of the file

aio_buf
address of the buffer from/to which AIO is requested

aio_nbytes
number of bytes to read or write

aio_reqprio
priority reduction for this AIO request

aio_sigevent
signal to return on completion of an operation (optional)

aio_lio_opcode
operation to be performed by a ***lio_listio*( )** call

aio_sys
VxWorks-specific data (non-POSIX)

For full definitions and important additional information, see the reference entry for **aioPxLib**.

3.6.3 Using AIO

The routines ***aio_read*( )**, ***aio_write*( )**, or ***lio_listio*( )** initiate AIO operations. The last of these, ***lio_listio*( )**, allows you to submit a number of asynchronous requests (read and/or write) at one time. In general, the actual I/O (reads and writes) initiated by these routines does not happen immediately after the AIO request. For that reason, their return values do not reflect the outcome of the actual I/O operation, but only whether a request is successful—that is, whether the AIO routine is able to put the operation on a queue for eventual execution.

After the I/O operations themselves execute, they also generate return values that reflect the success or failure of the I/O. There are two routines that you can use to get information about the success or failure of the I/O operation: ***aio_error*( )** and ***aio_return*( )**. You can use ***aio_error*( )** to get the status of an AIO operation (success, failure, or in progress), and ***aio_return*( )** to obtain the return values from the individual I/O operations. Until an AIO operation completes, its error status is **EINPROGRESS**. To cancel an AIO operation, call ***aio_cancel*( )**.

AIO with Periodic Checks for Completion

The following code uses a pipe for the asynchronous I/O operations. The example creates the pipe, submits an AIO read request, verifies that the read request is still in progress, and submits an AIO write request. Under normal circumstances, a synchronous read to an empty pipe blocks and the task does not execute the write, but in the case of AIO, we initiate the read request and continue. After the write request is submitted, the example task loops, checking the status of the AIO requests periodically until both the read and write complete. Because the AIO control blocks are on the stack, we must call ***aio_return*( )** before returning from ***aioExample*( )**.

Example 3-2 **Asynchronous I/O**

```
/* aioEx.c - example code for using asynchronous I/O */

/* includes */

#include "vxWorks.h"
#include "aio.h"
#include "errno.h"

/* defines */

#define BUFFER_SIZE 200

/*************************************************************************
* aioExample - use AIO library
*
* This example shows the basic functions of the AIO library.
*
* RETURNS: OK if successful, otherwise ERROR.
*/
```

```
STATUS aioExample (void)
  {
  int       fd;
  static char   exFile [] = "/pipe/1stPipe";
  struct aiocb  aiocb_read; /* read aiocb */
  struct aiocb  aiocb_write; /* write aiocb */
  static char *  test_string = "testing 1 2 3";
  char      buffer [BUFFER_SIZE]; /* buffer for read aiocb */

pipeDevCreate (exFile, 50, 100);

if ((fd = open (exFile, O_CREAT | O_TRUNC | O_RDWR, 0666)) ==
    ERROR)
  {
  printf ("aioExample: cannot open %s errno 0x%x\n", exFile, errno);
  return (ERROR);
  }

printf ("aioExample: Example file = %s\tFile descriptor = %d\n",
      exFile, fd);

/* initialize read and write aiocbs */
  bzero ((char *) &aiocb_read, sizeof (struct aiocb));
  bzero ((char *) buffer, sizeof (buffer));
  aiocb_read.aio_fildes = fd;
  aiocb_read.aio_buf = buffer;
  aiocb_read.aio_nbytes = BUFFER_SIZE;
  aiocb_read.aio_reqprio = 0;

bzero ((char *) &aiocb_write, sizeof (struct aiocb));
  aiocb_write.aio_fildes = fd;
  aiocb_write.aio_buf = test_string;
  aiocb_write.aio_nbytes = strlen (test_string);
  aiocb_write.aio_reqprio = 0;

/* initiate the read */
  if (aio_read (&aiocb_read) == -1)
    printf ("aioExample: aio_read failed\n");

/* verify that it is in progress */
  if (aio_error (&aiocb_read) == EINPROGRESS)
    printf ("aioExample: read is still in progress\n");

/* write to pipe - the read should be able to complete */
  printf ("aioExample: getting ready to initiate the write\n");
  if (aio_write (&aiocb_write) == -1)
    printf ("aioExample: aio_write failed\n");

/* wait til both read and write are complete */
  while ((aio_error (&aiocb_read) == EINPROGRESS) ||
      (aio_error (&aiocb_write) == EINPROGRESS))
    taskDelay (1);

/* print out what was read */
  printf ("aioExample: message = %s\n", buffer);
/* clean up */
  if (aio_return (&aiocb_read) == -1)
    printf ("aioExample: aio_return for aiocb_read failed\n");
  if (aio_return (&aiocb_write) == -1)
    printf ("aioExample: aio_return for aiocb_write failed\n");

close (fd);
  return (OK);
  }
```

Alternatives for Testing AIO Completion

A task can determine whether an AIO request is complete in any of the following ways:

- Check the result of ***aio_error*( )** periodically, as in the previous example, until the status of an AIO request is no longer **EINPROGRESS**.
- Use ***aio_suspend*( )** to suspend the task until the AIO request is complete.
- Use signals to be informed when the AIO request is complete.

The following example is similar to the preceding ***aioExample*( )**, except that it uses signals to be notified when the write is complete. If you test this from the shell, spawn the routine to run at a lower priority than the AIO system tasks to assure that the test routine does not block completion of the AIO request. (For details on the shell, see the *Tornado User's Guide: Shell*.)

Example 3-3 **Asynchronous I/O with Signals**

```
/* aioExSig.c - example code for using signals with asynchronous I/O */

/* includes */

#include "vxWorks.h"
#include "aio.h"
#include "errno.h"

/* defines */

#define BUFFER_SIZE   200
#define LIST_SIZE    1
#define EXAMPLE_SIG_NO  25 /* signal number */

/* forward declarations */

void mySigHandler (int sig, struct siginfo * info, void * pContext);
```

```
/*************************************************************************
* aioExampleSig - use AIO library.
*
* This example shows the basic functions of the AIO library.
* Note if this is run from the shell it must be spawned. Use:
*  -> sp aioExampleSig
*
* RETURNS: OK if successful, otherwise ERROR.
*/

STATUS aioExampleSig (void)
  {
  int           fd;
  static char       exFile [] = "/pipe/1stPipe";
  struct aiocb      aiocb_read;      /* read aiocb */
  static struct aiocb   aiocb_write;      /* write aiocb */
  struct sigaction    action;        /* signal info */
  static char *      test_string = "testing 1 2 3";
  char          buffer [BUFFER_SIZE]; /* aiocb read buffer */

pipeDevCreate (exFile, 50, 100);

if ((fd = open (exFile, O_CREAT | O_TRUNC| O_RDWR, 0666)) == ERROR)
    {
    printf ("aioExample: cannot open %s errno 0x%x\n", exFile, errno);
    return (ERROR);
    }

printf ("aioExampleSig: Example file = %s\tFile descriptor = %d\n",
      exFile, fd);

/* set up signal handler for EXAMPLE_SIG_NO */

  action.sa_sigaction = mySigHandler;
  action.sa_flags = SA_SIGINFO;
  sigemptyset (&action.sa_mask);
  sigaction (EXAMPLE_SIG_NO, &action, NULL);

/* initialize read and write aiocbs */

  bzero ((char *) &aiocb_read, sizeof (struct aiocb));
  bzero ((char *) buffer, sizeof (buffer));
  aiocb_read.aio_fildes = fd;
  aiocb_read.aio_buf = buffer;
  aiocb_read.aio_nbytes = BUFFER_SIZE;
  aiocb_read.aio_reqprio = 0;

bzero ((char *) &aiocb_write, sizeof (struct aiocb));
  aiocb_write.aio_fildes = fd;
  aiocb_write.aio_buf = test_string;
  aiocb_write.aio_nbytes = strlen (test_string);
  aiocb_write.aio_reqprio = 0;

/* set up signal info */

  aiocb_write.aio_sigevent.sigev_signo = EXAMPLE_SIG_NO;
  aiocb_write.aio_sigevent.sigev_notify = SIGEV_SIGNAL;
  aiocb_write.aio_sigevent.sigev_value.sival_ptr =
                      (void *) &aiocb_write;

/* initiate the read */

  if (aio_read (&aiocb_read) == -1)
    printf ("aioExampleSig: aio_read failed\n");

/* verify that it is in progress */

  if (aio_error (&aiocb_read) == EINPROGRESS)
    printf ("aioExampleSig: read is still in progress\n");

/* write to pipe - the read should be able to complete */

  printf ("aioExampleSig: getting ready to initiate the write\n");
  if (aio_write (&aiocb_write) == -1)
    printf ("aioExampleSig: aio_write failed\n");

/* clean up */

  if (aio_return (&aiocb_read) == -1)
    printf ("aioExampleSig: aio_return for aiocb_read failed\n");
  else
    printf ("aioExampleSig: aio read message = %s\n",
         aiocb_read.aio_buf);

close (fd);
  return (OK);
  }

void mySigHandler
  (
  int        sig,
  struct siginfo * info,
  void *      pContext
  )

  {
  /* print out what was read */

  printf ("mySigHandler: Got signal for aio write\n");

  /* write is complete so let’s do cleanup for it here */

  if (aio_return (info->si_value.sival_ptr) == -1)
    {
    printf ("mySigHandler: aio_return for aiocb_write failed\n");
    printErrno (0);
    }
  }
```

3.7 Devices in VxWorks

The VxWorks I/O system is flexible, allowing specific device drivers to handle the seven I/O functions. All VxWorks device drivers follow the basic conventions outlined previously, but differ in specifics; this section describes those specifics.

Table 3-6 **Drivers Provided with VxWorks**

Module	Driver Description
ttyDrv	Terminal driver
ptyDrv	Pseudo-terminal driver
pipeDrv	Pipe driver
memDrv	Pseudo memory device driver
nfsDrv	NFS client driver
netDrv	Network driver for remote file access
ramDrv	RAM driver for creating a RAM disk
scsiLib	SCSI interface library
-	Other hardware-specific drivers

3.7.1 Serial I/O Devices (Terminal and Pseudo-Terminal Devices)

VxWorks provides terminal and pseudo-terminal device drivers (*tty* and *pty* drivers). The *tty* driver is for actual terminals; the *pty* driver is for processes that simulate terminals. These pseudo terminals are useful in applications such as remote login facilities.[1]

VxWorks serial I/O devices are buffered serial byte streams. Each device has a ring buffer (circular buffer) for both input and output. Reading from a *tty* device extracts bytes from the input ring. Writing to a *tty* device adds bytes to the output ring. The size of each ring buffer is specified when the device is created during system initialization.

1. For the remainder of this section, the term *tty* is used to indicate both *tty* and *pty* devices.

Tty Options

The *tty* devices have a full range of options that affect the behavior of the device. These options are selected by setting bits in the device option word using the ***ioctl( )*** routine with the **FIOSETOPTIONS** function (see *I/O Control Functions*, p. 121). For example, to set all the *tty* options except **OPT_MON_TRAP**:

```
status = ioctl (fd, FIOSETOPTIONS, OPT_TERMINAL & ~OPT_MON_TRAP);
```

Table 3-7 is a summary of the available options. The listed names are defined in the header file **ioLib.h**. For more detailed information, see the reference entry for **tyLib**.

Table 3-7 **Tty Options**

Library	Description
OPT_LINE	Select *line mode*. (See *Raw Mode and Line Mode*, p. 119.)
OPT_ECHO	Echo input characters to the output of the same channel.
OPT_CRMOD	Translate input **RETURN** characters into **NEWLINE** (\n); translate output **NEWLINE** into **RETURN-LINEFEED**.
OPT_TANDEM	Respond to X-on/X-off protocol (**CTRL+Q** and **CTRL+S**).
OPT_7_BIT	Strip the most significant bit from all input bytes.
OPT_MON_TRAP	Enable the special *ROM monitor trap* character, **CTRL+X** by default.
OPT_ABORT	Enable the special *target shell abort* character, **CTRL+C** by default. (Only useful if the target shell is configured into the system; see *9. Target Shell* in this manual for details.)
OPT_TERMINAL	Set all of the above option bits.
OPT_RAW	Set none of the above option bits.

Raw Mode and Line Mode

A *tty* device operates in one of two modes: *raw mode* (unbuffered) or *line mode*. Raw mode is the default. Line mode is selected by the **OPT_LINE** bit of the device option word (see *Tty Options*, p. 119).

In *raw mode*, each input character is available to readers as soon as it is input from the device. Reading from a *tty* device in raw mode causes as many characters as possible to be extracted from the input ring, up to the limit of the user's read buffer. Input cannot be modified except as directed by other *tty* option bits.

In *line mode*, all input characters are saved until a **NEWLINE** character is input; then the entire line of characters, including the **NEWLINE**, is made available in the ring at one time. Reading from a *tty* device in line mode causes characters up to the end of the next line to be extracted from the input ring, up to the limit of the user's read buffer. Input can be modified by the special characters **CTRL+H** (backspace), **CTRL+U** (line-delete), and **CTRL+D** (end-of-file), which are discussed in *Tty Special Characters*, p. 120.

Tty Special Characters

The following special characters are enabled if the *tty* device operates in line mode, that is, with the **OPT_LINE** bit set:

- The backspace character, by default **CTRL+H**, causes successive previous characters to be deleted from the current line, up to the start of the line. It does this by echoing a backspace followed by a space, and then another backspace.
- The line-delete character, by default **CTRL+U**, deletes all the characters of the current line.
- The end-of-file (EOF) character, by default **CTRL+D**, causes the current line to become available in the input ring without a **NEWLINE** and without entering the EOF character itself. Thus if the EOF character is the first character typed on a line, reading that line returns a zero byte count, which is the usual indication of end-of-file.

The following characters have special effects if the *tty* device is operating with the corresponding option bit set:

- The flow control characters, **CTRL+Q** and **CTRL+S**, commonly known as *X-on/X-off protocol*. Receipt of a **CTRL+S** input character suspends output to that channel. Subsequent receipt of a **CTRL+Q** resumes the output. Conversely, when the VxWorks input buffer is almost full, a **CTRL+S** is output to signal the other side to suspend transmission. When the input buffer is empty enough, a **CTRL+Q** is output to signal the other side to resume transmission. X-on/X-off protocol is enabled by **OPT_TANDEM**.
- The *ROM monitor trap* character, by default **CTRL+X**. This character traps to the ROM-resident monitor program. Note that this is drastic. All normal VxWorks functioning is suspended, and the computer system is controlled entirely by the monitor. Depending on the particular monitor, it may or may not be

possible to restart VxWorks from the point of interruption.[2] The monitor trap character is enabled by **OPT_MON_TRAP**.

- The special *target shell abort* character, by default **CTRL+C**. This character restarts the target shell if it gets stuck in an unfriendly routine, such as one that has taken an unavailable semaphore or is caught in an infinite loop. The target shell abort character is enabled by **OPT_ABORT**.

The characters for most of these functions can be changed using the **tyLib** routines shown in Table 3-8.

Table 3-8 **Tty Special Characters**

Character	Description	Modifier
CTRL+H	backspace (character delete)	***tyBackspaceSet*( )**
CTRL+U	line delete	***tyDeleteLineSet*( )**
CTRL+D	EOF (end of file)	***tyEOFSet*( )**
CTRL+C	target shell abort	***tyAbortSet*( )**
CTRL+X	trap to boot ROMs	***tyMonitorTrapSet*( )**
CTRL+S	output suspend	N/A
CTRL+Q	output resume	N/A

I/O Control Functions

The *tty* devices respond to the ***ioctl*( )** functions in Table 3-9, defined in **ioLib.h**. For more information, see the reference entries for **tyLib**, **ttyDrv**, and ***ioctl*( )**.

Table 3-9 **I/O Control Functions Supported by tyLib**

Function	Description
FIOBAUDRATE	Set the baud rate to the specified argument.
FIOCANCEL	Cancel a read or write.
FIOFLUSH	Discard all bytes in the input and output buffers.

2. It will not be possible to restart VxWorks if unhandled external interrupts occur during the boot countdown.

Table 3-9 **I/O Control Functions Supported by tyLib** *(Continued)*

Function	Description
FIOGETNAME	Get the file name of the *fd*.
FIOGETOPTIONS	Return the current device option word.
FIONREAD	Get the number of unread bytes in the input buffer.
FIONWRITE	Get the number of bytes in the output buffer.
FIOSETOPTIONS	Set the device option word.

⚠ **CAUTION:** To change the driver's hardware options (for example, the number of stop bits or parity bits), use the ***ioctl*( )** function **SIO_HW_OPTS_SET**. Because this command is not implemented in most drivers, you may need to add it to your BSP serial driver, which resides in *installDir***/target/src/drv/sio**. The details of how to implement this command depend on your board's serial chip. The constants defined in the header file *installDir***/target/h/sioLib.h** provide the POSIX definitions for setting the hardware options.

3.7.2 Pipe Devices

Pipes are virtual devices by which tasks communicate with each other through the I/O system. Tasks write messages to pipes; these messages can then be read by other tasks. Pipe devices are managed by **pipeDrv** and use the kernel message queue facility to bear the actual message traffic.

Creating Pipes

Pipes are created by calling the pipe create routine:

```
status = pipeDevCreate ("/pipe/name", maxMsgs, maxLength);
```

The new pipe can have at most *maxMsgs* messages queued at a time. Tasks that write to a pipe that already has the maximum number of messages queued are delayed until a message is dequeued. Each message in the pipe can be at most *maxLength* bytes long; attempts to write longer messages result in an error.

Writing to Pipes from ISRs

VxWorks pipes are designed to allow ISRs to write to pipes in the same way as task-level code. Many VxWorks facilities cannot be used from ISRs, including I/O to devices other than pipes. However, ISRs can use pipes to communicate with tasks, which can then invoke such facilities.

ISRs write to a pipe using the ***write*( )** call. Tasks and ISRs can write to the same pipes. However, if the pipe is full, the message is discarded because the ISRs cannot pend. ISRs must not invoke any I/O function on pipes other than ***write*( )**.

I/O Control Functions

Pipe devices respond to the ***ioctl*( )** functions summarized in Table 3-10. The functions listed are defined in the header file **ioLib.h**. For more information, see the reference entries for **pipeDrv** and for ***ioctl*( )** in **ioLib**.

Table 3-10 **I/O Control Functions Supported by pipeDrv**

Function	Description
FIOFLUSH	Discard all messages in the pipe.
FIOGETNAME	Get the pipe name of the *fd*.
FIONMSGS	Get the number of messages remaining in the pipe.
FIONREAD	Get the size in bytes of the first message in the pipe.

3.7.3 Pseudo Memory Devices

The **memDrv** driver allows the I/O system to access memory directly as a pseudo-I/O device. Memory location and size are specified when the device is created. This feature is useful when data must be preserved between boots of VxWorks or when sharing data between CPUs. This driver does not implement a file system as does **ramDrv**. The **ramDrv** driver must be given memory over which it has absolute control; whereas **memDrv** provides a high-level method of reading and writing bytes in absolute memory locations through I/O calls.

Installing the Memory Driver

The driver is first initialized and then the device is created:

```
STATUS memDrv
    (void)
STATUS memDevCreate
    (char * name, char * base, int length)
```

Memory for the device is an absolute memory location beginning at *base*. The *length* parameter indicates the size of the memory. For additional information on the memory driver, see the reference entries for **memDrv**, ***memDevCreate*( )**, and ***memDrv*( )**.

I/O Control Functions

The memory driver responds to the ***ioctl*( )** functions summarized in Table 3-11. The functions listed are defined in the header file **ioLib.h**. For more information, see the reference entries for **memDrv** and for ***ioctl*( )** in **ioLib**.

Table 3-11 **I/O Control Functions Supported by memDrv**

Function	Description
FIOSEEK	Set the current byte offset in the file.
FIOWHERE	Return the current byte position in the file.

3.7.4 Network File System (NFS) Devices

Network File System (NFS) devices allow files on remote hosts to be accessed with the NFS protocol. The NFS protocol specifies both *client* software, to read files from remote machines, and *server* software, to export files to remote machines.

The driver **nfsDrv** acts as a VxWorks NFS client to access files on any NFS server on the network. VxWorks also allows you to run an NFS server to export files to other systems; see *VxWorks Network Programmer's Guide: File Access Applications*l.

Using NFS devices, you can create, open, and access remote files exactly as though they were on a file system on a local disk. This is called *network transparency.*

Mounting a Remote NFS File System from VxWorks

Access to a remote NFS file system is established by mounting that file system locally and creating an I/O device for it using ***nfsMount*( )**. Its arguments are (1) the host name of the NFS server, (2) the name of the host file system, and (3) the local name for the file system.

For example, the following call mounts **/usr** of the host **mars** as **/vxusr** locally:

```
nfsMount ("mars", "/usr", "/vxusr");
```

This creates a VxWorks I/O device with the specified local name (**/vxusr**, in this example). If the local name is specified as **NULL**, the local name is the same as the remote name.

After a remote file system is mounted, the files are accessed as though the file system were local. Thus, after the previous example, opening the file **/vxusr/foo** opens the file **/usr/foo** on the host **mars**.

The remote file system must be *exported* by the system on which it actually resides. However, NFS servers can export only local file systems. Use the appropriate command on the server to see which file systems are local. NFS requires *authentication* parameters to identify the user making the remote access. To set these parameters, use the routines ***nfsAuthUnixSet*( )** and ***nfsAuthUnixPrompt*( )**.

Select **INCLUDE_NFS** for inclusion in the project facility VxWorks view to include NFS client support in your VxWorks configuration; see *Tornado User's Guide: Projects* for information on configuring VxWorks.

The subject of exporting and mounting NFS file systems and authenticating access permissions is discussed in more detail in *VxWorks Network Programmer's Guide: File Access Applications*. See also the reference entries **nfsLib** and **nfsDrv**, and the NFS documentation from Sun Microsystems.

I/O Control Functions for NFS Clients

NFS client devices respond to the ***ioctl*( )** functions summarized in Table 3-12. The functions listed are defined in **ioLib.h**. For more information, see the reference entries for **nfsDrv** and for ***ioctl*( )** in **ioLib**.

Table 3-12 **I/O Control Functions Supported by nfsDrv**

Function	Description
FIOFSTATGET	Get file status information (directory entry data).
FIOGETNAME	Get the file name of the *fd*.
FIONREAD	Get the number of unread bytes in the file.
FIOREADDIR	Read the next directory entry.
FIOSEEK	Set the current byte offset in the file.
FIOSYNC	Flush data to a remote NFS file.
FIOWHERE	Return the current byte position in the file.

3.7.5 Non-NFS Network Devices

VxWorks also supports network access to files on the remote host through the Remote Shell protocol (RSH) or the File Transfer Protocol (FTP). These implementations of network devices use the driver **netDrv**. When a remote file is opened using RSH or FTP, the entire file is copied into local memory. As a result, the largest file that can be opened is restricted by the available memory. Read and write operations are performed on the in-memory copy of the file. When closed, the file is copied back to the original remote file if it was modified.

In general, NFS devices are preferable to RSH and FTP devices for performance and flexibility, because NFS does not copy the entire file into local memory. However, NFS is not supported by all host systems.

Creating Network Devices

To access files on a remote host using either RSH or FTP, a network device must first be created by calling the routine ***netDevCreate*( )**. The arguments to ***netDevCreate*( )** are (1) the name of the device, (2) the name of the host the device accesses, and (3) which protocol to use: 0 (RSH) or 1 (FTP).

For example, the following call creates an RSH device called **mars:** that accesses the host **mars**. By convention, the name for a network device is the remote machine's name followed by a colon (**:**).

```
netDevCreate ("mars:", "mars", 0);
```

Files on a network device can be created, opened, and manipulated as if on a local disk. Thus, opening the file **mars:/usr/foo** actually opens **/usr/foo** on host **mars**.

Note that creating a network device allows access to any file or device on the remote system, while mounting an NFS file system allows access only to a specified file system.

For the files of a remote host to be accessible with RSH or FTP, permissions and user identification must be established on both the remote and local systems. Creating and configuring network devices is discussed in detail in *VxWorks Network Programmer's Guide: File Access Applications* and in the reference entry for **netDrv**.

I/O Control Functions

RSH and FTP devices respond to the same ***ioctl( )*** functions as NFS devices except for **FIOSYNC** and **FIOREADDIR**. The functions are defined in the header file **ioLib.h**. For more information, see the reference entries for **netDrv** and ***ioctl( )***.

3.7.6 Block Devices

A *block device* is a device that is organized as a sequence of individually accessible blocks of data. The most common type of block device is a disk. In VxWorks, the term *block* refers to the smallest addressable unit on the device. For most disk devices, a VxWorks block corresponds to a *sector*, although terminology varies.

Block devices in VxWorks have a slightly different interface than other I/O devices. Rather than interacting directly with the I/O system, block device support consists of low-level drivers that interact with a file system. The file system, in turn, interacts with the I/O system. This arrangement allows a single low-level driver to be used with various different file systems and reduces the number of I/O functions that must be supported in the driver. The internal implementation of low-level drivers for block devices is discussed in *3.9.4 Block Devices*, p. 158.

File Systems

For use with block devices, VxWorks is supplied with file system libraries compatible with the MS-DOS (dosFs) and RT-11 (rt11Fs) file systems. In addition, there is a library for a simple raw disk file system (rawFs), which treats an entire disk much like a single large file. Also supplied is a file system that supports SCSI tape devices, which are organized so that individual blocks of data are read and written sequentially, and a file system that supports CD-ROM devices. Use of these file systems is discussed in *4. Local File Systems* in this manual. Also see the reference entries for **dosFsLib**, **rt11FsLib**, **rawFsLib**, **tapeFsLib**, and **cdromFsLib**.

RAM Disk Drivers

RAM drivers, as implemented in **ramDrv**, emulate disk devices but actually keep all data in memory. Memory location and "disk" size are specified when a RAM device is created by calling ***ramDevCreate*( )**. This routine can be called repeatedly to create multiple RAM disks.

Memory for the RAM disk can be preallocated and the address passed to ***ramDevCreate*( )**, or memory can be automatically allocated from the system memory pool using ***malloc*( )**.

After the device is created, a name and file system (dosFs, rt11Fs, or rawFs) must be associated with it using the file system's device initialization routine or file system's make routine, for example, ***dosFsDevInit*( )** or ***dosFsMkfs*( )**. Information describing the device is passed to the file system in a **BLK_DEV** structure. A pointer to this structure is returned by the RAM disk creation routine.

In the following example, a 200KB RAM disk is created with automatically allocated memory, 512-byte sections, a single track, and no sector offset. The device is assigned the name **DEV1:** and initialized for use with dosFs.

```
BLK_DEV              *pBlkDev;
DOS_VOL_DESC         *pVolDesc;
pBlkDev = ramDevCreate (0, 512, 400, 400, 0);
pVolDesc = dosFsMkfs ("DEV1:", pBlkDev);
```

The ***dosFsMkfs*( )** routine calls ***dosFsDevInit*( )** with default parameters and initializes the file system on the disk by calling ***ioctl*( )** with the **FIODISKINIT**.

If the RAM disk memory already contains a disk image, the first argument to ***ramDevCreate*( )** is the address in memory, and the formatting arguments must be identical to those used when the image was created. For example:

```
pBlkDev = ramDevCreate (0xc0000, 512, 400, 400, 0);
pVolDesc = dosFsDevInit ("DEV1:", pBlkDev, NULL);
```

In this case, ***dosFsDevInit***( ) must be used instead, because the file system already exists on the disk and does not require re-initialization. This procedure is useful if a RAM disk is to be created at the same address used in a previous boot of VxWorks. The contents of the RAM disk are then preserved. Creating a RAM disk with rt11Fs using ***rt11FsMkfs***( ) and ***rt11FsDevInit***( ) follows these same procedures. For more information on RAM disk drivers, see the reference entry for **ramDrv**. For more information on file systems, see *4. Local File Systems*.

SCSI Drivers

SCSI is a standard peripheral interface that allows connection with a wide variety of hard disks, optical disks, floppy disks, tape drives, and CD-ROM devices. SCSI block drivers are compatible with the dosFs and rt11Fs libraries, and offer several advantages for target configurations. They provide:

– local mass storage in non-networked environments
– faster I/O throughput than Ethernet networks

The SCSI-2 support in VxWorks supersedes previous SCSI support, although it offers the option of configuring the original SCSI functionality, now known as SCSI-1. With SCSI-2 enabled, the VxWorks environment can still handle SCSI-1 applications, such as file systems created under SCSI-1. However, applications that directly used SCSI-1 data structures defined in **scsiLib.h** may require modifications and recompilation for SCSI-2 compatibility.

The VxWorks SCSI implementation consists of two modules, one for the device-independent SCSI interface and one to support a specific SCSI controller. The **scsiLib** library provides routines that support the device-independent interface; device-specific libraries provide configuration routines that support specific controllers (for example, **wd33c93Lib** for the Western Digital WD33C93 device or **mb87030Lib** for the Fujitsu MB87030 device). There are also additional support routines for individual targets in **sysLib.c**.

Configuring SCSI Drivers

Constants associated with SCSI drivers are listed in Table 3-13. Define these in the indicated portion of the VxWorks view or in the configuration files. To enable SCSI functionality, select **INCLUDE_SCSI** for inclusion in the project facility VxWorks view. This enables SCSI-1. To enable SCSI-2, you must select, in addition to SCSI-1, **INCLUDE_SCSI2**.

Table 3-13 **SCSI Constants**

Constant	Description	Where to Configure
INCLUDE_SCSI	Include SCSI interface.	hardware/buses
INCLUDE_SCSI2	SCSI-2 extensions.	hardware/buses

Table 3-13 **SCSI Constants**

Constant	Description	Where to Configure
INCLUDE_SCSI_DMA	Enable DMA for SCSI.	**sysLib.c** or **sysScsi.c**
INCLUDE_SCSI_BOOT	Allow booting from a SCSI device.	**sysLib.c** or **sysScsi.c**
SCSI_AUTO_CONFIG	Auto-configure and locate all targets on a SCSI bus.	**sysLib.c** or **sysScsi.c**
INCLUDE_DOSFS	Include the DOS file system.	operating system components/IO system components
INCLUDE_TAPEFS	Include the tape file system.	**config.h**
INCLUDE_CDROMFS	Include CD-ROM file system support.	**config.h**

Autoconfiguration, DMA, and booting from a SCSI device are defined appropriately for each BSP. If you need to change these settings, see the online reference for ***sysScsiConfig*( )** under VxWorks Reference>Manual: Libraries and the source file *installDir*/**target/src/config/usrScsi.c**. Except for dosFs, which can be configured from the project facility, the file systems that can be used with SCSI must be defined in **config.h**. (For more information see *8. Configuration and Build*.)

⚠ **CAUTION:** Including SCSI-2 in your VxWorks image can significantly increase the image size. If you receive a warning from **vxsize** when building VxWorks, or if the size of your image becomes greater than that supported by the current setting of **RAM_HIGH_ADRS**, be sure to see *8.6.1 Scaling Down VxWorks*, p.344 and *8.9 Creating Bootable Applications*, p.364 for information on how to resolve the problem.

Configuring the SCSI Bus ID

Each board in a SCSI-2 environment must define a unique SCSI bus ID for the SCSI initiator. SCSI-1 drivers, which support only a single initiator at a time, assume an initiator SCSI bus ID of 7. However, SCSI-2 supports multiple initiators, up to eight initiators and targets at one time. Therefore, to ensure a unique ID, choose a value in the range 0-7 to be passed as a parameter to the driver's initialization routine (for example, ***ncr710CtrlInitScsi2*( )**) by the ***sysScsiInit*( )** routine in **sysScsi.c**. For more information, see the reference entry for the relevant driver initialization routine. If there are multiple boards on one SCSI bus, and all of these boards use the same BSP, then different versions of the BSP must be compiled for each board by assigning unique SCSI bus IDs.

ROM Size Adjustment for SCSI Boot

If **INCLUDE_SCSI_BOOT** is defined, larger ROMs may be required for some boards. If this is the case, the definition of **ROM_SIZE** in **Makefile** and in **config.h** should be changed to a size that suits the capabilities of the target hardware.

Structure of the SCSI Subsystem

The SCSI subsystem supports libraries and drivers for both SCSI-1 and SCSI-2. It consists of the following six libraries which are independent of any SCSI controller:

scsiLib
: routines that provide the mechanism for switching SCSI requests to either the SCSI-1 library (**scsi1Lib**) or the SCSI-2 library (**scsi2Lib**), as configured by the board support package (BSP).

scsi1Lib
: SCSI-1 library routines and interface, used when only **INCLUDE_SCSI** is selected for inclusion in the project facility VxWorks view (see *Configuring SCSI Drivers*, p. 129.)

scsi2Lib
: SCSI-2 library routines and all physical device creation and deletion routines.

scsiCommonLib
: commands common to all types of SCSI devices.

scsiDirectLib
: routines and commands for direct access devices (disks).

scsiSeqLib
: routines and commands for sequential access block devices (tapes).

Controller-independent support for the SCSI-2 functionality is divided into **scsi2Lib**, **scsiCommonLib**, **scsiDirectLib**, and **scsiSeqLib**. The interface to any of these SCSI-2 libraries can be accessed directly. However, **scsiSeqLib** is designed to be used in conjunction with tapeFs, while **scsiDirectLib** works with dosFs, rt11Fs, and rawFs. Applications written for SCSI-1 can be used with SCSI-2; however, SCSI-1 device drivers cannot.

VxWorks targets using SCSI interface controllers require a controller-specific device driver. These device drivers work in conjunction with the controller-independent SCSI libraries, and they provide controller configuration and initialization routines contained in controller-specific libraries. For example, the Western Digital WD33C93 SCSI controller is supported by the device driver libraries **wd33c93Lib**, **wd33c93Lib1**, and **wd33c93Lib2**. Routines tied to SCSI-1 (such as ***wd33c93CtrlCreate*( )**) and SCSI-2 (such as ***wd33c93CtrlCreateScsi2*( )**) are segregated into separate libraries to simplify configuration. There are also additional support routines for individual targets in **sysLib.c**.

Booting and Initialization

To boot from a SCSI device, see *4.2.21 Booting from a Local dosFs File System Using SCSI*, p. 203.

After VxWorks is built with SCSI support, the system startup code initializes the SCSI interface by executing ***sysScsiInit*( )** and ***usrScsiConfig*( )** when **INCLUDE_SCSI** is selected for inclusion in the project facility VxWorks view. The call to ***sysScsiInit*( )** initializes the SCSI controller and sets up interrupt handling. The physical device configuration is specified in ***usrScsiConfig*( )**, which is in *installDir***/target/src/config/usrScsi.c**. The routine contains an example of the calling sequence to declare a hypothetical configuration, including:

– definition of physical devices with ***scsiPhysDevCreate*( )**
– creation of logical partitions with ***scsiBlkDevCreate*( )**
– specification of a file system with either ***dosFsDevInit*( )** or ***rt11FsDevInit*( )**

If you are not using **SCSI_AUTO_CONFIG**, modify ***usrScsiConfig*( )** to reflect your actual configuration. For more information on the calls used in this routine, see the reference entries for ***scsiPhysDevCreate*( )**, ***scsiBlkDevCreate*( )**, ***dosFsDevInit*( )**, ***rt11FsDevInit*( )**, ***dosFsMkfs*( )**, and ***rt11FsMkfs*( )**.

Device-Specific Configuration Options

The SCSI libraries have the following default behaviors enabled:

– SCSI messages
– disconnects
– minimum period and maximum REQ/ACK offset
– tagged command queuing
– wide data transfer

Device-specific options do not need to be set if the device shares this default behavior. However, if you need to configure a device that diverges from these default characteristics, use ***scsiTargetOptionsSet*( )** to modify option values. These options are fields in the **SCSI_OPTIONS** structure, shown below. **SCSI_OPTIONS** is declared in **scsi2Lib.h**. You can choose to set some or all of these option values to suit your particular SCSI device and application.

```
typedef struct                    /* SCSI_OPTIONS - programmable options */
    {
    UINT     selTimeOut;          /* device selection time-out (us)      */
    BOOL     messages;            /* FALSE => do not use SCSI messages   */
    BOOL     disconnect;          /* FALSE => do not use disconnect      */
    UINT8     maxOffset;          /* max sync xfer offset (0 => async.)  */
    UINT8     minPeriod;          /* min sync xfer period (x 4 ns)       */
    SCSI_TAG_TYPE tagType;        /* default tag type                    */
    UINT     maxTags;            /* max cmd tags available (0 => untag   */
    UINT8     xferWidth;         /* wide data trnsfr width in SCSI units */
    } SCSI_OPTIONS;
```

There are numerous types of SCSI devices, each supporting its own mix of SCSI-2 features. To set device-specific options, define a **SCSI_OPTIONS** structure and assign the desired values to the structure's fields. After setting the appropriate fields, call ***scsiTargetOptionsSet*( )** to effect your selections. Example 3-5 illustrates one possible device configuration using **SCSI_OPTIONS**.

Call ***scsiTargetOptionsSet*( )** after initializing the SCSI subsystem, but before initializing the SCSI physical device. For more information about setting and implementing options, see the reference entry for ***scsiTargetOptionsSet*( )**.

WARNING: Calling ***scsiTargetOptionsSet*( )** after the physical device has been initialized may lead to undefined behavior.

The SCSI subsystem performs each SCSI command request as a SCSI transaction. This requires the SCSI subsystem to select a device. Different SCSI devices require different amounts of time to respond to a selection; in some cases, the **selTimeOut** field may need to be altered from the default.

If a device does not support SCSI messages, the boolean field **messages** can be set to FALSE. Similarly, if a device does not support disconnect/reconnect, the boolean field **disconnect** can be set to FALSE.

The SCSI subsystem automatically tries to negotiate synchronous data transfer parameters. However, if a SCSI device does not support synchronous data transfer, set the **maxOffset** field to 0. By default, the SCSI subsystem tries to negotiate the maximum possible REQ/ACK offset and the minimum possible data transfer period supported by the SCSI controller on the VxWorks target. This is done to maximize the speed of transfers between two devices. However, speed depends upon electrical characteristics, like cable length, cable quality, and device termination; therefore, it may be necessary to reduce the values of **maxOffset** or **minPeriod** for fast transfers.

The **tagType** field defines the type of tagged command queuing desired, using one of the following macros:

– **SCSI_TAG_UNTAGGED**
– **SCSI_TAG_SIMPLE**
– **SCSI_TAG_ORDERED**
– **SCSI_TAG_HEAD_OF_QUEUE**

For more information about the types of tagged command queuing available, see the ANSI X3T9-I/O Interface Specification *Small Computer System Interface (SCSI-2)*.

The **maxTags** field sets the maximum number of command tags available for a particular SCSI device.

Wide data transfers with a SCSI target device are automatically negotiated upon initialization by the SCSI subsystem. Wide data transfer parameters are always negotiated before synchronous data transfer parameters, as specified by the SCSI ANSI specification, because a wide negotiation resets any prior negotiation of synchronous parameters. However, if a SCSI device does not support wide parameters and there are problems initializing that device, you must set the **xferWidth** field to 0. By default, the SCSI subsystem tries to negotiate the maximum possible transfer width supported by the SCSI controller on the VxWorks target in order to maximize the default transfer speed between the two devices. For more information on the actual routine call, see the reference entry for ***scsiTargetOptionsSet*( )**.

SCSI Configuration Examples

The following examples show some possible configurations for different SCSI devices. Example 3-4 is a simple block device configuration setup. Example 3-5 involves selecting special options and demonstrates the use of ***scsiTargetOptionsSet*( )**. Example 3-6 configures a tape device and a tape file system. Example 3-7 configures a SCSI device for synchronous data transfer. Example 3-8 shows how to configure the SCSI bus ID. These examples can be embedded either in the ***usrScsiConfig*( )** routine or in a user-defined SCSI configuration function.

Example 3-4 **Configuring SCSI Drivers**

In the following example, ***usrScsiConfig*( )** was modified to reflect a new system configuration. The new configuration has a SCSI disk with a bus ID of 4 and a Logical Unit Number (LUN) of 0 (zero). The disk is configured with a dosFs file system (with a total size of 0x20000 blocks) and a rawFs file system (spanning the remainder of the disk). The following ***usrScsiConfig*( )** code reflects this modification.

```
/* configure Winchester at busId = 4, LUN = 0 */

if ((pSpd40 = scsiPhysDevCreate (pSysScsiCtrl, 4, 0, 0, NONE, 0, 0, 0))
        == (SCSI_PHYS_DEV *) NULL)
    {
    SCSI_DEBUG_MSG ("usrScsiConfig: scsiPhysDevCreate failed.\n");
    }
else
    {
    /* create block devices - one for dosFs and one for rawFs */

    if (((pSbd0 = scsiBlkDevCreate (pSpd40, 0x20000, 0)) == NULL) ||
        ((pSbd1 = scsiBlkDevCreate (pSpd40, 0, 0x20000)) == NULL))
        {
        return (ERROR);
        }

    /* initialize both dosFs and rawFs file systems */

    if ((dosFsDevInit ("/sd0/", pSbd0, NULL) == NULL) ||
        (rawFsDevInit ("/sd1/", pSbd1) == NULL))
        {
        return (ERROR);
        }
    }
```

If problems with your configuration occur, insert the following lines at the beginning of ***usrScsiConfig*( )** to obtain further information on SCSI bus activity.

```
    #if FALSE
    scsiDebug = TRUE;
    scsiIntsDebug = TRUE;
    #endif
```

Do not declare the global variables **scsiDebug** and **scsiIntsDebug** locally. They can be set or reset from the shell; see the *Tornado User's Guide: Shell* for details.

Example 3-5 **Configuring a SCSI Disk Drive with Asynchronous Data Transfer and No Tagged Command Queuing**

In this example, a SCSI disk device is configured without support for synchronous data transfer and tagged command queuing. The ***scsiTargetOptionsSet*( )** routine is used to turn off these features. The SCSI ID of this disk device is 2, and the LUN is 0:

```
int                 which;
SCSI_OPTIONS        option;
int                 devBusId;

devBusId = 2;
which = SCSI_SET_OPT_XFER_PARAMS | SCSI_SET_OPT_TAG_PARAMS;
option.maxOffset = SCSI_SYNC_XFER_ASYNC_OFFSET;
                                             /* => 0 defined in scsi2Lib.h */
option.minPeriod = SCSI_SYNC_XFER_MIN_PERIOD;  /* defined in scsi2Lib.h */
option.tagType = SCSI_TAG_UNTAGGED;      /* defined in scsi2Lib.h */
option.maxTag = SCSI_MAX_TAGS;

if (scsiTargetOptionsSet (pSysScsiCtrl, devBusId, &option, which) == ERROR)
    {
    SCSI_DEBUG_MSG ("usrScsiConfig: could not set options\n", 0, 0, 0, 0,
        0, 0);
    return (ERROR);
    }

/* configure SCSI disk drive at busId = devBusId, LUN = 0 */

if ((pSpd20 = scsiPhysDevCreate (pSysScsiCtrl, devBusId, 0, 0, NONE, 0, 0,
        0)) == (SCSI_PHYS_DEV *) NULL)
    {
    SCSI_DEBUG_MSG ("usrScsiConfig: scsiPhysDevCreate failed.\n");
    return (ERROR);
    }
```

Example 3-6 **Working with Tape Devices**

SCSI tape devices can be controlled using common commands from **scsiCommonLib** and sequential commands from **scsiSeqLib**. These commands use a pointer to a SCSI sequential device structure, **SEQ_DEV**, defined in **seqIo.h**. For more information on controlling SCSI tape devices, see the reference entries for these libraries.

This example configures a SCSI tape device whose bus ID is 5 and whose LUN is 0. It includes commands to create a physical device pointer, set up a sequential device, and initialize a tapeFs device.

```
/* configure Exabyte 8mm tape drive at busId = 5, LUN = 0 */

if ((pSpd50 = scsiPhysDevCreate (pSysScsiCtrl, 5, 0, 0, NONE, 0, 0, 0))
        == (SCSI_PHYS_DEV *) NULL)
    {
    SCSI_DEBUG_MSG ("usrScsiConfig: scsiPhysDevCreate failed.\n");
    return (ERROR);
    }

/* configure the sequential device for this physical device */

if ((pSd0 = scsiSeqDevCreate (pSpd50)) == (SEQ_DEV *) NULL)
    {
    SCSI_DEBUG_MSG ("usrScsiConfig: scsiSeqDevCreate failed.\n");
        return (ERROR);
    }

/* setup the tape device configuration */

pTapeConfig = (TAPE_CONFIG *) calloc (sizeof (TAPE_CONFIG), 1);
pTapeConfig->rewind = TRUE;   /* this is a rewind device */
pTapeConfig->blkSize = 512;   /* uses 512 byte fixed blocks */
```

```
/* initialize a tapeFs device */

if (tapeFsDevInit ("/tape1", pSd0, pTapeConfig) == NULL)
    {
    return (ERROR);
    }

/* rewind the physical device using scsiSeqLib interface directly*/

if (scsiRewind (pSd0) == ERROR)
    {
    return (ERROR);
    }
```

Example 3-7 **Configuring a SCSI Disk for Synchronous Data Transfer with Non-Default Offset and Period Values**

In this example, a SCSI disk drive is configured with support for synchronous data transfer. The offset and period values are user-defined and differ from the driver default values.The chosen period is 25, defined in SCSI units of 4 ns. Thus the period is actually 4 * 25 = 100 ns. The synchronous offset is chosen to be 2. Note that you may need to adjust the values depending on your hardware environment.

```
int                     which;
SCSI_OPTIONS            option;
int                     devBusId;

devBusId = 2;

    which = SCSI_SET_IPT_XFER_PARAMS;
    option.maxOffset = 2;
    option.minPeriod = 25;

    if (scsiTargetOptionsSet (pSysScsiCtrl, devBusId &option, which) ==
        ERROR)
        {
        SCSI_DEBUG_MSG ("usrScsiConfig: could not set options\n",
                         0, 0, 0, 0, 0, 0)
        return (ERROR);
        }

    /* configure SCSI disk drive at busId = devBusId, LUN = 0 */

    if ((pSpd20 = scsiPhysDevCreate (pSysScsiCtrl, devBusId, 0, 0, NONE,
                                     0, 0, 0)) == (SCSI_PHYS_DEV *) NULL)
        {
        SCSI_DEBUG_MSG ("usrScsiConfig: scsiPhysDevCreate failed.\n")
        return (ERROR);
        }
```

Example 3-8 **Changing the Bus ID of the SCSI Controller**

To change the bus ID of the SCSI controller, modify ***sysScsiInit*( )** in **sysScsi.c**. Set the SCSI bus ID to a value between 0 and 7 in the call to *xxx***CtrlInitScsi2*( )** (where *xxx* is the controller name); the default bus ID for the SCSI controller is 7.

Troubleshooting

- **Incompatibilities Between SCSI-1 and SCSI-2**

  Applications written for SCSI-1 may not execute for SCSI-2 because data structures in **scsi2Lib.h**, such as **SCSI_TRANSACTION** and **SCSI_PHYS_DEV**, have changed. This applies only if the application used these structures directly.

  If this is the case, you can choose to configure only the SCSI-1 level of support, or you can modify your application according to the data structures in **scsi2Lib.h**. In order to set new fields in the modified structure, some applications may simply need to be recompiled, and some applications will have to be modified and then recompiled.

- **SCSI Bus Failure**

  If your SCSI bus hangs, it could be for a variety of reasons. Some of the more common are:

  – Your cable has a defect. This is the most common cause of failure.

  – The cable exceeds the cumulative maximum length of 6 meters specified in the SCSI-2 standard, thus changing the electrical characteristics of the SCSI signals.

  – The bus is not terminated correctly. Consider providing termination power at both ends of the cable, as defined in the SCSI-2 ANSI specification.

  – The minimum transfer period is insufficient or the REQ/ACK offset is too great. Use ***scsiTargetOptionsSet*( )** to set appropriate values for these options.

  – The driver is trying to negotiate wide data transfers on a device that does not support them. In rejecting wide transfers, the device-specific driver cannot handle this phase mismatch. Use ***scsiTargetOptionsSet*( )** to set the appropriate value for the **xferWidth** field for that particular SCSI device.

3.7.7 Sockets

In VxWorks, the underlying basis of network communications is *sockets*. A socket is an endpoint for communication between tasks; data is sent from one socket to another. Sockets are not created or opened using the standard I/O functions. Instead they are created by calling ***socket*( )**, and connected and accessed using other routines in **sockLib**. However, after a *stream* socket (using TCP) is created and connected, it can be accessed as a standard I/O device, using ***read*( )**, ***write*( )**, ***ioctl*( )**, and ***close*( )**. The value returned by ***socket*( )** as the socket handle is in fact an I/O system *fd*.

VxWorks socket routines are source-compatible with the BSD 4.4 UNIX socket functions and the Windows Sockets (Winsock 1.1) networking standard. Use of these routines is discussed in *VxWorks Network Programmer's Guide: Networking APIs*.

3.8 Differences Between VxWorks and Host System I/O

Most commonplace uses of I/O in VxWorks are completely source-compatible with I/O in UNIX and Windows. However, note the following differences:

- **Device Configuration.** In VxWorks, device drivers can be installed and removed dynamically.
- **File Descriptors.** In UNIX and Windows, *fd*s are unique to each process. In VxWorks, *fd*s are global entities, accessible by any task, except for standard input, standard output, and standard error (0, 1, and 2), which can be task specific.
- **I/O Control.** The specific parameters passed to ***ioctl*( )** functions can differ between UNIX and VxWorks.
- **Driver Routines.** In UNIX, device drivers execute in system mode and are not preemptible. In VxWorks, driver routines are in fact preemptible because they execute within the context of the task that invoked them.

3.9 Internal Structure

The VxWorks I/O system is different from most in the way the work of performing user I/O requests is apportioned between the device-independent I/O system and the device drivers themselves.

In many systems, the device driver supplies a few routines to perform low-level I/O functions such as inputting or outputting a sequence of bytes to character-oriented devices. The higher-level protocols, such as communications protocols on character-oriented devices, are implemented in the device-independent part of the I/O system. The user requests are heavily processed by the I/O system before the driver routines get control.

While this approach is designed to make it easy to implement drivers and to ensure that devices behave as much alike as possible, it has several drawbacks. The driver writer is often seriously hampered in implementing alternative protocols that are not provided by the existing I/O system. In a real-time system, it is sometimes desirable to bypass the standard protocols altogether for certain devices where throughput is critical, or where the device does not fit the standard model.

In the VxWorks I/O system, minimal processing is done on user I/O requests before control is given to the device driver. Instead, the VxWorks I/O system acts as a switch to route user requests to appropriate driver-supplied routines. Each driver can then process the raw user requests as appropriate to its devices. In addition, however, several high-level subroutine libraries are available to driver writers that implement standard protocols for both character- and block-oriented devices. Thus the VxWorks I/O system gives you the best of both worlds: while it is easy to write a standard driver for most devices with only a few pages of device-specific code, driver writers are free to execute the user requests in nonstandard ways where appropriate.

There are two fundamental types of device: *block* and *character* (or *non-block*; see Figure 3-8). Block devices are used for storing file systems. They are random access devices where data is transferred in blocks. Examples of block devices include hard and floppy disks. Character devices are any device that does not fall in the block category. Examples of character devices include serial and graphical input devices, for example, terminals and graphics tablets.

As discussed in earlier sections, the three main elements of the VxWorks I/O system are drivers, devices, and files. The following sections describe these elements in detail. The discussion focuses on character drivers; however, much of it is applicable for block devices. Because block drivers must interact with

VxWorks file systems, they use a slightly different organization; see *3.9.4 Block Devices*, p.158.

NOTE: This discussion is designed to clarify the structure of VxWorks I/O facilities and to highlight some considerations relevant to writing I/O drivers for VxWorks. It is not a complete text on writing a device driver. For detailed information on this subject, see the *Tornado BSP Developer's Kit User's Guide*.

Example 3-9 shows the abbreviated code for a hypothetical driver that is used as an example throughout the following discussions. This example driver is typical of drivers for character-oriented devices.

In VxWorks, each driver has a short, unique abbreviation, such as **net** or **tty**, which is used as a prefix for each of its routines. The abbreviation for the example driver is *xx*.

Example 3-9 **Hypothetical Driver**

```
/************************************************************************
* xxDrv - driver initialization routine
*
* xxDrv() initializes the driver. It installs the driver via iosDrvInstall.
* It may allocate data structures, connect ISRs, and initialize hardware.
*/

STATUS xxDrv ()
  {
  xxDrvNum = iosDrvInstall (xxCreat, 0, xxOpen, 0, xxRead, xxWrite, xxIoctl);
  (void) intConnect (intvec, xxInterrupt, ...);
  ...
  }

/************************************************************************
* xxDevCreate - device creation routine
*
* Called to add a device called <name> to be serviced by this driver. Other
* driver-dependent arguments may include buffer sizes, device addresses...
* The routine adds the device to the I/O system by calling iosDevAdd.
* It may also allocate and initialize data structures for the device,
* initialize semaphores, initialize device hardware, and so on.
*/

STATUS xxDevCreate (name, ...)
  char * name;
  ...
  {
  status = iosDevAdd (xxDev, name, xxDrvNum);
  ...
  }
```

```
/*************************************************************************
* The following routines implement the basic I/O functions. The xxOpen()
* return value is meaningful only to this driver, and is passed back as an
* argument to the other I/O routines.
*/

int xxOpen (xxDev, remainder, mode)
  XXDEV * xxDev;
  char * remainder;
  int mode;
  {
  /* serial devices should have no file name part */

  if (remainder[0] != 0)
    return (ERROR);
  else
    return ((int) xxDev);
  }

int xxRead (xxDev, buffer, nBytes)
  XXDEV * xxDev;
  char * buffer;
  int nBytes;
  ...
int xxWrite (xxDev, buffer, nBytes)
  ...
int xxIoctl (xxDev, requestCode, arg)
  ...

/*************************************************************************
* xxInterrupt - interrupt service routine
*
* Most drivers have routines that handle interrupts from the devices
* serviced by the driver. These routines are connected to the interrupts
* by calling intConnect (usually in xxDrv above). They can receive a
* single argument, specified in the call to intConnect (see intLib).
*/

VOID xxInterrupt (arg)
  ...
```

3.9.1 Drivers

A driver for a non-block device implements the seven basic I/O functions—***creat*( )**, ***remove*( )**, ***open*( )**, ***close*( )**, ***read*( )**, ***write*( )**, and ***ioctl*( )**—for a particular kind of device. In general, this type of driver has routines that implement each of these functions, although some of the routines can be omitted if the functions are not operative with that device.

Drivers can optionally allow tasks to wait for activity on multiple file descriptors. This is implemented using the driver's ***ioctl*( )** routine; see *Implementing select( )*, p. 152.

A driver for a block device interfaces with a file system, rather than directly with the I/O system. The file system in turn implements most I/O functions. The driver need only supply routines to read and write blocks, reset the device, perform I/O control, and check device status. Drivers for block devices have a number of special requirements that are discussed in *3.9.4 Block Devices*, p. 158.

When the user invokes one of the basic I/O functions, the I/O system routes the request to the appropriate routine of a specific driver, as detailed in the following sections. The driver's routine runs in the calling task's context, as though it were called directly from the application. Thus, the driver is free to use any facilities normally available to tasks, including I/O to other devices. This means that most drivers have to use some mechanism to provide mutual exclusion to critical regions of code. The usual mechanism is the semaphore facility provided in **semLib**.

In addition to the routines that implement the seven basic I/O functions, drivers also have three other routines:

- An initialization routine that installs the driver in the I/O system, connects to any interrupts used by the devices serviced by the driver, and performs any necessary hardware initialization (typically named *xx***Drv( )**).
- A routine to add devices that are to be serviced by the driver (typically named *xx***DevCreate( )**) to the I/O system.
- Interrupt-level routines that are connected to the interrupts of the devices serviced by the driver.

The Driver Table and Installing Drivers

The function of the I/O system is to route user I/O requests to the appropriate routine of the appropriate driver. The I/O system does this by maintaining a table that contains the address of each routine for each driver. Drivers are installed dynamically by calling the I/O system internal routine ***iosDrvInstall*( )**. The arguments to this routine are the addresses of the seven I/O routines for the new driver. The ***iosDrvInstall*( )** routine enters these addresses in a free slot in the driver table and returns the index of this slot. This index is known as the *driver number* and is used subsequently to associate particular devices with the driver.

Null (0) addresses can be specified for some of the seven routines. This indicates that the driver does not process those functions. For non-file-system drivers, ***close*( )** and ***remove*( )** often do nothing as far as the driver is concerned.

VxWorks file systems (**dosFsLib**, **rt11FsLib**, and **rawFsLib**) contain their own entries in the driver table, which are created when the file system library is initialized.

Example of Installing a Driver

Figure 3-2 shows the actions taken by the example driver and by the I/O system when the initialization routine *xx****Drv*( )** runs.

[1] The driver calls ***iosDrvInstall*( )**, specifying the addresses of the driver's routines for the seven basic I/O functions.

The I/O system:

[2] Locates the next available slot in the driver table, in this case slot 2.

[3] Enters the addresses of the driver routines in the driver table.

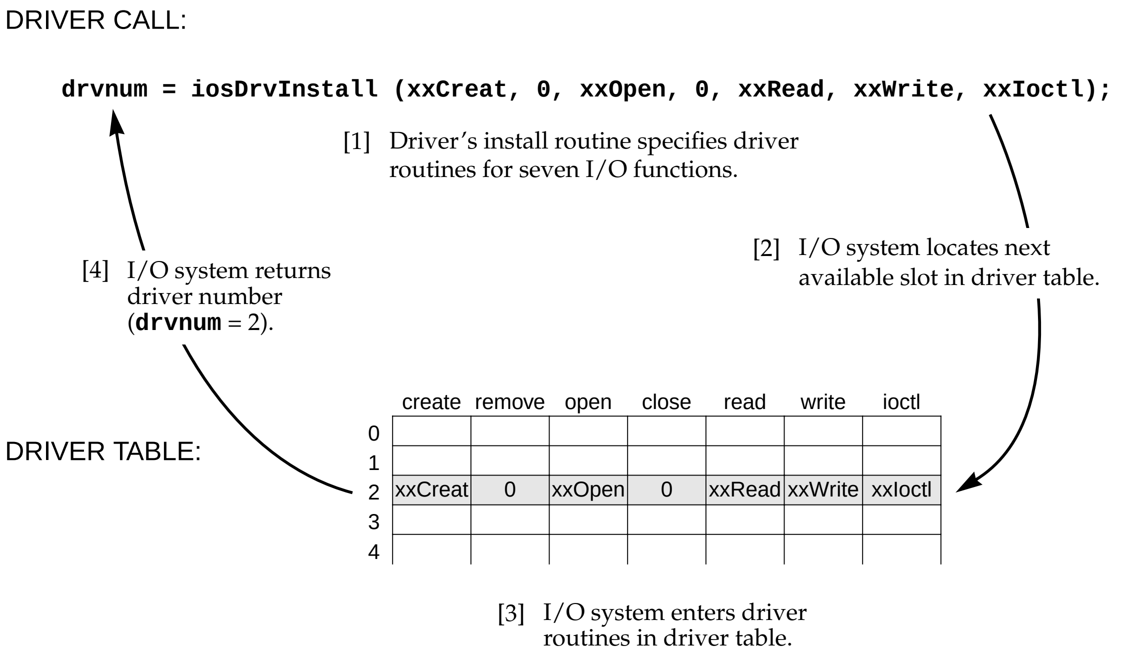
[4] Returns the slot number as the driver number of the newly installed driver.

3.9.2 Devices

Some drivers are capable of servicing many instances of a particular kind of device. For example, a single driver for a serial communications device can often handle many separate channels that differ only in a few parameters, such as device address.

In the VxWorks I/O system, devices are defined by a data structure called a *device header* (**DEV_HDR**). This data structure contains the device name string and the driver number for the driver that services this device. The device headers for all the devices in the system are kept in a memory-resident linked list called the *device list*. The device header is the initial part of a larger structure determined by the individual drivers. This larger structure, called a *device descriptor*, contains additional device-specific data such as device addresses, buffers, and semaphores.

Figure 3-2 **Example – Driver Initialization for Non-Block Devices**


DRIVER CALL:
drvnum = iosDrvInstall (xxCreat, 0, xxOpen, 0, xxRead, xxWrite, xxIoctl);
[1] Driver's install routine specifies driver routines for seven I/O functions.
[2] I/O system locates next available slot in driver table.
[4] I/O system returns driver number (drvnum = 2).
DRIVER TABLE:
create remove open close read write ioctl
0
1
2 xxCreat 0 xxOpen 0 xxRead xxWrite xxIoctl
3
4
[3] I/O system enters driver routines in driver table.

The Device List and Adding Devices

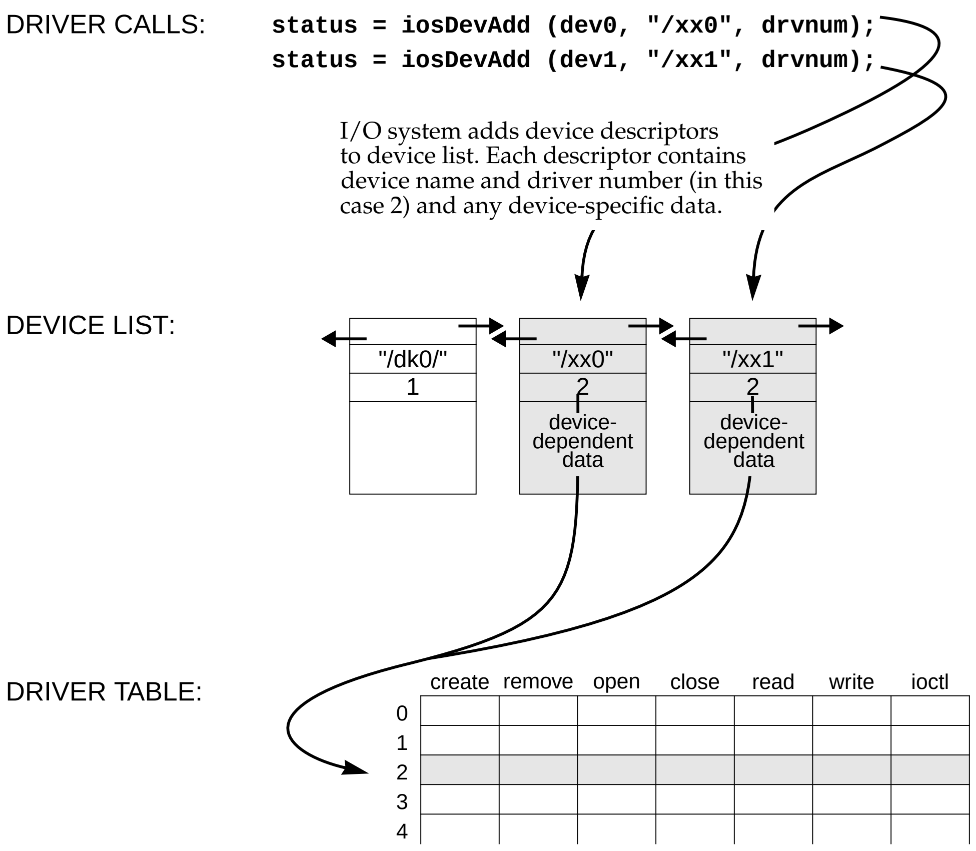
Non-block devices are added to the I/O system dynamically by calling the internal I/O routine ***iosDevAdd( )***. The arguments to ***iosDevAdd( )*** are the address of the device descriptor for the new device, the device's name, and the driver number of the driver that services the device. The device descriptor specified by the driver can contain any necessary device-dependent information, as long as it begins with a device header. The driver does not need to fill in the device header, only the device-dependent information. The ***iosDevAdd( )*** routine enters the specified device name and the driver number in the device header and adds it to the system device list.

To add a block device to the I/O system, call the device initialization routine for the file system required on that device (***dosFsDevInit( )***, ***rt11FsDevInit( )***, or ***rawFsDevInit( )***). The device initialization routine then calls ***iosDevAdd( )*** automatically.

Example of Adding Devices

In Figure 3-3, the example driver's device creation routine ***xxDevCreate*( )** adds devices to the I/O system by calling ***iosDevAdd*( )**.

Figure 3-3 **Example – Addition of Devices to I/O System**


DRIVER CALLS:
status = iosDevAdd (dev0, "/xx0", drvnum);
status = iosDevAdd (dev1, "/xx1", drvnum);
I/O system adds device descriptors to device list. Each descriptor contains device name and driver number (in this case 2) and any device-specific data.
DEVICE LIST:
"/dk0/"
1
"/xx0"
2
device-dependent data
"/xx1"
2
device-dependent data
DRIVER TABLE:
create
remove
open
close
read
write
ioctl
0
1
2
3
4

3.9.3 File Descriptors

Several *fd*s can be open to a single device at one time. A device driver can maintain additional information associated with an *fd* beyond the I/O system's device information. In particular, devices on which multiple files can be open at one time have file-specific information (for example, file offset) associated with each *fd*. You can also have several *fd*s open to a non-block device, such as a *tty*; typically there is no additional information, and thus writing on any of the *fd*s produces identical results.

The Fd Table

Files are opened with ***open*( )** (or ***creat*( )**). The I/O system searches the device list for a device name that matches the file name (or an initial substring) specified by the caller. If a match is found, the I/O system uses the driver number contained in the corresponding device header to locate and call the driver's open routine in the driver table.

The I/O system must establish an association between the file descriptor used by the caller in subsequent I/O calls, and the driver that services it. Additionally, the driver must associate some data structure per descriptor. In the case of non-block devices, this is usually the device descriptor that was located by the I/O system.

The I/O system maintains these associations in a table called the *fd table*. This table contains the driver number and an additional driver-determined 4-byte value. The driver value is the internal descriptor returned by the driver's open routine, and can be any nonnegative value the driver requires to identify the file. In subsequent calls to the driver's other I/O functions (***read*( )**, ***write*( )**, ***ioctl*( )**, and ***close*( )**), this value is supplied to the driver in place of the *fd* in the application-level I/O call.

Example of Opening a File

In Figure 3-4 and Figure 3-5, a user calls ***open*( )** to open the file **/*xx*0**. The I/O system takes the following series of actions:

[1] It searches the device list for a device name that matches the specified file name (or an initial substring). In this case, a complete device name matches.

[2] It reserves a slot in the *fd* table, which is used if the open is successful.

[3] It then looks up the address of the driver's open routine, *xx****Open*( )**, and calls that routine. Note that the arguments to *xx****Open*( )** are transformed by the I/O system from the user's original arguments to ***open*( )**. The first argument to *xx****Open*( )** is a pointer to the device descriptor the I/O system located in the full file name search. The next parameter is the *remainder* of the file name specified by the user, after removing the initial substring that matched the device name.

Figure 3-4 **Example: Call to I/O Routine *open*( )** [*Part 1*]

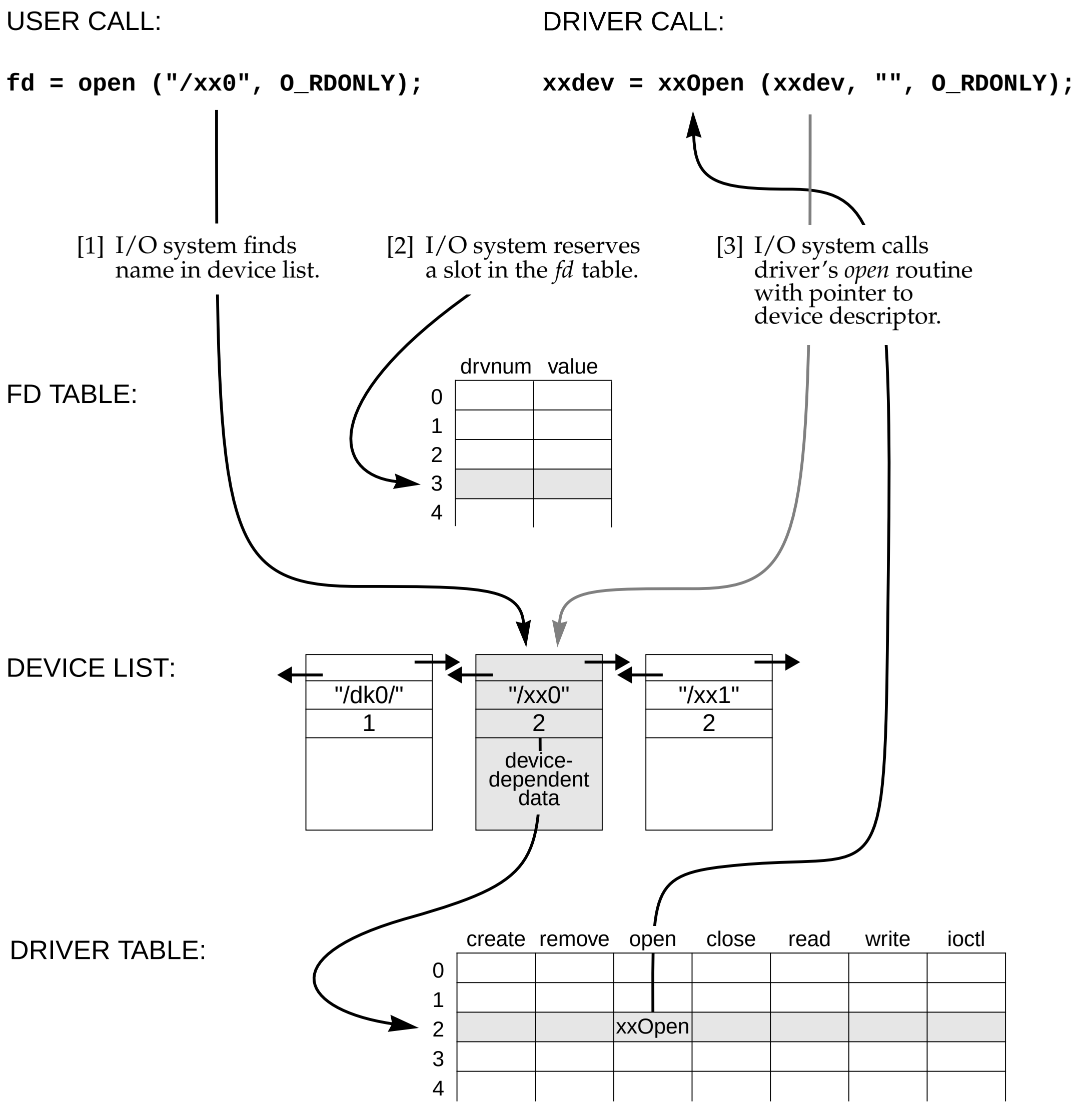
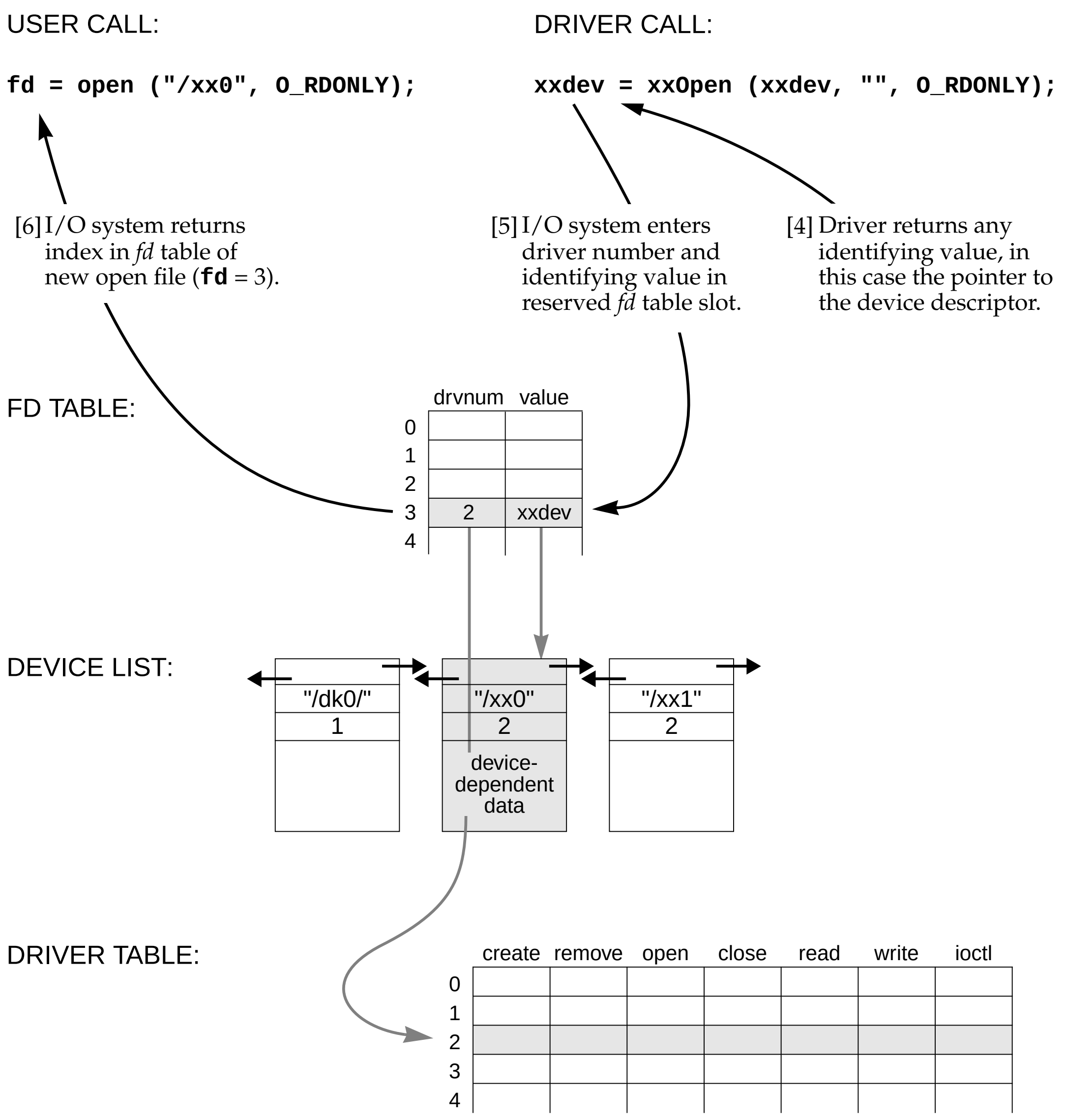

USER CALL:
fd = open ("/xx0", O_RDONLY);
DRIVER CALL:
xxdev = xxOpen (xxdev, "", O_RDONLY);
[1] I/O system finds name in device list.
[2] I/O system reserves a slot in the fd table.
[3] I/O system calls driver's open routine with pointer to device descriptor.
FD TABLE:
drvnum
value
0
1
2
3
4
DEVICE LIST:
"/dk0/"
1
"/xx0"
2
device-dependent data
"/xx1"
2
DRIVER TABLE:
create
remove
open
close
read
write
ioctl
0
1
2
xxOpen
3
4

Figure 3-5 **Example: Call to I/O Routine *open*( )** [*Part 2*]


USER CALL:
fd = open ("/xx0", O_RDONLY);
DRIVER CALL:
xxdev = xxOpen (xxdev, "", O_RDONLY);
[6] I/O system returns index in fd table of new open file (fd = 3).
[5] I/O system enters driver number and identifying value in reserved fd table slot.
[4] Driver returns any identifying value, in this case the pointer to the device descriptor.
FD TABLE:
drvnum
value
0
1
2
3
2
xxdev
4
DEVICE LIST:
"/dk0/"
1
"/xx0"
2
device-dependent data
"/xx1"
2
DRIVER TABLE:
create
remove
open
close
read
write
ioctl
0
1
2
3
4

In this case, because the device name matched the entire file name, the remainder passed to the driver is a null string. The driver is free to interpret this remainder in any way it wants. In the case of block devices, this remainder is the name of a file on the device. In the case of non-block devices like this one, it is usually an error for the remainder to be anything *but* the null string. The last parameter is the file access flag, in this case **O_RDONLY**; that is, the file is opened for reading only.

[4] It executes *xx**Open*****( )**, which returns a value that subsequently identifies the newly opened file. In this case, the value is the pointer to the device descriptor. This value is supplied to the driver in subsequent I/O calls that refer to the file being opened. Note that if the driver returns only the device descriptor, the driver cannot distinguish multiple files opened to the same device. In the case of non-block device drivers, this is usually appropriate.

[5] The I/O system then enters the driver number and the value returned by *xx**Open*****( )** in the reserved slot in the *fd* table. Again, the value entered in the *fd* table has meaning only for the driver, and is arbitrary as far as the I/O system is concerned.

[6] Finally, it returns to the user the index of the slot in the *fd* table, in this case 3.

Example of Reading Data from the File

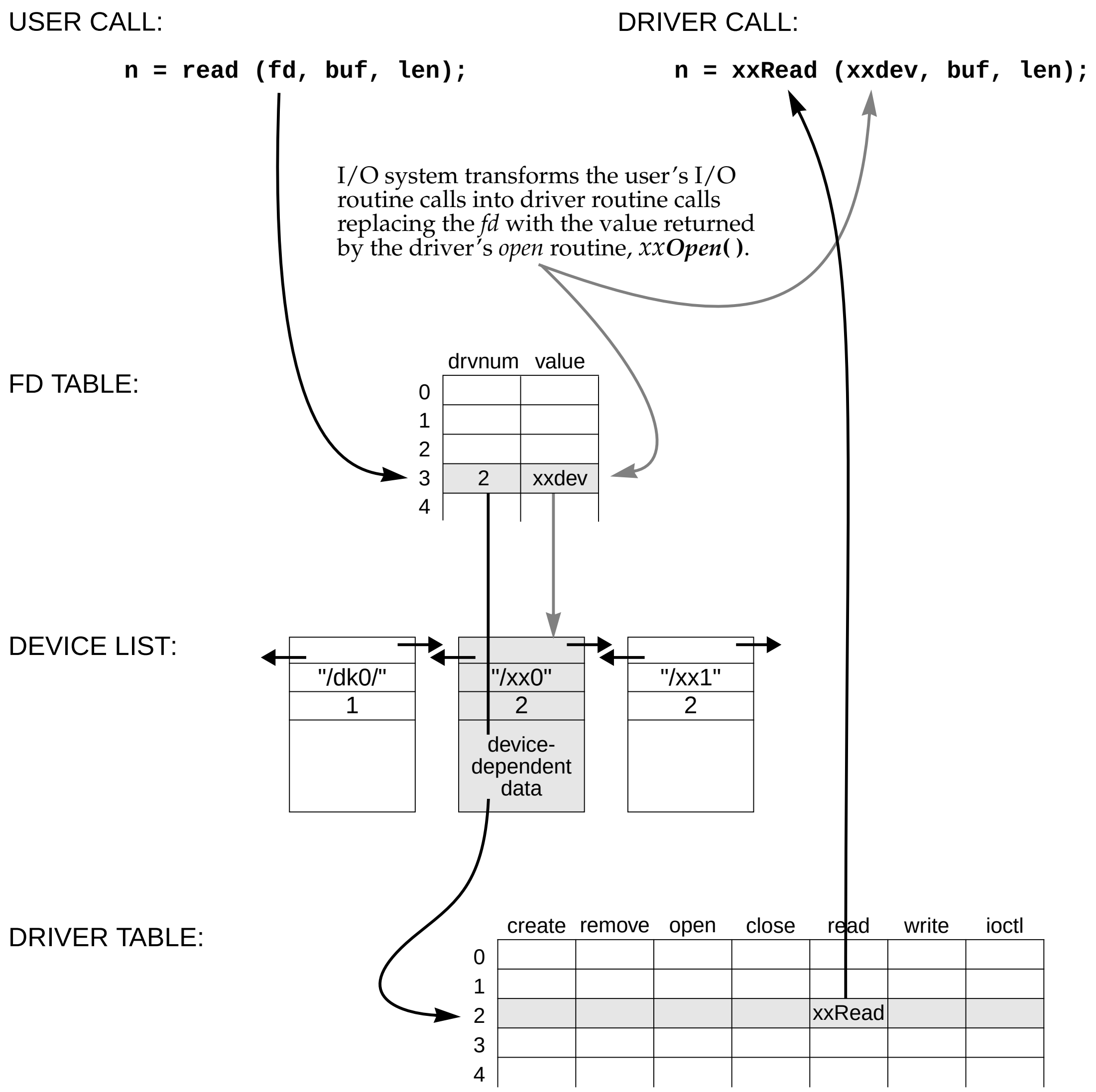
In Figure 3-6, the user calls ***read*( )** to obtain input data from the file. The specified *fd* is the index into the *fd* table for this file. The I/O system uses the driver number contained in the table to locate the driver's read routine, *xx**Read*****( )**. The I/O system calls *xx**Read*****( )**, passing it the identifying value in the *fd* table that was returned by the driver's open routine, *xx**Open*****( )**. Again, in this case the value is the pointer to the device descriptor. The driver's read routine then does whatever is necessary to read data from the device.

The process for user calls to ***write*( )** and ***ioctl*( )** follow the same procedure.

Example of Closing a File

The user terminates the use of a file by calling ***close*( )**. As in the case of ***read*( )**, the I/O system uses the driver number contained in the *fd* table to locate the driver's close routine. In the example driver, no close routine is specified; thus no driver routines are called. Instead, the I/O system marks the slot in the *fd* table as being available. Any subsequent references to that *fd* cause an error. However, subsequent calls to ***open*( )** can reuse that slot.

Figure 3-6 **Example: Call to I/O Routine *read*( )**



Implementing ***select( )***

Supporting ***select( )*** in your driver allows tasks to wait for input from multiple devices or to specify a maximum time to wait for the device to become ready for I/O. Writing a driver that supports ***select( )*** is simple, because most of the functionality is provided in **selectLib**. You might want your driver to support ***select( )*** if any of the following is appropriate for the device:

- The tasks want to specify a timeout to wait for I/O from the device. For example, a task might want to time out on a UDP socket if the packet never arrives.
- The driver supports multiple devices, and the tasks want to wait simultaneously for any number of them. For example, multiple pipes might be used for different data priorities.
- The tasks want to wait for I/O from the device while also waiting for I/O from another device. For example, a server task might use both pipes and sockets.

To implement ***select( )***, the driver must keep a list of tasks waiting for device activity. When the device becomes ready, the driver unblocks all the tasks waiting on the device.

For a device driver to support ***select( )***, it must declare a **SEL_WAKEUP_LIST** structure (typically declared as part of the device descriptor structure) and initialize it by calling ***selWakeupListInit( )***. This is done in the driver's ***xxDevCreate( )*** routine. When a task calls ***select( )***, **selectLib** calls the driver's ***ioctl( )*** routine with the function **FIOSELECT** or **FIOUNSELECT**. If ***ioctl( )*** is called with **FIOSELECT,** the driver must do the following:

1. Add the **SEL_WAKEUP_NODE** (provided as the third argument of ***ioctl( )***) to the **SEL_WAKEUP_LIST** by calling ***selNodeAdd( )***.
2. Use the routine ***selWakeupType( )*** to check whether the task is waiting for data to read from the device (**SELREAD**) or if the device is ready to be written (**SELWRITE**).
3. If the device is ready (for reading or writing as determined by ***selWakeupType( )***), the driver calls the routine ***selWakeup( )*** to make sure that the ***select( )*** call in the task does not pend. This avoids the situation where the task is blocked but the device is ready.

If ***ioctl( )*** is called with **FIOUNSELECT**, the driver calls ***selNodeDelete( )*** to remove the provided **SEL_WAKEUP_NODE** from the wakeup list.

When the device becomes available, ***selWakeupAll( )*** is used to unblock all the tasks waiting on this device. Although this typically occurs in the driver's ISR, it can also occur elsewhere. For example, a pipe driver might call ***selWakeupAll*( )** from its *xx**Read*( )** routine to unblock all the tasks waiting to write, now that there is room in the pipe to store the data. Similarly the pipe's *xx**Write*( )** routine might call ***selWakeupAll*( )** to unblock all the tasks waiting to read, now that there is data in the pipe.

Example 3-10 **Driver Code Using the Select Facility**

```
/* This code fragment shows how a driver might support select(). In this
 * example, the driver unblocks tasks waiting for the device to become ready
 * in its interrupt service routine.
 */

/* myDrvLib.h - header file for driver */

typedef struct     /* MY_DEV */
    {
    DEV_HDR     devHdr;                  /* device header */
    BOOL       myDrvDataAvailable;      /* data is available to read */
    BOOL       myDrvRdyForWriting;      /* device is ready to write */
    SEL_WAKEUP_LIST selWakeupList;      /* list of tasks pended in select */
    } MY_DEV;
```

```
/* myDrv.c - code fragments for supporting select() in a driver */

#include "vxWorks.h"
#include "selectLib.h"

/* First create and initialize the device */

STATUS myDrvDevCreate
    (
    char *  name,                       /* name of device to create */
    )
    {
    MY_DEV * pMyDrvDev;                 /* pointer to device descriptor*/
    ... additional driver code ...

    /* allocate memory for MY_DEV */
    pMyDrvDev = (MY_DEV *) malloc (sizeof MY_DEV);
    ... additional driver code ...

    /* initialize MY_DEV */
    pMyDrvDev->myDrvDataAvailable=FALSE
    pMyDrvDev->myDrvRdyForWriting=FALSE

    /* initialize wakeup list */
    selWakeupListInit (&pMyDrvDev->selWakeupList);
    ... additional driver code ...
    }
```

```
/* ioctl function to request reading or writing */

STATUS myDrvIoctl
    (
    MY_DEV * pMyDrvDev,                /* pointer to device descriptor */
    int      request,                  /* ioctl function */
    int      arg                       /* where to send answer */
    )
    {
    ... additional driver code ...

    switch (request)
        {
        ... additional driver code ...

        case FIOSELECT:

            /* add node to wakeup list */

            selNodeAdd (&pMyDrvDev->selWakeupList, (SEL_WAKEUP_NODE *) arg);

            if (selWakeupType ((SEL_WAKEUP_NODE *) arg) == SELREAD
                && pMyDrvDev->myDrvDataAvailable)
                {
                /* data available, make sure task does not pend */
                selWakeup ((SEL_WAKEUP_NODE *) arg);
                }
            if (selWakeupType ((SEL_WAKEUP_NODE *) arg) == SELWRITE
                && pMyDrvDev->myDrvRdyForWriting)
                {
                /* device ready for writing, make sure task does not pend */
                selWakeup ((SEL_WAKEUP_NODE *) arg);
                }
            break;

        case FIOUNSELECT:

            /* delete node from wakeup list */
            selNodeDelete (&pMyDrvDev->selWakeupList, (SEL_WAKEUP_NODE *) arg);
            break;

            ... additional driver code ...
        }
    }

/* code that actually uses the select() function to read or write */

void myDrvIsr
    (
    MY_DEV * pMyDrvDev;
    )
    {
    ... additional driver code ...

    /* if there is data available to read, wake up all pending tasks */
    if (pMyDrvDev->myDrvDataAvailable)
        selWakeupAll (&pMyDrvDev->selWakeupList, SELREAD);

    /* if the device is ready to write, wake up all pending tasks */

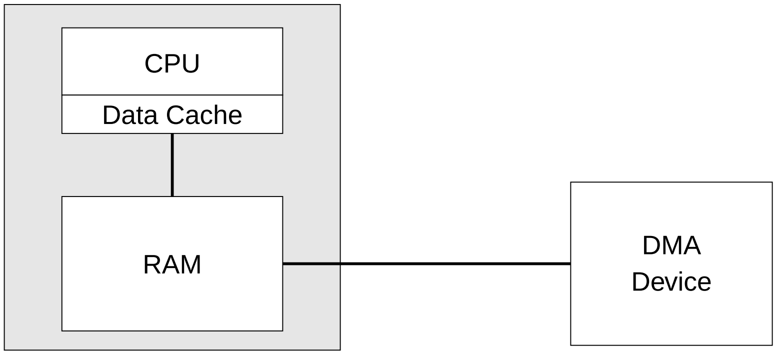
    if (pMyDrvDev->myDrvRdyForWriting)
        selWakeupAll (&pMyDrvDev->selWakeupList, SELWRITE);
    }
```

Cache Coherency

Drivers written for boards with caches must guarantee *cache coherency*. Cache coherency means data in the cache must be in sync, or coherent, with data in RAM. The data cache and RAM can get out of sync any time there is asynchronous access to RAM (for example, DMA device access or VMEbus access). Data caches are used to increase performance by reducing the number of memory accesses. Figure 3-7 shows the relationships between the CPU, data cache, RAM, and a DMA device.

Data caches can operate in one of two modes: *writethrough* and *copyback*. Write-through mode writes data to both the cache and RAM; this guarantees cache coherency on output but not input. Copyback mode writes the data only to the cache; this makes cache coherency an issue for both input and output of data.

Figure 3-7 **Cache Coherency**



If a CPU writes data to RAM that is destined for a DMA device, the data can first be written to the data cache. When the DMA device transfers the data from RAM, there is no guarantee that the data in RAM was updated with the data in the cache. Thus, the data output to the device may not be the most recent—the new data may still be sitting in the cache. This data incoherency can be solved by making sure the data cache is flushed to RAM before the data is transferred to the DMA device.

If a CPU reads data from RAM that originated from a DMA device, the data read can be from the cache buffer (if the cache buffer for this data is not marked invalid) and not the data just transferred from the device to RAM. The solution to this data incoherency is to make sure that the cache buffer is marked invalid so that the data is read from RAM and not from the cache.

Drivers can solve the cache coherency problem either by allocating cache-safe buffers (buffers that are marked non-cacheable) or flushing and invalidating cache entries any time the data is written to or read from the device. Allocating cache-safe buffers is useful for static buffers; however, this typically requires MMU support. Non-cacheable buffers that are allocated and freed frequently (dynamic buffers) can result in large amounts of memory being marked non-cacheable. An alternative to using non-cacheable buffers is to flush and invalidate cache entries manually; this allows dynamic buffers to be kept coherent.

The routines ***cacheFlush*( )** and ***cacheInvalidate*( )** are used to manually flush and invalidate cache buffers. Before a device reads the data, flush the data from the cache to RAM using ***cacheFlush*( )** to ensure the device reads current data. After the device has written the data into RAM, invalidate the cache entry with ***cacheInvalidate*( )**. This guarantees that when the data is read by the CPU, the cache is updated with the new data in RAM.

Example 3-11 **DMA Transfer Routine**

```
/* This a sample DMA transfer routine. Before programming the device to
 * output the data to the device, it flushes the cache by calling
 * cacheFlush(). On a read, after the device has transferred the data, the
 * cache entry must be invalidated using cacheInvalidate().
 */

#include "vxWorks.h"
#include "cacheLib.h"
#include "fcntl.h"
#include "example.h"
void exampleDmaTransfer   /* 1 = READ, 0 = WRITE */
    (
    UINT8 *pExampleBuf,
    int exampleBufLen,
    int xferDirection
    )
    {
    if (xferDirection == 1)
        {
        myDevToBuf (pExampleBuf);
        cacheInvalidate (DATA_CACHE, pExampleBuf, exampleBufLen);
        }
    else
        {
        cacheFlush (DATA_CACHE, pExampleBuf, exampleBufLen);
        myBufToDev (pExampleBuf);
        }
    }
```

It is possible to make a driver more efficient by combining cache-safe buffer allocation and cache-entry flushing or invalidation. The idea is to flush or invalidate a cache entry only when absolutely necessary. To address issues of cache coherency for static buffers, use ***cacheDmaMalloc*( )**. This routine initializes a **CACHE_FUNCS** structure (defined in **cacheLib.h**) to point to flush and invalidate routines that can be used to keep the cache coherent. The macros **CACHE_DMA_FLUSH** and **CACHE_DMA_INVALIDATE** use this structure to optimize the calling of the flush and invalidate routines. If the corresponding function pointer in the **CACHE_FUNCS** structure is **NULL**, no unnecessary flush/invalidate routines are called because it is assumed that the buffer is cache coherent (hence it is not necessary to flush/invalidate the cache entry manually).

Some architectures allow the virtual address to be different from the physical address seen by the device; see *7.3 Virtual Memory Configuration*, p.290 in this manual. In this situation, the driver code uses a virtual address and the device uses a physical address. Whenever a device is given an address, it must be a physical address. Whenever the driver accesses the memory, it uses the virtual address. The driver translates the address using the following macros: **CACHE_DMA_PHYS_TO_VIRT** (to translate a physical address to a virtual one) and **CACHE_DMA_VIRT_TO_PHYS** (to translate a virtual address to a physical one).

Example 3-12 **Address-Translation Driver**

```
/* The following code is an example of a driver that performs address
 * translations. It attempts to allocate a cache-safe buffer, fill it, and
 * then write it out to the device. It uses CACHE_DMA_FLUSH to make sure
 * the data is current. The driver then reads in new data and uses
 * CACHE_DMA_INVALIDATE to guarantee cache coherency.
 */

#include "vxWorks.h"
#include "cacheLib.h"
#include "myExample.h"
STATUS myDmaExample (void)
    {
    void * pMyBuf;
    void * pPhysAddr;

    /* allocate cache safe buffers if possible */

    if ((pMyBuf = cacheDmaMalloc (MY_BUF_SIZE)) == NULL)
    return (ERROR);
    … fill buffer with useful information …

    /* flush cache entry before data is written to device */

    CACHE_DMA_FLUSH (pMyBuf, MY_BUF_SIZE);

    /* convert virtual address to physical */

    pPhysAddr = CACHE_DMA_VIRT_TO_PHYS (pMyBuf);

    /* program device to read data from RAM */

    myBufToDev (pPhysAddr);
    … wait for DMA to complete …
    … ready to read new data …

    /* program device to write data to RAM */

    myDevToBuf (pPhysAddr);
    … wait for transfer to complete …

    /* convert physical to virtual address */

    pMyBuf = CACHE_DMA_PHYS_TO_VIRT (pPhysAddr);

    /* invalidate buffer */

    CACHE_DMA_INVALIDATE (pMyBuf, MY_BUF_SIZE);
    … use data …

    /* when done free memory */

    if (cacheDmaFree (pMyBuf) == ERROR)
        return (ERROR);

    return (OK);
    }
```

3.9.4 Block Devices

General Implementation

In VxWorks, block devices have a slightly different interface than other I/O devices. Rather than interacting directly with the I/O system, block device drivers interact with a file system. The file system, in turn, interacts with the I/O system. Direct access block devices have been supported since SCSI-1 and are used compatibly with dosFs, rt11Fs, and rawFs. In addition, VxWorks supports SCSI-2 sequential devices, which are organized so individual blocks of data are read and written sequentially. When data blocks are written, they are added sequentially at the end of the written medium; that is, data blocks cannot be replaced in the middle of the medium. However, data blocks can be accessed individually for reading throughout the medium. This process of accessing data on a sequential medium differs from that of other block devices.

Figure 3-8 **Non-Block Devices vs. Block Devices**

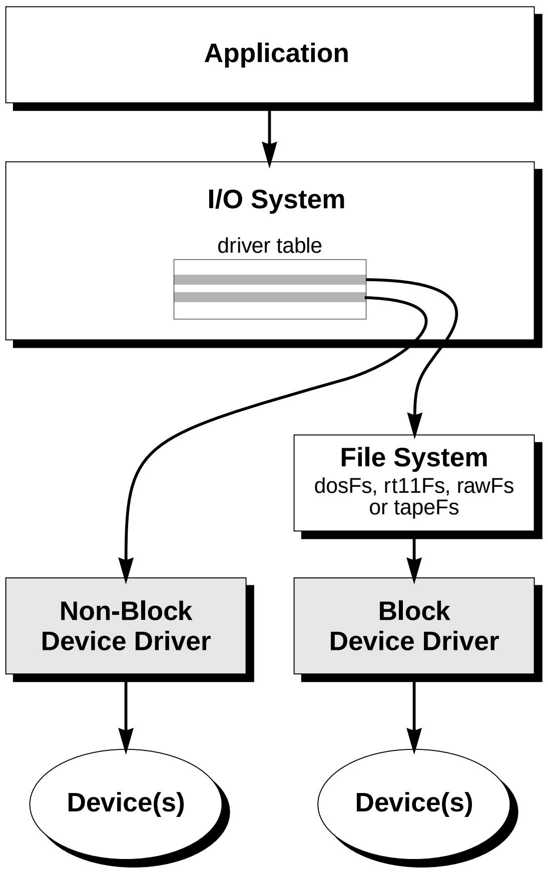


Figure 3-8 shows a layered model of I/O for both block and non-block (character) devices. This layered arrangement allows the same block device driver to be used with different file systems, and reduces the number of I/O functions that must be supported in the driver.

A device driver for a block device must provide a means for creating a logical block device structure, a **BLK_DEV** for direct access block devices or a **SEQ_DEV** for sequential block devices. The **BLK_DEV**/**SEQ_DEV** structure describes the device in a generic fashion, specifying only those common characteristics that must be known to a file system being used with the device. Fields within the structures specify various physical configuration variables for the device—for example, block size, or total number of blocks. Other fields in the structures specify routines within the device driver that are to be used for manipulating the device (reading blocks, writing blocks, doing I/O control functions, resetting the device, and checking device status). The **BLK_DEV**/**SEQ_DEV** structures also contain fields used by the driver to indicate certain conditions (for example, a disk change) to the file system.

When the driver creates the block device, the device has no name or file system associated with it. These are assigned during the device initialization routine for the chosen file system (for example, ***dosFsDevInit*( )**, ***rt11FsDevInit*( )** or ***tapeFsDevInit*( )**).

The low-level device driver for a block device is not installed in the I/O system driver table, unlike non-block device drivers. Instead, each file system in the VxWorks system is installed in the driver table as a "driver." Each file system has only one entry in the table, even though several different low-level device drivers can have devices served by that file system.

After a device is initialized for use with a particular file system, all I/O operations for the device are routed through that file system. To perform specific device operations, the file system in turn calls the routines in the specified **BLK_DEV** or **SEQ_DEV** structure.

A driver for a block device must provide the interface between the device and VxWorks. There is a specific set of functions required by VxWorks; individual devices vary based on what additional functions must be provided. The user manual for the device being used, as well as any other drivers for the device, is invaluable in creating the VxWorks driver. The following sections describe the components necessary to build low-level block device drivers that adhere to the standard interface for VxWorks file systems.

Low-Level Driver Initialization Routine

The driver normally requires a general initialization routine. This routine performs all operations that are done one time only, as opposed to operations that must be performed for each device served by the driver. As a general guideline, the operations in the initialization routine affect the whole device controller, while later operations affect only specific devices.

Common operations in block device driver initialization routines include:

– initializing hardware
– allocating and initializing data structures
– creating semaphores
– initializing interrupt vectors
– enabling interrupts

The operations performed in the initialization routine are entirely specific to the device (controller) being used; VxWorks has no requirements for a driver initialization routine.

Unlike non-block device drivers, the driver initialization routine does not call ***iosDrvInstall( )*** to install the driver in the I/O system driver table. Instead, the file system installs itself as a "driver" and routes calls to the actual driver using the routine addresses placed in the block device structure, **BLK_DEV** or **SEQ_DEV** (see *Device Creation Routine*, p.161).

Device Creation Routine

The driver must provide a routine to create (define) a logical disk or sequential device. A logical disk device may be only a portion of a larger physical device. If this is the case, the device driver must keep track of any block offset values or other means of identifying the physical area corresponding to the logical device. VxWorks file systems always use block numbers beginning with zero for the start of a device. A sequential access device can be either of variable block size or fixed block size. Most applications use devices of fixed block size.

The device creation routine generally allocates a device descriptor structure that the driver uses to manage the device. The first item in this device descriptor must be a VxWorks block device structure (**BLK_DEV** or **SEQ_DEV**). It must appear first because its address is passed by the file system during calls to the driver; having the **BLK_DEV** or **SEQ_DEV** as the first item permits also using this address to identify the device descriptor.

The device creation routine must initialize the fields within the **BLK_DEV** or **SEQ_DEV** structure. The **BLK_DEV** fields and their initialization values are shown in Table 3-14. The **SEQ_DEV** fields and their initialization values are shown in Table 3-15.

Table 3-14 **Fields in the BLK_DEV Structure**

Field	Value
bd_blkRd	Address of the driver routine that reads blocks from the device.
bd_blkWrt	Address of the driver routine that writes blocks to the device.
bd_ioctl	Address of the driver routine that performs device I/O control.
bd_reset	Address of the driver routine that resets the device (**NULL** if none).
bd_statusChk	Address of the driver routine that checks disk status (**NULL** if none).
bd_removable	TRUE if the device is removable (for example, a floppy disk); FALSE otherwise.
bd_nBlocks	Total number of blocks on the device.
bd_bytesPerBlk	Number of bytes per block on the device.
bd_blksPerTrack	Number of blocks per track on the device.
bd_nHeads	Number of heads (surfaces).
bd_retry	Number of times to retry failed reads or writes.
bd_mode	Device mode (write-protect status); generally set to **O_RDWR**.
bd_readyChanged	TRUE if the device ready status has changed; initialize to TRUE to cause the disk to be mounted.

Table 3-15 **Fields in the SEQ_DEV Structure**

Field	Value
sd_seqRd	Address of the driver routine that reads blocks from the device.
sd_seqWrt	Address of the driver routine that writes blocks to the device.
sd_ioctl	Address of the driver routine that performs device I/O control.
sd_seqWrtFileMarks	Address of the driver routine that writes file marks to the device.
sd_rewind	Address of the driver routine that rewinds the sequential device.
sd_reserve	Address of the driver routine that reserves a sequential device.
sd_release	Address of the driver routine that releases a sequential device.

Table 3-15 **Fields in the SEQ_DEV Structure** *(Continued)*

Field	Value
sd_readBlkLim	Address of the driver routine that reads the data block limits from the sequential device.
sd_load	Address of the driver routine that either loads or unloads a sequential device.
sd_space	Address of the driver routine that moves (spaces) the medium forward or backward to end-of-file or end-of-record markers.
sd_erase	Address of the driver routine that erases a sequential device.
sd_reset	Address of the driver routine that resets the device (**NULL** if none).
sd_statusChk	Address of the driver routine that checks sequential device status (**NULL** if none).
sd_blkSize	Block size of sequential blocks for the device. A block size of 0 means that variable block sizes are used.
sd_mode	Device mode (write protect status).
sd_readyChanged	TRUE if the device ready status has changed; initialize to TRUE to cause the sequential device to be mounted.
sd_maxVarBlockLimit	Maximum block size for a variable block.
sd_density	Density of sequential access media.

The device creation routine returns the address of the **BLK_DEV** or **SEQ_DEV** structure. This address is then passed during the file system device initialization call to identify the device.

Unlike non-block device drivers, the device creation routine for a block device does not call ***iosDevAdd*( )** to install the device in the I/O system device table. Instead, this is done by the file system's device initialization routine.

Read Routine (Direct-Access Devices)

The driver must supply a routine to read one or more blocks from the device. For a direct access device, the read-blocks routine must have the following arguments and result:

```
STATUS xxBlkRd
    (
    DEVICE *  pDev,        /* pointer to device descriptor */
    int       startBlk,    /* starting block to read */
    int       numBlks,     /* number of blocks to read */
    char *    pBuf         /* pointer to buffer to receive data */
    )
```

NOTE: In this and following examples, the routine names begin with *xx*. These names are for illustration only, and do not have to be used by your device driver. VxWorks references the routines by address only; the name can be anything.

pDev	a pointer to the driver's device descriptor structure, represented here by the symbolic name **DEVICE**. (Actually, the file system passes the address of the corresponding **BLK_DEV** structure; these are equivalent, because the **BLK_DEV** is the first item in the device descriptor.) This identifies the device.
startBlk	the starting block number to be read from the device. The file system always uses block numbers beginning with zero for the start of the device. Any offset value used for this logical device must be added in by the driver.
numBlks	the number of blocks to be read. If the underlying device hardware does not support multiple-block reads, the driver routine must do the necessary looping to emulate this ability.
pBuf	the address where data read from the disk is to be copied.

The read routine returns **OK** if the transfer is successful, or **ERROR** if a problem occurs.

Read Routine (Sequential Devices)

The driver must supply a routine to read a specified number of bytes from the device. The bytes being read are always assumed to be read from the current location of the read/write head on the media. The read routine must have the following arguments and result:

```
STATUS xxSeqRd
    (
    DEVICE *  pDev,         /* pointer to device descriptor */
    int       numBytes,     /* number of bytes to read */
    char *    buffer,       /* pointer to buffer to receive data */
    BOOL      fixed         /* TRUE => fixed block size */
    )
```

pDev	a pointer to the driver's device descriptor structure, represented here by the symbolic name **DEVICE**. (Actually, the file system passes the address of the corresponding **SEQ_DEV** structure; these are equivalent, because the **SEQ_DEV** structure is the first item in the device descriptor.) This identifies the device.
numBytes	the number of bytes to be read.
buffer	the buffer into which *numBytes* of data are read.
fixed	specifies whether the read routine reads fixed-sized blocks from the sequential device or variable-sized blocks, as specified by the file system. If *fixed* is TRUE, then fixed sized blocks are used.

The read routine returns **OK** if the transfer is completed successfully, or **ERROR** if a problem occurs.

Write Routine (Direct-Access Devices)

The driver must supply a routine to write one or more blocks to the device. The definition of this routine closely parallels that of the read routine. For direct-access devices, the write routine is as follows:

```
STATUS xxBlkWrt
    (
    DEVICE *  pDev,     /* pointer to device descriptor */
    int       startBlk, /* starting block for write */
    int       numBlks,  /* number of blocks to write */
    char *    pBuf      /* ptr to buffer of data to write */
    )
```

pDev	a pointer to the driver's device descriptor structure.
startBlk	the starting block number to be written to the device.
numBlks	the number of blocks to be written. If the underlying device hardware does not support multiple-block writes, the driver routine must do the necessary looping to emulate this ability.
pBuf	the address of the data to be written to the disk.

The write routine returns **OK** if the transfer is successful, or **ERROR** if a problem occurs.

Write Routine (Sequential Devices)

The driver must supply a routine to write a specified number of bytes to the device. The bytes being written are always assumed to be written to the current location of the read/write head on the media. For sequential devices, the write routine is as follows:

```
STATUS xxWrtTape
    (
    DEVICE *  pDev,       /* ptr to SCSI sequential device info */
    int       numBytes,   /* total bytes or blocks to be written */
    char *    buffer,     /* ptr to input data buffer      */
    BOOL      fixed       /* TRUE => fixed block size */
    )
```

pDev	a pointer to the driver's device descriptor structure.
numBytes	the number of bytes to be written.
buffer	the buffer from which *numBytes* of data are written.
fixed	specifies whether the write routine reads fixed-sized blocks from the sequential device or variable-sized blocks, as specified by the file system. If *fixed* is TRUE, then fixed sized blocks are used.

The write routine returns **OK** if the transfer is successful, or **ERROR** if a problem occurs.

I/O Control Routine

The driver must provide a routine that can handle I/O control requests. In VxWorks, most I/O operations beyond basic file handling are implemented through ***ioctl*( )** functions. The majority of these are handled directly by the file system. However, if the file system does not recognize a request, that request is passed to the driver's I/O control routine.

Define the driver's I/O control routine as follows:

```
STATUS xxIoctl
    (
    DEVICE *  pDev,       /* pointer to device descriptor */
    int        funcCode,  /* ioctl() function code */
    int        arg        /* function-specific argument */
    )
```

pDev	a pointer to the driver's device descriptor structure.

funcCode	the requested ***ioctl( )*** function. Standard VxWorks I/O control functions are defined in the include file **ioLib.h**. Other user-defined function code values can be used as required by your device driver. The I/O control functions supported by the dosFs, rt11Fs, rawFs, and tapeFs are summarized in *4. Local File Systems* in this manual.
arg	specific to the particular ***ioctl( )*** function requested. Not all ***ioctl( )*** functions use this argument.

The driver's I/O control routine typically takes the form of a multi-way switch statement, based on the function code. The driver's I/O control routine must supply a default case for function code requests it does not recognize. For such requests, the I/O control routine sets **errno** to **S_ioLib_UNKNOWN_REQUEST** and returns **ERROR**.

The driver's I/O control routine returns **OK** if it handled the request successfully; otherwise, it returns **ERROR**.

Device-Reset Routine

The driver usually supplies a routine to reset a specific device, but it is not required. This routine is called when a VxWorks file system first mounts a disk or tape, and again during retry operations when a read or write fails.

Declare the driver's device-reset routine as follows:

```
STATUS xxReset
    (
    DEVICE *  pDev
    )
```

pDev	a pointer to the driver's device descriptor structure.

When called, this routine resets the device and controller. Do not reset other devices, if it can be avoided. The routine returns **OK** if the driver succeeded in resetting the device; otherwise, it returns **ERROR**.

If no reset operation is required for the device, this routine can be omitted. In this case, the device-creation routine sets the *xx*_**reset** field in the **BLK_DEV** or **SEQ_DEV** structure to **NULL**.

NOTE: In this and following examples, the names of fields in the **BLK_DEV** and **SEQ_DEV** structures are parallel except for the initial letters **bd_** or **sd_**. In these cases, the initial letters are represented by *xx_*, as in the *xx*_**reset** field to represent both the **bd_reset** field and the **sd_reset** field.

Status-Check Routine

If the driver provides a routine to check device status or perform other preliminary operations, the file system calls this routine at the beginning of each ***open*( )** or ***creat*( )** on the device.

Define the status-check routine as follows:

```
STATUS xxStatusChk
    (
    DEVICE *  pDev    /* pointer to device descriptor */
    )
```

pDev a pointer to the driver's device descriptor structure.

The routine returns **OK** if the open or create operation can continue. If it detects a problem with the device, it sets **errno** to some value indicating the problem, and returns **ERROR**. If **ERROR** is returned, the file system does not continue the operation.

A primary use of the status-check routine is to check for a disk change on devices that do not detect the change until after a new disk is inserted. If the routine determines that a new disk is present, it sets the **bd_readyChanged** field in the **BLK_DEV** structure to TRUE and returns **OK** so that the open or create operation can continue. The new disk is then mounted automatically by the file system. (See *Change in Ready Status*, p.169.)

Similarly, the status check routine can be used to check for a tape change. This routine determines whether a new tape has been inserted. If a new tape is present, the routine sets the **sd_readyChanged** field in the **SEQ_DEV** structure to TRUE and returns **OK** so that the open or create operation can continue. The device driver should not be able to unload a tape, nor should you physically eject a tape, while a file descriptor is open on the tape device.

If the device driver requires no status-check routine, the device-creation routine sets the *xx*_**statusChk** field in the **BLK_DEV** or **SEQ_DEV** structure to **NULL**.

Write-Protected Media

The device driver may detect that the disk or tape in place is write-protected. If this is the case, the driver sets the *xx*_**mode** field in the **BLK_DEV** or **SEQ_DEV** structure to **O_RDONLY**. This can be done at any time (even after the device is initialized for use with the file system). The file system checks this value and does not allow writes to the device until the *xx*_**mode** field is changed (to **O_RDWR** or **O_WRONLY**) or the file system's mode change routine (for example,

***dosFsModeChange*( )**) is called to change the mode. (The *xx*_**mode** field is changed automatically if the file system's mode change routine is used.)

Change in Ready Status

The driver informs the file system whenever a change in the device's ready status is recognized. This can be the changing of a floppy disk, changing of the tape medium, or any other situation that makes it advisable for the file system to remount the disk.

To announce a change in ready status, the driver sets the *xx*_**readyChanged** field in the **BLK_DEV** or **SEQ_DEV** structure to TRUE. This is recognized by the file system, which remounts the disk during the next I/O initiated on the disk. The file system then sets the *xx*_**readyChanged** field to FALSE. The *xx*_**readyChanged** field is never cleared by the device driver.

Setting *xx*_**readyChanged** to TRUE has the same effect as calling the file system's ready-change routine (for example, ***dosFsReadyChange*( )**) or calling ***ioctl*( )** with the **FIODISKCHANGE** function code.

An optional status-check routine (see *Status-Check Routine*, p.168) can provide a convenient mechanism for asserting a ready-change, particularly for devices that cannot detect a disk change until after the new disk is inserted. If the status-check routine detects that a new disk is present, it sets *xx*_**readyChanged** to TRUE. This routine is called by the file system at the beginning of each open or create operation.

Write-File-Marks Routine (Sequential Devices)

The sequential driver must provide a routine that can write file marks onto the tape device. The write file marks routine must have the following arguments

```
STATUS xxWrtFileMarks
    (
    DEVICE *  pDev,       /* pointer to device descriptor */
    int       numMarks,   /* number of file marks to write */
    BOOL      shortMark   /* short or long file marks */
    )
```

pDev	a pointer to the driver's device descriptor structure.
numMarks	the number of file marks to be written sequentially.

shortMark	the type of file mark (short or long). If *shortMark is* TRUE, short marks are written.

The write file marks routine returns **OK** if the file marks are written correctly on the tape device; otherwise, it returns **ERROR**.

Rewind Routine (Sequential Devices)

The sequential driver must provide a rewind routine in order to rewind tapes in the tape device. The rewind routine is defined as follows:

```
STATUS xxRewind
    (
    DEVICE *  pDev  /* pointer to device descriptor */
    )
```

pDev	a pointer to the driver's device descriptor structure.

When called, this routine rewinds the tape in the tape device. The routine returns **OK** if completion is successful; otherwise, it returns **ERROR**.

Reserve Routine (Sequential Devices)

The sequential driver can provide a reserve routine that reserves the physical tape device for exclusive access by the host that is executing the reserve routine. The tape device remains reserved until it is released by that host, using a release routine, or by some external stimulus.

The reserve routine is defined as follows:

```
STATUS xxReserve
    (
    DEVICE *  pDev  /* pointer to device descriptor */
    )
```

pDev	a pointer to the driver's device descriptor structure.

If a tape device is reserved successfully, the reserve routine returns **OK**. However, if the tape device cannot be reserved or an error occurs, it returns **ERROR**.

Release Routine (Sequential Devices)

This routine releases the exclusive access that a host has on a tape device. The tape device is then free to be reserved again by the same host or some other host. This routine is the opposite of the reserve routine and must be provided by the driver if the reserve routine is provided.

The release routine is defined as follows:

```
STATUS xxReset
    (
    DEVICE *  pDev  /* pointer to device descriptor */
    )
```

pDev a pointer to the driver's device descriptor structure.

If the tape device is released successfully, this routine returns **OK**. However, if the tape device cannot be released or an error occurs, this routine returns **ERROR**.

Read-Block-Limits Routine (Sequential Devices)

The read-block-limits routine can poll a tape device for its physical block limits. These block limits are then passed back to the file system so the file system can decide the range of block sizes to be provided to a user.

The read-block-limits routine is defined as follows:

```
STATUS xxReadBlkLim
    (
    DEVICE *  pDev,         /* pointer to device descriptor */
    int      *maxBlkLimit,  /* maximum block size for device */
    int      *minBlkLimit   /* minimum block size for device */
    )
```

pDev a pointer to the driver's device descriptor structure.

maxBlkLimit
returns the maximum block size that the tape device can handle to the calling tape file system.

minBlkLimit
returns the minimum block size that the tape device can handle.

The routine returns **OK** if no error occurred while acquiring the block limits; otherwise, it returns **ERROR**.

Load/Unload Routine (Sequential Devices)

The sequential device driver must provide a load/unload routine in order to mount or unmount tape volumes from a physical tape device. Loading means that a volume is being mounted by the file system. This is usually done upon an ***open*()** or a ***creat*()**. However, a device should be unloaded or unmounted only when the file system wants to eject the tape volume from the tape device.

The load/unload routine is defined as follows:

```
STATUS xxLoad
    (
    DEVICE *  pDev,  /* pointer to device descriptor */
    BOOL      load   /* load or unload device */
    )
```

pDev a pointer to the driver's device descriptor structure.

load a boolean variable that determines if the tape is loaded or unloaded. If *load* is TRUE, the tape is loaded. If *load* is FALSE, the tape is unloaded.

The load/unload routine returns **OK** if the load or unload operation ends successfully; otherwise, it returns **ERROR**.

Space Routine (Sequential Devices)

The sequential device driver must provide a space routine that moves, or spaces, the tape medium forward or backward. The amount of distance that the tape spaces depends on the kind of search that must be performed. In general, tapes can be searched by end-of-record marks, end-of-file marks, or other types of device-specific markers.

The basic definition of the space routine is as follows; however, other arguments can be added to the definition:

```
STATUS xxSpace
    (
    DEVICE *  pDev,       /* pointer to device descriptor */
    int       count,      /* number of spaces */
    int       spaceCode   /* type of space */
    )
```

pDev a pointer to the driver's device descriptor structure.

count specifies the direction of search. A positive *count* value represents forward movement of the tape device from its current location (forward space); a negative *count* value represents a reverse movement (back space).

spaceCode defines the type of space mark that the tape device searches for on the tape medium. The basic types of space marks are end-of-record and end-of-file. However, different tape devices may support more sophisticated kinds of space marks designed for more efficient maneuvering of the medium by the tape device.

If the device is able to space in the specified direction by the specified count and space code, the routine returns **OK**; if these conditions cannot be met, it returns **ERROR**.

Erase Routine (Sequential Devices)

The sequential driver must provide a routine that allows a tape to be erased. The erase routine is defined as follows:

```
STATUS xxErase
    (
    DEVICE *  pDev  /* pointer to device descriptor */
    )
```

pDev	a pointer to the driver's device descriptor structure.

The routine returns **OK** if the tape is erased; otherwise, it returns **ERROR**.

3.9.5 Driver Support Libraries

The subroutine libraries in Table 3-16 may assist in the writing of device drivers. Using these libraries, drivers for most devices that follow standard protocols can be written with only a few pages of device-dependent code. See the reference entry for each library for details.

Table 3-16 **VxWorks Driver Support Routines**

Library	Description
errnoLib	Error status library
ftpLib	ARPA File Transfer Protocol library
ioLib	I/O interface library
iosLib	I/O system library
intLib	Interrupt support subroutine library
remLib	Remote command library
rngLib	Ring buffer subroutine library
ttyDrv	Terminal driver
wdLib	Watchdog timer subroutine library

4
Local File Systems

4.1 Introduction

This chapter discusses the organization, configuration, and use of VxWorks file systems. VxWorks provides two local file systems appropriate for real-time use with block devices (disks): one is compatible with MS-DOS file systems and the other with the RT-11 file system. The support libraries for these file systems are **dosFsLib** and **rt11FsLib**. VxWorks also provides a simple *raw file system*, which treats an entire disk much like a single large file. The support library for this "file system" is **rawFsLib**.

VxWorks also provides a file system for tape devices that do not use a standard file or directory structure on tape. The tape volume is treated much like a raw device where the entire volume is a large file. The support library for this file system is **tapeFsLib**. In addition, VxWorks provides a file system library, **cdromFsLib**, that allows applications to read data from CD-ROMs formatted according to the ISO 9660 standard file system.

In VxWorks, the file system is not tied to a specific type of block device or its driver. VxWorks block devices all use a standard interface so that file systems can be freely mixed with device drivers. Alternatively, you can write your own file systems that can be used by drivers in the same way, by following the same standard interfaces between the file system, the driver, and the I/O system. VxWorks I/O architecture makes it possible to have multiple file systems, even of different types, in a single VxWorks system. The block device interface is discussed in *3.9.4 Block Devices*, p. 158.

4.2 MS-DOS-Compatible File System: dosFs

Diskettes formatted using the dosFs file system are compatible with MS-DOS diskettes up to and including release 6.2. Hard disks initialized by the two file systems have slightly different formats. However, the data itself is compatible and dosFs can be configured to use a disk formatted by MS-DOS.

The dosFs file system offers considerable flexibility appropriate to the varying demands of real-time applications. Major features include:

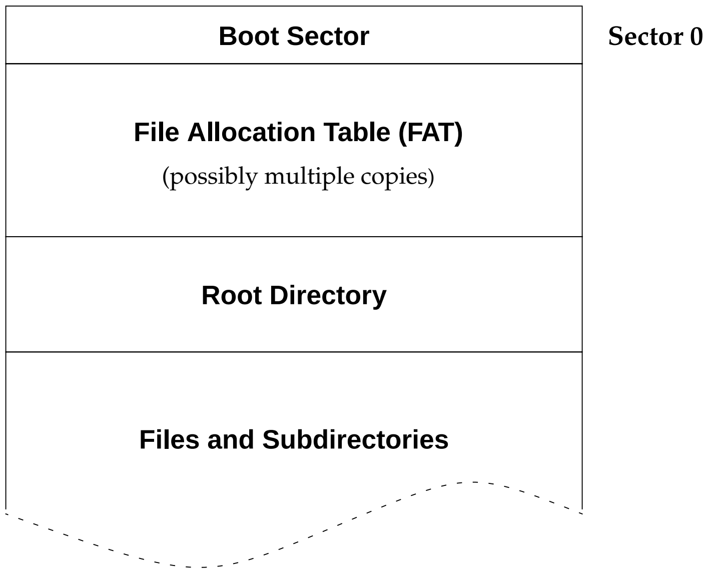
- A hierarchical arrangement of files and directories, allowing efficient organization and permitting an arbitrary number of files to be created on a volume.
- A choice of contiguous or non-contiguous files on a per-file basis. Non-contiguous files result in more efficient use of available disk space, while contiguous files offer enhanced performance.
- Compatibility with widely available storage and retrieval media. Diskettes created with VxWorks (that do not use dosFs extended filenames) and MS-DOS PCs and other systems can be freely interchanged. Hard disks are compatible if the partition table is accounted for.
- The ability to boot VxWorks from any local SCSI device that has a dosFs file system.
- The ability to use longer file names than the 8-character filename plus 3-character extension (8.3) convention allowed by MS-DOS.
- NFS (Network File System) support.

4.2.1 Disk Organization

The MS-DOS/dosFs file system provides the means for organizing disk data in a flexible manner. It maintains a hierarchical set of named directories, each containing files or other directories. Files can be appended; as they expand, new disk space is allocated automatically. The disk space allocated to a file is not necessarily contiguous, which results in a minimum of wasted space. However, to enhance its real-time performance, the dosFs file system allows contiguous space to be pre-allocated to files individually, thereby minimizing seek operations and providing more deterministic behavior.

The general organization of an MS-DOS/dosFs file system is shown in Figure 4-1 and the various elements are discussed in the following sections.

Figure 4-1 **MS-DOS Disk Organization**



NOTE: If the number of reserved sectors (**dosvc_nResrvd**) is greater than 1, the first FAT copy does not immediately follow the boot sector.

Clusters

The disk space allocated to a file in an MS-DOS/dosFs file system consists of one or more disk *clusters*. A cluster is a set of contiguous disk sectors.[1] For floppy disks, two sectors generally make up a cluster; for fixed disks, there can be more sectors per cluster. A cluster is the smallest amount of disk space the file system can allocate at a time. A large number of sectors per cluster allows a larger disk to be described in a fixed-size File Allocation Table (FAT; see *File Allocation Table*, p. 178), but can result in wasted disk space.

1. In this and subsequent sections covering the dosFs file system, the term *sector* refers to the minimum addressable unit on a disk, because this is the term used by most MS-DOS documentation. In VxWorks, the units are normally referred to as *blocks*, and a disk device is called a *block device*.

Boot Sector

The first sector on an MS-DOS/dosFs hard disk or diskette is called the *boot sector*. This sector contains a variety of configuration data. Some of the data fields describe the physical properties of the disk (such as the total number of sectors), and other fields describe file system variables (such as the size of the root directory).

The boot sector information is written to a disk when it is initialized. The dosFs file system can use diskettes that are initialized on another system (for example, using the **FORMAT** utility on an MS-DOS PC), or VxWorks can initialize the diskette, using the **FIODISKINIT** function of the ***ioctl*( )** call.

As the MS-DOS standard has evolved, various fields have been added to the boot sector definition. Disks initialized under VxWorks use the boot sector fields defined by MS-DOS version 5.0.

When MS-DOS initializes a hard disk, it writes a *partition table* in addition to the boot sector. VxWorks does not create such a table. Therefore hard disks initialized by the two systems are not identical. VxWorks can read files from a disk formatted by MS-DOS if the block offset parameter in the device creation routine points beyond the partition table to the first byte of the data area.

File Allocation Table

Each MS-DOS/dosFs volume contains a File Allocation Table (FAT). The FAT contains an entry for each cluster on the disk that can be allocated to a file or directory. When a cluster is unused (available for allocation), its entry is zero. If a cluster is allocated to a file, its entry is the cluster number of the next portion of the file. If a cluster is the last in a file, its entry is -1. Thus, the representation of a file (or directory) consists of a linked list of FAT entries. In the example shown in Figure 4-2, one file consists of clusters 2, 300, and 500. Cluster 3 is unused.

NOTE: dosFs does not map bad disk sectors to the FAT.

The FAT uses either 12 or 16 bits per entry. Disk volumes that contain up to 4085 clusters use 12-bit entries; disks with more than 4085 clusters use 16-bit entries. The entries (particularly 12-bit entries) are encoded in a specific manner, done originally to take advantage of the Intel 8088 architecture. However, all FAT handling is done by the dosFs file system; thus the encoding and decoding is of no concern to VxWorks applications.

Figure 4-2 **FAT Entries**

cluster	FAT
0	
1	
2	300
3	0
⋮	⋮
300	500
⋮	⋮
500	-1

A volume typically contains multiple copies of the FAT. This redundancy allows data recovery in the event of a media error in the first FAT copy.

CAUTION: The dosFs file system maintains multiple FAT copies if that is the specified configuration; however, the copies are not automatically used in the event of an error.

The size of the FAT and the number of FAT copies are determined by fields in the boot sector. For disks initialized using the dosFs file system, these parameters are specified during the ***dosFsDevInit*( )** call by setting fields in the volume configuration structure, **DOS_VOL_CONFIG**.

Root Directory

Each MS-DOS/dosFs volume contains a root directory. The root directory always occupies a set of contiguous disk sectors immediately following the FAT copies. The disk area occupied by the root directory is not described by entries in the FAT.

The root directory is of a fixed size; this size is specified by a field in the boot sector as the maximum allowed number of directory entries. For disks initialized using the dosFs file system, this size is specified during the ***dosFsDevInit*( )** call, by setting a field in the volume configuration structure, **DOS_VOL_CONFIG**.

Because the root directory has a fixed size, an error is returned if the directory is full and an attempt is made to add entries to it.

For more information on the contents of the directory entry, see *4.2.13 Directory Entries*, p.192.

Subdirectories

In addition to the root directory, MS-DOS/dosFs volumes sometimes contain a hierarchy of subdirectories. Like the root directory, subdirectories contain entries for files and other subdirectories; however, in other ways they differ from the root directory and resemble files:

- First, each subdirectory is described by an entry in another directory, as is a file. Such a directory entry has a bit set in the file-attribute byte to indicate that it describes a subdirectory. Also, subdirectories, unlike the root directory, have user-assigned names.
- Second, the disk space allocated to a subdirectory is composed of a set of disk clusters, linked by FAT entries. This means that a subdirectory can grow as entries are added to it, and that the subdirectory is not necessarily made up of contiguous clusters. The root directory, unlike subdirectories, can be made up of any number of sectors, not necessarily equal to a whole number of clusters.
- Third, subdirectories always contain two special entries. The "**.**" entry refers to the subdirectory itself, while the "**..**" entry refers to the subdirectory's parent directory. The root directory does not contain these special entries.

Files

The disk space allocated to a file in the MS-DOS/dosFs file system is a set of clusters that are chained together through entries in the FAT. A file is not necessarily made up of contiguous clusters; the various clusters can be located anywhere on the disk and in any order.

Each file has a descriptive entry in the directory where it resides. This entry contains the file's name, size, last modification date and time, and a field giving several important attributes (read-only, system, hidden, modified since last archived). It also contains the starting cluster number for the file; subsequent clusters are located using the FAT.

Volume Label

An MS-DOS/dosFs disk can have a *volume label* associated with it. The volume label is a special entry in the root directory. Rather than containing the name of a file or subdirectory, the volume label entry contains a string used to identify the volume. This string can contain up to 11 characters. The volume label entry is identified by a special value of the file-attribute byte in the directory entry.

Note that a volume label entry is not reported using ***ls( )***. However, it does occupy one of the fixed number of entries in the root directory.

The volume label can be added to a dosFs volume by using the ***ioctl( )*** call with the **FIOLABELSET** function. This adds a label entry to the volume's root directory if none exists or changes the label string in an existing volume label entry. The volume label entry takes up one of the fixed number of root directory entries; attempting to add an entry when the root directory is full results in an error.

The current volume label string for a volume can be obtained by calling the ***ioctl( )*** call with the **FIOLABELGET** function. If the volume has no label, this call returns **ERROR** and sets **errno** to **S_dosFsLib_NO_LABEL**.

Disks initialized under VxWorks or under MS-DOS 5.0 (or later) also contain the volume label string within a boot sector field.

4.2.2 Initializing the dosFs File System

Note that before any other operations can be performed, the dosFs file system library, **dosFsLib**, must be initialized by calling ***dosFsInit( )***. This routine takes a single parameter, the maximum number of dosFs file descriptors that can be open at one time. That number of file descriptors is allocated during initialization; a descriptor is used each time your application opens a file, directory, or the file system device.

The ***dosFsInit( )*** routine also makes an entry for the file system in the I/O system driver table (with ***iosDrvInstall( )***). This entry specifies entry points for dosFs file operations and is used for all devices that use the dosFs file system. The driver number assigned to the dosFs file system is recorded in a global variable **dosFsDrvNum**.

The ***dosFsInit( )*** routine is normally called by the ***usrRoot( )*** task after starting the VxWorks system. To use this initialization, select **INCLUDE_DOSFS** for inclusion in the project facility VxWorks view, and set **NUM_DOSFS_FILES** to the desired maximum open file count on the Params properties tab.

4.2.3 Initializing a Device for Use with dosFs

After the dosFs file system is initialized, the next step is to create one or more devices. Devices are created by the device driver's device creation routine (*xxDevCreate*( )). The driver routine returns a pointer to a block device descriptor structure (**BLK_DEV**). The **BLK_DEV** structure describes the physical aspects of the device and specifies the routines that the device driver provides to a file system. For more information on block devices, see *3.9.4 Block Devices*, p. 158.

Immediately after its creation, the block device has neither a name nor a file system associated with it. To initialize a block device for use with the dosFs file system, the already-created block device must be associated with dosFs and a name must be assigned to it. This is done with the ***dosFsDevInit*( )** routine. Its parameters are the name to be used to identify the device, a pointer to the block device descriptor structure (**BLK_DEV**), and a pointer to the volume configuration structure **DOS_VOL_CONFIG** (see *4.2.4 Volume Configuration*, p. 183). For example:

```
DOS_VOL_DESC *pVolDesc;
DOS_VOL_CONFIG configStruct;
pVolDesc = dosFsDevInit ("DEV1:", pBlkDev, &configStruct);
```

The ***dosFsDevInit*( )** call performs the following tasks:

- Assigns the specified name to the device and enters the device in the I/O system device table (with ***iosDevAdd*( )**).
- Allocates and initializes the file system's volume descriptor for the device.
- Returns a pointer to the volume descriptor. This pointer is subsequently used to identify the volume during certain file system calls.

Initializing the device for use with dosFs does not format the disk, nor does it initialize the disk with MS-DOS structures (root directory, FAT, and so on). This permits using ***dosFsDevInit*( )** with disks that already have data in an existing MS-DOS file system; see *4.2.6 Using an Already Initialized Disk*, p. 188. Formatting and DOS disk initialization can be done using the ***ioctl*( )** functions **FIODISKFORMAT** and **FIODISKINIT**, respectively.

The ***dosFsMkfs*( )** call provides an easier method of initializing a dosFs device; it does the following:

- Provides a set of default configuration values.
- Calls ***dosFsDevInit*( ).**
- Initializes the disk structures using ***ioctl*( )** with the **FIODISKINIT** function.

The routine ***dosFsMkfs*( )** by default does not enable any dosFs-specific volume options (**DOS_OPT_CHANGENOWARN, DOS_OPT_AUTOSYNC**, **DOS_OPT_LONGNAMES**, **DOS_OPT_LOWERCASE**, or **DOS_OPT_EXPORT**). To enable any combination of these options, use ***dosFsMkfsOptionsSet*( )** before calling ***dosFsMkfs*( )** to initialize the disk. For more information on the default configuration values, see the manual entry for ***dosFsMkfs*( )**.

4.2.4 Volume Configuration

The volume configuration structure, **DOS_VOL_CONFIG**, is used during the ***dosFsDevInit*( )** call. This structure contains various dosFs file system variables describing the layout of data on the disk. Most of the fields in the structure correspond to those in the boot sector. Table 4-1 lists the fields in the **DOS_VOL_CONFIG** structure.

Table 4-1 **DOS_VOL_CONFIG Fields**

Field	Description
dosvc_mediaByte	Media-descriptor byte
dosvc_secPerClust	Number of sectors per cluster
dosvc_nResrvd	Number of reserved sectors that precede the first FAT copy; the minimum is 1 (the boot sector)
dosvc_nFats	Number of FAT copies
dosvc_secPerFat	Number of sectors per FAT copy
dosvc_maxRootEnts	Maximum number of entries in root directory
dosvc_nHidden	Number of hidden sectors, normally 0
dosvc_options	VxWorks-specific file system options
dosvc_reserved	Reserved for future use by Wind River Systems

Calling ***dosFsConfigInit*( )**is a convenient way to initialize **DOS_VOL_CONFIG**. It takes the configuration variables as parameters and fills in the structure. This is useful for initializing devices interactively from the Tornado shell (see the *Tornado User's Guide: Shell*). The **DOS_VOL_CONFIG** structure must be allocated *before* ***dosFsConfigInit*( )** is called.

DOS_VOL_CONFIG *Fields*

All but the last two **DOS_VOL_CONFIG** fields in Table 4-1 describe standard MS-DOS characteristics. The field **dosvc_options** is specific to the dosFs file system. Possible options for this field are shown in Table 4-2.

Table 4-2 **dosFs Volume Options**

Option	Hex Value	Description
DOS_OPT_CHANGENOWARN	0x1	Disk may be changed without warning.
DOS_OPT_AUTOSYNC	0x2	Synchronize disk during I/O.
DOS_OPT_LONGNAMES	0x4	Use case-sensitive file names not restricted to 8.3 convention.
DOS_OPT_EXPORT	0x8	Allow exporting using NFS.
DOS_OPT_LOWERCASE	0x40	Use lower case filenames on disk.

The first two options specify the action used to synchronize the disk buffers with the physical device. The remaining options involve extensions to dosFs capabilities.

DOS_OPT_CHANGENOWARN
Set this option if the device is a disk that can be replaced without being unmounted or having its change in ready-status declared. In this situation, check the disk regularly to determine whether it has changed. This causes significant overhead; thus, we recommend that you provide a mechanism that always synchronizes and unmounts a disk before it is removed, or at least announces a change in ready-status. If such a mechanism is in place, or if the disk is not removable, do not set this option. Auto-sync mode is enabled automatically when **DOS_OPT_CHANGENOWARN** is set (see the description for **DOS_OPT_AUTOSYNC**, next). For more information on **DOS_OPT_CHANGENOWARN**, see *4.2.17 Changing Disks*, p.196.

DOS_OPT_AUTOSYNC
Set this option to assure that directory and FAT data in the disk's buffers are written to the physical device as soon as possible after modification, rather than only when the file is closed. This can be desirable in situations where it is important that data be stored on the physical medium as soon as possible so as to avoid loss in the event of a system crash. There is a significant performance penalty incurred when using auto-sync mode;

limit its use, therefore, to circumstances where there is a threat to data integrity.

However, **DOS_OPT_AUTOSYNC** does not make dosFs automatically write data to disk immediately after every ***write*( )**; doing so implies an extreme performance penalty. If your application requires this effect, use the ***ioctl*( )** function **FIOFLUSH** after every call to ***write*( )**.

Note that auto-sync mode is automatically enabled whenever **DOS_OPT_CHANGENOWARN** is set. For more information on auto-sync mode, see *4.2.17 Changing Disks*, p.196.

DOS_OPT_LONGNAMES
Set this option to allow the use of case-sensitive file names, with name lengths not restricted to MS-DOS's 8.3 convention. For more information on this option, see *4.2.18 Long Name Support*, p.199.

DOS_OPT_EXPORT
Set this option to initialize file systems that you intend to export using NFS. With this option, dosFs initialization creates additional in-memory data structures that are required to support the NFS protocol. While this option is necessary to initialize a file system that can be exported, it does not actually export the file system. See *VxWorks Network Programmer's Guide: File Access Applications*.

DOS_OPT_LOWERCASE
Set this option to force filenames created by dosFs to use lowercase alphabetical characters. (Normally, filenames are created using uppercase characters, unless the **DOS_OPT_LONGNAMES** option is enabled.) This option may be required if the dosFs volume is mounted by a PC-based NFS client. This option has no effect if **DOS_OPT_LONGNAMES** is also specified.

Calculating Configuration Values

The values for **dosvc_secPerClust** and **dosvc_secPerFat** in the **DOS_VOL_CONFIG** structure must be calculated based on the particular device being used.

dosvc_secPerClust
This field specifies how many contiguous disk sectors make up a single cluster. Because a cluster is the smallest amount of disk space that can be allocated at a time, the size of a cluster determines how finely the disk allocation can be controlled. A large number of sectors per cluster causes more sectors to be allocated at a time and reduces the overall efficiency of

disk space usage. For this reason, it is generally preferable to use the smallest possible number of sectors per cluster, although having less than two sectors per cluster is generally not necessary.

The maximum size of a FAT entry is 16 bits; thus, there is a maximum of 65,536 (64KB, or 0x10000) clusters that can be described. This is therefore the maximum number of clusters for a device. To determine the appropriate number of sectors per cluster, divide the total number of sectors on the disk (the **bd_nBlocks** field in the device's **BLK_DEV** structure) by 0x10000 (64KB). Round up the resulting value to the next whole number. The final result is the number of sectors per cluster; place this value in the **dosvc_secPerClust** field in the **DOS_VOL_CONFIG** structure.

dosvc_secPerFat

This field specifies the number of sectors required on the disk for each copy of the FAT. To calculate this value, first determine the total number of clusters on the disk. The total number of clusters is equal to the total number of sectors (**bd_nBlocks** in the **BLK_DEV** structure) divided by the number of sectors per cluster. As mentioned previously, the maximum number of clusters on a disk is 64KB.

The cluster count must then be multiplied by the size of each FAT entry: if the total number of clusters is 4085 or less, each FAT entry requires 12 bits (1½ bytes); if the number of clusters is greater than 4085, each FAT entry requires 16 bits (2 bytes). The result of this multiplication is the total number of bytes required by each copy of the FAT. This byte count is then divided by the size of each sector (the **bd_bytesPerBlk** field in the **BLK_DEV** structure) to determine the number of sectors required for each FAT copy; if there is any remainder, add one (1) to the result. Place this final value in the **dosvc_secPerFat** field.

Assuming 512-byte sectors, the largest possible FAT (with entries describing 64KB clusters) occupies 256 sectors per copy, calculated as follows:

$$\frac{\text{64KB entries} \times \text{2 bytes/entry}}{\text{512 bytes/sector}} = \text{256 sectors}$$

Standard Disk Configurations

For floppy disks, a number of standard disk configurations are used in MS-DOS systems. In general, these are uniquely identified by the media-descriptor byte value (at least for a given size of floppy disk), although some manufacturers have used duplicate values for different formats. Some widely used configurations are summarized in Table 4-3.

Fixed disks do not use standard disk configurations because they are rarely attached to a foreign system. Usually fixed disks use a media format byte of 0xF8.

Table 4-3 **MS-DOS Floppy Disk Configurations**

Capacity	160KB	180KB	320KB	360KB	1.2MB	720KB	1.44MB
Size	5.25"	5.25"	5.25"	5.25"	5.25"	3.5"	3.5"
Sides	1	1	2	2	2	2	2
Tracks	40	40	40	40	80	80	80
Sectors/Track	8	9	8	9	15	9	18
Bytes/Sector	512	512	512	512	512	512	512
secPerClust	1	1	2	2	1	2	1
nResrvd	1	1	1	1	1	1	1
nFats	2	2	2	2	2	2	2
maxRootEnts	64	64	112	112	224	112	224
mediaByte	0xFE	0xFC	0xFF	0xFD	0xF9	0xF9	0xF0
secPerFat	1	2	1	2	7	3	9
nHidden	0	0	0	0	0	0	0

4.2.5 Changes In Volume Configuration

As mentioned previously, various disk configuration parameters are specified when the dosFs file system device is first initialized using ***dosFsDevInit( )***. These parameters are kept in the volume descriptor, **DOS_VOL_DESC**, for the device. However, it is possible for a disk with different parameter values to be placed in a drive after the device is already initialized. If another disk is substituted for the one with the configuration parameters that were last entered into the volume descriptor, the configuration parameters of the new disk must be obtained before it can be used.

When a disk is mounted, the boot sector information is read from the disk. This data is used to update the configuration data in the volume descriptor. Note that this happens the first time the disk is accessed, and again after the volume is unmounted (using ***dosFsVolUnmount*( )**) or a ready-change operation is performed. For more information, see *4.2.17 Changing Disks*, p.196.

This automatic re-initialization of the configuration data has an important implication. The volume descriptor data is used when initializing a disk (with **FIODISKINIT**); thus, the disk is initialized with the configuration of the most recently mounted disk, regardless of the original specification during ***dosFsDevInit*( )**. Therefore, we recommend that you use **FIODISKINIT** immediately after ***dosFsDevInit*( )**, before any disk is mounted. (The device is opened in raw mode, the **FIODISKINIT** ***ioctl*( )** function is performed, and the device is closed.)

4.2.6 Using an Already Initialized Disk

If you are using a disk that is already initialized with an MS-DOS boot sector, FAT, and root directory (for example, by using the FORMAT utility in MS-DOS), it is not necessary to provide the volume configuration data during ***dosFsDevInit*( )**.

You can omit the MS-DOS configuration data by specifying a **NULL** pointer instead of the address of a **DOS_VOL_CONFIG** structure during ***dosFsDevInit*( )**. However, only use this method if you are sure that the first use of the volume is with a properly formatted and initialized disk.

When mounting an already initialized disk, all standard MS-DOS configuration values are obtained from the disk's boot sector. However, the options that are specific to dosFs must be determined differently.

Disks that are already initialized with the **DOS_OPT_LONGNAMES** (case-sensitive file names not restricted to 8.3 convention) option are recognized automatically by a specific volume ID string that is placed in the boot sector.

The **DOS_OPT_CHANGENOWARN**, **DOS_OPT_AUTOSYNC**, **DOS_OPT_LOWERCASE**, and **DOS_OPT_EXPORT** options are recorded only in memory, not on disk. Therefore they cannot be detected when you initialize a disk with **NULL** in place of the **DOS_VOL_CONFIG** structure pointer; you must re-enable them each time you mount a disk. You can set default values for these options with the ***dosFsDevInitOptionsSet*( )** routine: the defaults apply to any dosFs file systems you initialize with ***dosFsDevInit*( )** thereafter, unless you supply explicit **DOS_VOL_CONFIG** information.

You can also enable the **DOS_OPT_CHANGENOWARN** and **DOS_OPT_AUTOSYNC** options dynamically during disk operation, rather than during initialization, with the ***dosFsVolOptionsSet*( )** routine.

4.2.7 Accessing Volume Configuration Information

Disk configuration information is available using ***dosFsConfigShow*( )**[2] and ***dosFsConfigGet*( )** from the Tornado shell. See the *Tornado User's Guide: Shell*.

Use ***dosFsConfigShow*( )** to display configuration information such as the largest contiguous area and the device name. For example:

```
-> dosFsConfigShow "/RAM1/"
value = 0 = 0x0
```

The output is sent to the standard output device, and looks like the following:

```
device name:                    /RAM1/
total number of sectors:        400
bytes per sector:               512
media byte:                     0xf0
# of sectors per cluster:       2
# of reserved sectors:          1
# of FAT tables:                2
# of sectors per FAT:           1
max # of root dir entries:      112
# of hidden sectors:            0
removable medium:               FALSE
disk change w/out warning:      not enabled
auto-sync mode:                 not enabled
long file names:                not enabled
exportable file system:         not enabled
volume mode:                    O_RDWR (read/write)
available space:               199680 bytes
max avail. contig space:       199680 bytes
```

The ***dosFsConfigGet*( )** routine stores the disk configuration information in a **DOS_VOL_CONFIG** structure. This can be useful if you have a pre-existing disk and want to initialize a new disk with the same parameters, or if you initialized the dosFs file system on the disk using ***dosFsMkfs*( )** and need to obtain the actual configuration values that were calculated.

2. ***dosFsConfigShow*( )** is automatically when dosFs is included in your VxWorks image.

4.2.8 Mounting Volumes

A disk volume is *mounted* automatically, generally during the first ***open*( )** or ***creat*( )** operation for a file or directory on the disk. (Certain ***ioctl*( )** calls also cause the disk to be mounted.) If a NULL pointer is specified instead of the address of a **DOS_VOL_CONFIG** structure during the ***dosFsDevInit*( )** call, the disk is mounted immediately to obtain the configuration values.

When a disk is mounted, the boot sector, FAT, and directory data are read from the disk. The volume descriptor, **DOS_VOL_DESC**, is updated to reflect the configuration of the newly mounted disk.

Automatic mounting occurs on the first file access following ***dosFsVolUnmount*( )** or a ready-change operation (see *4.2.17 Changing Disks*, p.196), or periodically if the disk is defined during the ***dosFsDevInit*( )** call with the option **DOS_OPT_CHANGENOWARN** set. Automatic mounting does not occur when a disk is opened in raw mode; see *4.2.10 Opening the Whole Device (Raw Mode)*, p.190.

⚠ **CAUTION:** Because device names are recognized by the I/O system using simple substring matching, file systems should not use a slash (**/**) alone as a name; unexpected results may occur.

It is possible to mount a volume with ***usrFdConfig*( )**, but this routine does not return the **DOS_VOL_DESC** structure. A volume mounted with ***usrFdConfig*( )** can not be operated on with most dosFs commands, including ***dosFsVolUnmount*( )**. However, the dosFs ***ioctl*( )** commands, including **FIOUNMOUNT**, access the volume information through the *fd*, so they can be used with ***usrFdConfig*( )**.

4.2.9 File I/O

Files on a dosFs file system device are created, deleted, written, and read using the standard VxWorks I/O routines: ***creat*( )**, ***remove*( )**, ***write*( )**, and ***read*( )**. See *3.3 Basic I/O*, p.98 for more information.

4.2.10 Opening the Whole Device (Raw Mode)

It is possible to open an entire dosFs volume. This is done by specifying only the device name during the ***open*( )** or ***creat*( )** call. A file descriptor is returned, as when a regular file is opened; however, operations on that file descriptor affect the entire device. Opening the entire volume in this manner is called *raw mode*.

The most common reason for opening the entire device is to obtain a file descriptor for an ***ioctl*( )** function that does not pertain to an individual file. An example is the **FIONFREE** function, which returns the number of available bytes on the volume. However, for many of these functions, the file descriptor can be any open file descriptor to the volume, even one for a specific file.

When a disk is initialized with MS-DOS data structures (boot sector, empty root directory, FAT), open the device in raw mode. The ***ioctl*( )** function **FIODISKINIT** performs the initialization.

You can both read and write data on a disk in raw mode. In this mode, the entire disk data area (that is, the disk portion following the boot sector, root directory, and FAT) is treated much like a single large file. No directory entry is made to describe any data written using raw mode.

For low-level I/O to an entire device, including the area used by MS-DOS data structures, see *4.4 Raw File System: rawFs*, p.209 and the online reference for **rawFsLib** under VxWorks Reference Manual>Libraries.

4.2.11 Creating Subdirectories

Subdirectories can be created in any directory at any time, except in the root directory if it has reached its maximum entry count. Subdirectories can be created in two ways:

1. Using ***ioctl*( )** with the **FIOMKDIR** function: The name of the directory to be created is passed as a parameter to ***ioctl*( )**. The file descriptor used for the ***ioctl*( )** call is acquired either through opening the entire volume (raw mode), a regular file, or another directory on the volume.

2. Using ***open*( )**: To create a directory, the **O_CREAT** option must be set in the *flags* parameter to open, and the **FSTAT_DIR** option must be set in the *mode* parameter. The ***open*( )** call returns a file descriptor that describes the new directory. Use this file descriptor for reading only and close it when it is no longer needed.

When creating a directory using either method, the new directory name must be specified. This name can be either a full path name or a path name relative to the current working directory.

4.2.12 Removing Subdirectories

A directory that is to be deleted must be empty (except for the "**.**" and "**..**" entries). The root directory can never be deleted. There are two methods for removing directories:

1. Using ***ioctl*( )** call with the **FIORMDIR** function, specifying the name of the directory. Again, the file descriptor used can refer to any file or directory on the volume, or to the entire volume itself.
2. Using the ***remove*( )** function, specifying the name of the directory.

4.2.13 Directory Entries

Each dosFs directory contains a set of entries describing its files and immediate subdirectories. Each entry contains the following information about a file or subdirectory:

file name
: an 8-byte string (padded with spaces, if necessary) specifying the base name of the file. (Names can be up to 40 characters; for details see *4.2.18 Long Name Support*, p. 199.)

file extension
: a 3-byte string (space-padded) specifying an optional extension to the file or subdirectory name. (If case-sensitive file names not restricted to the 8.3 convention are selected, the extension concept is not applicable.)

file attribute
: a one-byte field specifying file characteristics; see *4.2.15 File Attributes*, p. 193.

time
: the encoded creation or modification time for the file.

date
: the encoded creation or modification date for the file.

cluster number
: the number of the starting cluster within the file. Subsequent clusters are found by searching the FAT.

file size
: the size of the file, in bytes. This field is always 0 for entries describing subdirectories.

4.2.14 Reading Directory Entries

Directories on dosFs volumes can be searched using the ***opendir*( )**, ***readdir*( )**, ***rewinddir*( )**, and ***closedir*( )** routines. These calls can be used to determine the names of files and subdirectories.

To obtain more detailed information about a specific file, use the ***fstat*( )** or ***stat*( )** function. Along with standard file information, the structure used by these routines also returns the file-attribute byte from a directory entry.

For more information, see the manual entry for **dirLib**.

4.2.15 File Attributes

The file-attribute byte in a dosFs directory entry consists of a set of flag bits, each indicating a particular file characteristic. The characteristics described by the file-attribute byte are shown in Table 4-4.

Table 4-4 **Flags in the File-Attribute Byte**

VxWorks Flag Name	Hex value	Description
DOS_ATTR_RDONLY	0x01	read-only file
DOS_ATTR_HIDDEN	0x02	hidden file
DOS_ATTR_SYSTEM	0x04	system file
DOS_ATTR_VOL_LABEL	0x08	volume label
DOS_ATTR_DIRECTORY	0x10	subdirectory
DOS_ATTR_ARCHIVE	0x20	file is subject to archiving

DOS_ATTR_RDONLY is checked when a file is opened for **O_WRONLY** or **O_RDWR**. If the flag is set, ***open*( )** returns **ERROR** and sets **errno** to **S_dosFsLib_READ_ONLY**.

⚠ **CAUTION:** The MS-DOS hidden file and system file flags, **DOS_ATTR_HIDDEN** and **DOS_ATTR_SYSTEM**, are ignored by **dosFsLib**. If present, they are kept intact, but they produce no special handling (for example, entries with these flags are reported when searching directories).

The volume label flag, **DOS_ATTR_VOL_LABEL**, indicates that a directory entry contains the dosFs volume label for the disk. A label is not required. If used, there can be only one volume label entry per volume, in the root directory. The volume label entry is not reported when reading the contents of a directory (using ***readdir*( )**). It can only be determined using the ***ioctl*( )** function **FIOLABELGET**. The volume label can be set (or reset) to any string of 11 or fewer characters, using the ***ioctl*( )** function **FIOLABELSET**. Any file descriptor open to the volume can be used during these ***ioctl*( )** calls.

The directory flag, **DOS_ATTR_DIRECTORY**, indicates that this entry is not a regular file, but a subdirectory.

The archive flag, **DOS_ATTR_ARCHIVE**, is set when a file is created or modified. This flag is intended for use by other programs that search a volume for modified files and selectively archive them. Such a program must clear the archive flag since VxWorks does not.

All the flags in the attribute byte, except the directory and volume label flags, can be set or cleared using the ***ioctl*( )** function **FIOATTRIBSET**. This function is called after the opening of the specific file with the attributes to be changed. The attribute-byte value specified in the **FIOATTRIBSET** call is copied directly; to preserve existing flag settings, determine the current attributes using ***stat*( )** or ***fstat*( )**, then change them using bitwise *and* and *or* operations.

Example 4-1 **Setting DosFs File Attributes**

This example makes a dosFs file read-only, and leaves other attributes intact.

```
#include "vxWorks.h"
#include "ioLib.h"
#include "dosFsLib.h"
#include "sys/stat.h"
#include "fcntl.h"

STATUS changeAttributes (void)
    {
    int         fd;
    struct stat statStruct;

    /* open file */

    if ((fd = open ("file", O_RDONLY, 0)) == ERROR)
        return (ERROR);

    /* get directory entry data */

    if (fstat (fd, &statStruct) == ERROR)
        return (ERROR);
    /* set read-only flag on file */

    if (ioctl (fd, FIOATTRIBSET, (statStruct.st_attrib | DOS_ATTR_RDONLY))
        == ERROR)
        return (ERROR);

    /* close file */

    close (fd);
    }
```

4.2.16 File Date and Time

Directory entries contain a time and date for each file or directory. This time is set when the file is created, and it is updated when a file that was modified is closed. Entries describing subdirectories are not updated—they always contain the creation date and time for the subdirectory.

The **dosFsLib** library maintains the date and time in an internal structure. While there is currently no mechanism for automatically advancing the date or time, two different methods for setting the date and time are provided.

The first method involves using two routines, ***dosFsDateSet*( )** and ***dosFsTimeSet*( )**. The following examples illustrate their use:

```
dosFsDateSet (1990, 12, 25);        /* set date to Dec-25-1990 */
dosFsTimeSet (14, 30, 22);          /* set time to 14:30:22    */
```

These routines must be called periodically to update the time and date values.

The second method requires a user-supplied hook routine. If a time and date hook routine is installed using ***dosFsDateTimeInstall*( )**, that routine is called whenever **dosFsLib** requires the current date and time. You can use this to take advantage of hardware time-of-day clocks that can be read to obtain the current time. It can also be used with other applications that maintain actual time and date.

Define the date/time hook routine as follows (the name ***dateTimeHook*** is an example; the actual routine name can be anything):

```
void dateTimeHook
    (
    DOS_DATE_TIME * pDateTime   /* ptr to dosFs date & time struct */
    )
```

On entry to the hook routine, the **DOS_DATE_TIME** structure contains the last time and date set in **dosFsLib**. Next, the hook routine fills the structure with the correct values for the current time and date. Unchanged fields in the structure retain their previous values.

The MS-DOS specification provides only for 2-second granularity in file timestamps. If the number of seconds in the time specified during ***dosFsTimeSet( )*** or the date/time hook routine is odd, it is rounded down to the next even number.

The date and time used by **dosFsLib** is initially Jan-01-1980, 00:00:00.

4.2.17 Changing Disks

To increase performance, the dosFs file system keeps in memory copies of directory entries and the file allocation table (FAT) for each mounted volume. While this greatly speeds up access to files, it requires that **dosFsLib** be notified when removable disks are changed (for example, when floppies are swapped). Two different notification methods are provided: (1) ***dosFsVolUnmount( )*** and (2) the ready-change mechanism. The following sections are not generally applicable for non-removable media (although ***dosFsVolUnmount( )*** can be useful in system shutdown situations).

Unmounting Volumes

The preferred method of announcing a disk change is to call ***dosFsVolUnmount( )*** prior to removing the disk. This call flushes all modified data structures to disk if possible (see *Synchronizing Volumes*, p.198) and also marks any open file descriptors as obsolete. During the next I/O operation, the disk is remounted. The ***ioctl( )*** call can also be used to initiate ***dosFsVolUnmount( )***, by specifying the **FIOUNMOUNT** function code. Any open file descriptor to the device can be used in the ***ioctl( )*** call.

Subsequent attempts to use obsolete file descriptors for I/O operations return an **S_dosFsLib_FD_OBSOLETE** error. To free such file descriptors, use ***close( )***, as usual. This returns **S_dosFsLib_FD_OBSOLETE** as well, but it successfully frees the descriptor. File descriptors acquired when opening the entire volume (raw mode) are not marked as obsolete during ***dosFsVolUnmount( )*** and can still be used.

ISRs must not call ***dosFsVolUnmount( )*** directly, because it is possible for the call to pend while the device becomes available. The ISR can instead give a semaphore that prompts a task to unmount the volume. (Note that ***dosFsReadyChange( )*** can be called directly from ISRs; see *Announcing Disk Changes with Ready-Change*, p.197.)

When ***dosFsVolUnmount( )*** is called, it attempts to write buffered data out to the disk. Its use is therefore inappropriate for situations where the disk-change notification does not occur until a new disk is inserted, because the old buffered data would be written to the new disk. In this case, use ***dosFsReadyChange*( )**, which is described in *Announcing Disk Changes with Ready-Change*, p.197.

If ***dosFsVolUnmount*( )** is called after the disk is physically removed, the data-flushing portion of its operation fails. However, the file descriptors are still marked as obsolete and the disk is marked as requiring remounting. In this situation, ***dosFsVolUnmount*( )** does *not* return an error. To avoid lost data, explicitly synchronize the disk before removing it (see *Synchronizing Volumes*, p.198).

⚠ **CAUTION:** Do not attempt to unmount a volume that was mounted with ***usrFdConfig*( )** using ***dosFsVolUnmount*( )**. This routine does not return the **DOS_VOL_CONFIG** structure required by ***dosFsVolUnmount*( )**. You can use ***ioctl*( )** with **FIOUNMOUNT**, which accesses volume information through the *fd*.

Announcing Disk Changes with Ready-Change

The second method of informing **dosFsLib** that a disk change is taking place is with the *ready-change* mechanism. A change in the disk's ready-status is interpreted by **dosFsLib** as indicating that the disk must be remounted before the next I/O operation.

There are three ways to announce a ready-change:

- By calling ***dosFsReadyChange*( )** directly.
- By calling ***ioctl*( )** with the **FIODISKCHANGE** function.
- By having the device driver set the **bd_readyChanged** field in the **BLK_DEV** structure to TRUE; this has the same effect as notifying **dosFsLib** directly.

The ready-change mechanism does not provide the ability to flush data structures to the disk. It merely marks the volume as needing remounting. Thus, buffered data (data written to files, directory entries, or FAT changes) can be lost. This can be avoided by synchronizing the disk before asserting ready-change (see *Synchronizing Volumes*, p.198). The combination of synchronizing and asserting ready-change provides all the functionality of ***dosFsVolUnmount*( )**, except for marking file descriptors as obsolete.

Ready-change can be used in ISRs, because it does not attempt to flush data or perform other operations that could cause delay.

The block device driver status-check routine (identified by the **bd_statusChk** field in the **BLK_DEV** structure) can be useful for asserting ready-change for devices that detect a disk change only after the new disk is inserted. This routine is called at the beginning of each ***open*( )** or ***creat*( )** operation, before the file system checks for ready-change. See *3.9.4 Block Devices*, p.158.

Disks with No Change Notification

If it is not possible for ***dosFsVolUnmount*( )** to be called or a ready-change to be announced, then each time the disk is changed, the device must be specially identified when it is initialized for use with the file system. This is done by setting **DOS_OPT_CHANGENOWARN** in the **dosvc_options** field of the **DOS_VOL_CONFIG** structure when calling ***dosFsDevInit*( )**; see *4.2.4 Volume Configuration*, p.183.

This configuration option results in a significant performance penalty, because the disk configuration data must be read in regularly from the physical disk (in case it was removed and a new one inserted). In addition, setting **DOS_OPT_CHANGENOWARN** also enables auto-sync mode; see *Auto-Sync Mode*, p.199. Note that all that is required for disk change notification is that either the ***dosFsVolUnmount*( )** call or ready-change be issued each time the disk is changed. It is not necessary that it be called from the device driver or an ISR. For example, if your application provided a user interface through which an operator could enter a command resulting in an ***dosFsVolUnmount*( )** call before removing the disk, that would be sufficient, and **DOS_OPT_CHANGENOWARN** does not need to be set. However, it is important that the operator follow such a procedure strictly.

Synchronizing Volumes

When a disk is *synchronized*, all modified buffered data is physically written to the disk, so that the disk is up to date. This includes data written to files, updated directory information, and the FAT.

To avoid loss of data, synchronize a disk before removing it. You may need to explicitly synchronize a disk, depending on when (or if) ***dosFsVolUnmount*( )** is called. If your application does not call this routine, or it is called after the disk is removed, use ***ioctl*( )** to explicitly write the data to the device.

When ***dosFsVolUnmount*( )** is called, an attempt is made to synchronize the device before unmounting. If the disk is still present and writable at the time of the call, synchronization takes place, and no further action is required to protect the integrity of the data written to it before it is dismounted. However, if the ***dosFsVolUnmount*( )** call is made after a disk is removed, it is obviously too late to synchronize, and ***dosFsVolUnmount*( )** discards the buffered data.

To explicitly synchronize a disk before it is removed, use ***ioctl*( )** specifying the **FIOSYNC** function. (This could be done in response to an operator command.) Do this if the ***dosFsVolUnmount*( )** call is made after a disk is removed or if the routine ***dosFsVolUnmount*( )** is never called. The file descriptor used during the ***ioctl*( )** call is obtained when the whole volume (raw mode) is opened.

Auto-Sync Mode

dosFsLib provides a modified mode of synchronization called *auto-sync*. When this option is enabled, data for modified directories and the FAT are physically written to these devices as soon as they are logically altered. (Otherwise, such changes are not necessarily written out until the involved file is closed.)

Auto-sync mode is enabled by setting **DOS_OPT_AUTOSYNC** in the **dosvc_options** field of the **DOS_VOL_CONFIG** structure when ***dosFsDevInit*( )** is called; see *4.2.4 Volume Configuration*, p.183. Auto-sync mode is automatically enabled if the volume does not have disk change notification (that is, if **DOS_OPT_CHANGENOWARN** is set by ***dosFsDevInit*( )**).

Auto-sync results in a performance penalty, but it provides the highest level of data security, because it minimizes the period during which directory and FAT data are not up to date on the disk. Auto-sync is often desirable for applications where data integrity is threatened by events such as a system crash.

4.2.18 Long Name Support

The dosFs long name support allows the use of case-sensitive file names longer than MS-DOS's 8.3 convention. These names can be up to 40 characters long and can be made up of any ASCII characters. In addition, a dot (**.**), which in MS-DOS indicates a file-name extension, has no special significance.

Long name support is enabled by setting **DOS_OPT_LONGNAMES** in the **dosvc_options** field of the **DOS_VOL_CONFIG** structure when calling ***dosFsDevInit*( )**.

WARNING: If you use this feature, the disk is no longer MS-DOS compatible. Use long name support only for storing data local to VxWorks, on a disk that is initialized on a VxWorks system using ***dosFsDevInit*( )** or ***dosFsMkfs*( )**.

4.2.19 Contiguous File Support

The dosFs file system provides efficient handling of *contiguous files*. A contiguous file is made up of a series of consecutive disk sectors. This capability includes both the allocation of contiguous space to a specified file (or directory) and optimized access to such a file.

To allocate a contiguous area to a file, first create the file in the normal fashion, using ***open*( )** or ***creat*( )**. Then use the file descriptor returned during the creation of the file to make the ***ioctl*( )** call, specifying the **FIOCONTIG** function. The parameter to ***ioctl*( )** with the **FIOCONTIG** function is the size of the requested contiguous area, in bytes. The FAT is searched for a suitable section of the disk, and if found, it is assigned to the file. (If there is no contiguous area on the volume large enough to satisfy the request, an error is returned.) The file can then be closed, or it can be used for further I/O operations.

Example 4-2 **Creating a DosFs Contiguous File**

This example creates a dosFs file and allocates 0x10000 contiguous bytes to it.

```
#include "vxWorks.h"
#include "ioLib.h"
#include "fcntl.h"

STATUS fileContigTest (void)
    {
    int fd;
    STATUS status;

    /* open file */

    if ((fd = creat ("file", O_RDWR)) == ERROR)
        return (ERROR);

    /* get contiguous area */

    status = ioctl (fd, FIOCONTIG, 0x10000);
    if (status != OK)

      /* do error handling */

        printf ("ERROR");

    /* use file */

    /* close file */

    close (fd);
    }
```

It is also possible to request the largest available contiguous space. Use **CONTIG_MAX** for the size of the contiguous area. For example:

```
    status = ioctl (fd, FIOCONTIG, CONTIG_MAX);
```

It is important that the file descriptor used for the ***ioctl*( )** call be the only descriptor open to the file. Furthermore, because a file can be assigned a different area of the disk than is originally allocated, perform the ***ioctl*( ) FIOCONTIG** operation before any data is written to the file.

To deallocate unused reserved bytes, use the POSIX-compatible routine ***ftruncate*( )** or the ***ioctl*( )** function **FIOTRUNC**.

Subdirectories can also be allocated a contiguous disk area in the same manner. If the directory is created using the ***ioctl*( )** function **FIOMKDIR**, it must be explicitly opened to obtain a file descriptor to it; if the directory is created using options to ***open*( )**, the returned file descriptor from that call can be used. A directory must be empty (except for the "**.**" and "**..**" entries) when it has contiguous space allocated to it.

When any file is opened, it is checked for contiguity. If a file is recognized as contiguous, a more efficient technique for locating specific sections of the file is used, rather than following cluster chains in the FAT, as must be done for fragmented files. This enhanced handling of contiguous files takes place regardless of whether the space is explicitly allocated using **FIOCONTIG**.

To find the maximum contiguous area on a device, use the ***ioctl*( )** function **FIONCONTIG**. This information can also be displayed by ***dosFsConfigShow*( )**.

Example 4-3 **Finding the Maximum Contiguous Area on a DosFs Device**

In this example, the size (in bytes) of the largest contiguous area is copied to the integer pointed to by the third parameter to ***ioctl*( )** (*count*).

```
#include "vxWorks.h"
#include "fcntl.h"
#include "ioLib.h"

STATUS contigTest (void)
    {
    int count;
    int fd;

    /* open device in raw mode */
    if ((fd = open ("/DEV1/", O_RDONLY, 0)) == ERROR)
        return (ERROR);

    /* find max contiguous area */
    ioctl (fd, FIONCONTIG, &count);
    /* close device and display size of largest contiguous area */
    close (fd);
    printf ("largest contiguous area = %d\n", count);
    }
```

4.2.20 I/O Control Functions Supported by dosFsLib

The dosFs file system supports the ***ioctl*( )** functions listed in Table 4-5. These functions are defined in the header file **ioLib.h**. For more information, see the manual entries for **dosFsLib** and for ***ioctl*( )** in **ioLib**.

Table 4-5 **I/O Control Functions Supported by dosFsLib**

Function	Decimal Value	Description
FIOATTRIBSET	35	Set the file-attribute byte in the dosFs directory entry.
FIOCONTIG	36	Allocate contiguous disk space for a file or directory.
FIODISKCHANGE	13	Announce a media change.
FIODISKFORMAT	5	Format the disk (device driver function).
FIODISKINIT	6	Initialize a dosFs file system on a disk volume.
FIOFLUSH	2	Flush the file output buffer.
FIOFSTATGET	38	Get file status information (directory entry data).
FIOGETNAME	18	Get the file name of the *fd*.
FIOLABELGET	33	Get the volume label.
FIOLABELSET	34	Set the volume label.
FIOMKDIR	31	Create a new directory.
FIONCONTIG	41	Get the size of the maximum contiguous area on a device.
FIONFREE	30	Get the number of free bytes on the volume.
FIONREAD	1	Get the number of unread bytes in a file.
FIOREADDIR	37	Read the next directory entry.
FIORENAME	10	Rename a file or directory.
FIORMDIR	32	Remove a directory.

Table 4-5 **I/O Control Functions Supported by dosFsLib** *(Continued)*

Function	Decimal Value	Description
FIOSEEK	7	Set the current byte offset in a file.
FIOSYNC	21	Same as **FIOFLUSH**, but also re-reads buffered file data.
FIOTRUNC	42	Truncate a file to a specified length.
FIOUNMOUNT	39	Unmount a disk volume.
FIOWHERE	8	Return the current byte position in a file.

4.2.21 Booting from a Local dosFs File System Using SCSI

VxWorks can be booted from a local SCSI device. Before you can boot from SCSI, you must make new boot ROMs that contain the SCSI library. Define **INCLUDE_SCSI** in the project facility and **INCLUDE_SCSI_BOOT** in **config.h** and rebuild **bootrom.hex**. (For configuration information, see *8.5 Configuring VxWorks*, p.337; **INCLUDE_SCSI_BOOT** can only be configured in **config.h**. For boot ROM information, see *8.9 Creating Bootable Applications*, p.364.)

After burning the SCSI boot ROMs, you can prepare the dosFs file system for use as a boot device. The simplest way to do this is to partition the SCSI device so that a dosFs file system starts at block 0. You can then make the new **vxWorks** image, place it on your SCSI boot device, and boot the new VxWorks system. These steps are shown in more detail below.

WARNING: For use as a boot device, the directory name for the dosFs file system must begin and end with slashes (as with **/sd0/** used in the following example). This is an exception to the usual naming convention for dosFs file systems and is incompatible with the NFS requirement that device names not end in a slash.

1. Create the SCSI device using ***scsiPhysDevCreate*( )** (see *SCSI Drivers*, p.129), and initialize the disk with a dosFs file system (see *4.2.2 Initializing the dosFs File System*, p.181). Modify the file *installDir***/target/src/config/usrScsiConfig.c** to reflect your SCSI configuration. The following example creates a SCSI device with a dosFs file system spanning the full device:

```
pPhysDev = scsiPhysDevCreate (pSysScsiCtrl, 2, 0, 0, -1, 0, 0, 0);
pBlkDev = scsiBlkDevCreate (pPhysDev, 0, 0);
dosFsDevInit ("/sd0/", pBlkDev, 0);
```

2. Remake VxWorks and copy the new kernel to the drive:[3]

```
-> copy "unixHost:/usr/wind/target/config/bspname/vxWorks", \
"/sd0/vxWorks"
```

3. Reboot the system, and then change the boot parameters. Boot device parameters for SCSI devices follow this format:

   scsi=*id*,*lun*

   where *id* is the SCSI ID of the boot device, and *lun* is its Logical Unit Number (LUN). To enable use of the network, include the on-board Ethernet device (for example, **ln** for LANCE) in the *other* field. The following example boots from a SCSI device with a SCSI ID of 2 and a LUN of 0.

```
[VxWorks Boot]: @
boot device            : scsi=2,0
processor number       : 0
host name              : host
file name              : /sd0/vxWorks
inet on ethernet (e)   : 147.11.1.222:ffffff00
host inet (h)          : 147.11.1.3
user (u)               : jane
flags (f)              : 0x0
target name (tn)       : t222
other                  : ln
Attaching to scsi device... done.
Loading /sd0/vxWorks... 378060 + 27484 + 21544
Starting at 0x1000...
```

4.3 RT-11-Compatible File System: rt11Fs

VxWorks provides the file system rt11Fs, which is compatible with the RT-11 file system. It is provided primarily for compatibility with earlier versions of VxWorks. Normally, the dosFs file system is the preferred choice, because it offers such enhancements as optional contiguous file allocation, flexible file naming, and so on.

3. If you are using the target shell and have selected **INCLUDE_NET_SYM_TBL** for inclusion in the project facility VxWorks view, you must also copy the symbol table to the drive, as follows:

```
-> copy "unixHost:/usr/wind/target/config/bspname/vxWorks.sym", "/sd0/vxWorks.sym"
```

WARNING: The rt11Fs file system is considered obsolescent. In a future release of VxWorks, rt11Fs may not be supported.

4.3.1 Disk Organization

The rtllFs file system uses a simple disk organization. Although this simplicity results in some loss of flexibility, rt11Fs is suitable for many real-time applications.

The rt11Fs file system maintains only *contiguous files*. A contiguous file consists of a series of disk sectors that are consecutive. Contiguous files are well-suited to real-time applications because little time is spent locating specific portions of a file. The disadvantage of using contiguous files exclusively is that a disk can gradually become fragmented, reducing the efficiency of the disk space allocation.

The rt11Fs disk format uses a single directory to describe all files on the disk. The size of this directory is limited to a fixed number of directory entries. Along with regular files, unused areas of the disk are also described by special directory entries. These special entries are used to keep track of individual sections of free space on the disk.

4.3.2 Initializing the rt11Fs File System

Before any other operations can be performed, the rt11Fs file system library, **rt11FsLib**, must be initialized by calling ***rt11FsInit*( )**. This routine takes a single parameter, the maximum number of rt11Fs file descriptors that can be open at one time. This count is used to allocate a set of descriptors; a descriptor is used each time a file or an rt11Fs device is opened.

The ***rt11FsInit*( )** routine also makes an entry for the rt11Fs file system in the I/O system driver table (with ***iosDrvInstall*( )**). This entry specifies entry points for the rt11Fs file operations and is used for all devices that use the rt11Fs file system. The driver number assigned to the rt11Fs file systems is placed in a global variable **rt11FsDrvNum**.

The ***rt11FsInit*( )** routine is normally called by the ***usrRoot*( )** task after starting the VxWorks system. To use this initialization, make sure **INCLUDE_RT11FS** is selected for inclusion in the project facility VxWorks view, and set **NUM_RT11FS_FILES** to the desired maximum open file count in the Params tab of the properties window.

4.3.3 Initializing a Device for Use with rt11Fs

After the rt11Fs file system is initialized, the next step is to create one or more devices. Devices are created by the device driver's device creation routine (*xx***DevCreate( )**). The driver routine returns a pointer to a block device descriptor structure (**BLK_DEV**). The **BLK_DEV** structure describes the physical aspects of the device and specifies the routines in the device driver that a file system can call. For more information about block devices, see *3.9.4 Block Devices*, p. 158.

Immediately after its creation, the block device has neither a name nor a file system associated with it. To initialize a block device for use with rt11Fs, the already-created block device must be associated with rt11Fs and must have a name assigned to it. This is done with ***rt11FsDevInit*( )**. Its parameters are:

– the name to be used to identify the device

– a pointer to the **BLK_DEV** structure

– a boolean value indicating whether the disk uses standard RT-11 skew and interleave

– the number of entries to be used in the disk directory (in some cases, the actual number used is greater than the number specified)

– a boolean value indicating whether this disk is subject to being changed without notification to the file system

For example:

```
RT_VOL_DESC  *pVolDesc;
pVolDesc = rt11FsDevInit ("DEV1:", pBlkDev, rtFmt, nEntries, changeNoWarn);
```

The ***rt11FsDevInit*( )** call assigns the specified name to the device and enters the device in the I/O system device table (with ***iosDevAdd*( )**). It also allocates and initializes the file system's volume descriptor for the device. It returns a pointer to the volume descriptor to the caller; this pointer is used to identify the volume during some file system calls.

Note that initializing the device for use with the rt11Fs file system does not format the disk, nor does it initialize the rt11Fs disk directory. These are done using ***ioctl*( )** with the functions **FIODISKFORMAT** and **FIODISKINIT**, respectively.

4.3.4 Mounting Volumes

A disk volume is *mounted* automatically, generally during the first ***open*( )** or ***creat*( )** for a file or directory on the disk. (Certain ***ioctl*( )** functions also cause the disk to be mounted.) When a disk is mounted, the directory data is read it.

Automatic mounting reoccurs on the first file access following a ready-change operation (see *4.3.8 Changing Disks*, p.208) or periodically if the disk is defined during the ***rt11FsDevInit*( )** call with the **changeNoWarn** parameter set to TRUE. Automatic mounting does not occur when a disk is opened in raw mode. For more information, see *4.3.6 Opening the Whole Device (Raw Mode)*, p.207.

⚠ **CAUTION:** Because device names are recognized by the I/O system using simple substring matching, file systems should not use a slash (**/**) alone as a name; unexpected results may occur.

4.3.5 File I/O

Files on an rt11Fs file system device are created, deleted, written, and read using the standard VxWorks I/O routines: ***creat*( )**, ***remove*( )**, ***write*( )**, and ***read*( )**. The size of an rt11Fs file is determined during its initial ***open*( )** or ***creat*( )**. Once closed, additional space cannot be allocated to the file. For more information, see *3.3 Basic I/O*, p.98.

4.3.6 Opening the Whole Device (Raw Mode)

It is possible to open an entire rt11Fs volume by specifying only the device name during the ***open*( )** or ***creat*( )** call. A file descriptor is returned, as when opening a regular file; however, operations on that file descriptor affect the entire device. Opening the entire volume in this manner is called *raw mode*.

The most common reason for opening the entire device is to obtain a file descriptor to perform an ***ioctl*( )** function that does not pertain to an individual file. An example is the **FIOSQUEEZE** function, which combines fragmented free space across the entire volume.

When a disk is initialized with an rt11Fs directory, open the device in raw mode. The ***ioctl*( )** function **FIODISKINIT** performs the initialization.

A disk can be read or written in raw mode. In this case, the entire disk area is treated much like a single large file. No directory entry is made to describe any data written using raw mode, and care must be taken to avoid overwriting the regular rt11Fs directory at the beginning of the disk. This type of I/O is also provided by **rawFsLib**.

4.3.7 Reclaiming Fragmented Free Disk Space

As previously mentioned, the contiguous file allocation scheme used by the rt11Fs file system can gradually result in disk fragmentation. In this situation, the available free space on the disk is scattered in a number of small chunks. This reduces the ability of the system to create new files.

To correct this condition, **rt11FsLib** includes the ***ioctl*( )** function **FIOSQUEEZE**. This routine moves files so that the free space is combined at the end of the disk. When you call ***ioctl*( )** with **FIOSQUEEZE**, it is critical that there be no open files on the device. With large disks, this call may require considerable time to execute.

4.3.8 Changing Disks

To increase performance, rt11Fs keeps copies of directory entries for each volume in memory. While this greatly speeds up access to files, it requires that **rt11FsLib** be notified when removable disks are changed (for example, when floppies are swapped). This notification is provided by the ready-change mechanism.

Announcing Disk Changes with Ready-Change

A change in ready-status is interpreted by **rt11FsLib** to mean that the disk must be remounted during the next I/O operation. There are three ways to announce a ready-change:

- By calling ***rt11FsReadyChange*( )** directly.
- By calling ***ioctl*( )** with **FIODISKCHANGE**.
- By having the device driver set the **bd_readyChanged** field in the **BLK_DEV** structure to TRUE; this has the same effect as notifying **rt11FsLib** directly.

The ready-change announcement does not cause buffered data to be flushed to the disk; it merely marks the volume as needing remounting. As a result, data written to files or directory entry changes can be lost. To avoid this loss of data, close all files on the volume before changing the disk.

Ready-change can be used in ISRs, because it does not attempt to flush data or perform other operations that could cause delay.

The block device driver status-check routine (identified by the **bd_statusChk** field in the **BLK_DEV** structure) can be useful for asserting ready-change for devices that only detect a disk change after the new disk is inserted. This routine is called at the start of each ***open*( )** or ***creat*( )**, before the file system checks for ready-change.

Disks with No Change Notification

If it is not possible for a ready-change to be announced each time the disk is changed, the device must be specially identified when it is initialized for use with the file system. This is done by setting the **changeNoWarn** parameter to TRUE when calling ***rt11FsDevInit*( )**.

When this parameter is defined as TRUE, the disk is checked regularly to obtain the current directory information (in case the disk is removed and a new one inserted). As a result, this option causes a significant loss in performance.

4.3.9 I/O Control Functions Supported by rt11FsLib

The rt11Fs file system supports the ***ioctl*( )** functions shown in Table 4-6. The functions listed are defined in the header file **ioLib.h.** For more information, see the manual entries for **rt11FsLib** and for ***ioctl*( )** in **ioLib**.

4.4 Raw File System: rawFs

VxWorks provides a minimal "file system," rawFs, for use in systems that require only the most basic disk I/O functions. The rawFs file system, implemented in **rawFsLib**, treats the entire disk volume much like a single large file. Although the dosFs and rt11Fs file systems do provide this ability to varying degrees, the rawFs file system offers advantages in size and performance if more complex functions are not required.

Table 4-6 **I/O Control Functions Supported by rt11FsLib**

Function	Decimal Value	Description
FIODIRENTRY	9	Get information about specified device directory entries.
FIODISKCHANGE	13	Announce a media change.
FIODISKFORMAT	5	Format the disk.
FIODISKINIT	6	Initialize an rt11Fs file system on a disk volume.
FIOFLUSH	2	Flush the file output buffer.
FIOFSTATGET	38	Get file status information (directory entry data).
FIOGETNAME	18	Get the file name of the *fd*.
FIONREAD	1	Get the number of unread bytes in a file.
FIOREADDIR	37	Read the next directory entry.
FIORENAME	10	Rename a file.
FIOSEEK	7	Reset the current byte offset in a file.
FIOSQUEEZE	15	Coalesce fragmented free space on an rt11Fs volume.
FIOWHERE	8	Return the current byte position in a file.

4.4.1 Disk Organization

As mentioned previously, rawFs imposes no organization of the data on the disk.

The rawFs file system maintains no directory information; thus there is no division of the disk area into specific files, and no file names are used. All ***open*( )** operations on rawFs devices specify only the device name; no additional file names are allowed.

The entire disk area is available to any file descriptor that is open for the device. All read and write operations to the disk use a byte-offset relative to the start of the first block on the disk.

4.4.2 Initializing the rawFs File System

Before any other operations can be performed, the rawFs library, **rawFsLib**, must be initialized by calling ***rawFsInit*( )**. This routine takes a single parameter, the maximum number of rawFs file descriptors that can be open at one time. This count is used to allocate a set of descriptors; a descriptor is used each time a rawFs device is opened.

The ***rawFsInit*( )** routine also makes an entry for the rawFs file system in the I/O system driver table (with ***iosDrvInstall*( )**). This entry specifies the entry points for rawFs file operations and is for all devices that use the rawFs file system. The driver number assigned to the rawFs file systems is placed in a global variable **rawFsDrvNum**.

The ***rawFsInit*( )** routine is normally called by the ***usrRoot*( )** task after starting the VxWorks system. To use this initialization, define **INCLUDE_RAWFS** in the project facility VxWorks view, and set **NUM_RAWFS_FILES** to the desired maximum open file descriptor count on the Params tab of the properties window.

4.4.3 Initializing a Device for Use with the rawFs File System

After the rawFs file system is initialized, the next step is to create one or more devices. Devices are created by the device driver's device creation routine (*xx**DevCreate***( )**). The driver routine returns a pointer to a block device descriptor structure (**BLK_DEV**). The **BLK_DEV** structure describes the physical aspects of the device and specifies the routines in the device driver that a file system can call. For more information on block devices, see *3.9.4 Block Devices*, p.158.

Immediately after its creation, the block device has neither a name nor a file system associated with it. To initialize a block device for use with rawFs, the already-created block device must be associated with rawFs and a name must be assigned to it. This is done with the ***rawFsDevInit*( )** routine. Its parameters are the name to be used to identify the device and a pointer to the block device descriptor structure (**BLK_DEV**):

```
RAW_VOL_DESC *pVolDesc;
BLK_DEV      *pBlkDev;
pVolDesc = rawFsDevInit ("DEV1:", pBlkDev);
```

The ***rawFsDevInit*( )** call assigns the specified name to the device and enters the device in the I/O system device table (with ***iosDevAdd*( )**). It also allocates and initializes the file system's volume descriptor for the device. It returns a pointer to the volume descriptor to the caller; this pointer is used to identify the volume during certain file system calls.

Note that initializing the device for use with rawFs does not format the disk. That is done using an ***ioctl*( )** call with the **FIODISKFORMAT** function.

No disk initialization (**FIODISKINIT**) is required, because there are no file system structures on the disk. Note, however, that rawFs accepts that ***ioctl*( )** function code for compatibility with other file systems; in such cases, it performs no action and always returns **OK**.

4.4.4 Mounting Volumes

A disk volume is *mounted* automatically, generally during the first ***open*( )** or ***creat*( )** operation. (Certain ***ioctl*( )** functions also cause the disk to be mounted.) The volume is again mounted automatically on the first disk access following a ready-change operation (see *4.4.6 Changing Disks*, p. 213).

⚠ **CAUTION:** Because device names are recognized by the I/O system using simple substring matching, file systems should not use a slash (**/**) alone as a name; unexpected results may occur.

4.4.5 File I/O

To begin I/O to a rawFs device, first open the device using the standard ***open*( )** function. (The ***creat*( )** function can be used instead, although nothing is actually "created.") Data on the rawFs device is written and read using the standard I/O routines ***write*( )** and ***read*( )**. For more information, see *3.3 Basic I/O*, p. 98.

The character pointer associated with a file descriptor (that is, the byte offset where reads and writes take place) can be set by using ***ioctl*( )** with the **FIOSEEK** function.

Multiple file descriptors can be open simultaneously for a single device. These must be carefully managed to avoid modifying data that is also being used by another file descriptor. In most cases, such multiple open descriptors use **FIOSEEK** to set their character pointers to separate disk areas.

4.4.6 Changing Disks

The rawFs file system must be notified when removable disks are changed (for example, when floppies are swapped). Two different notification methods are provided: (1) ***rawFsVolUnmount( )*** and (2) the ready-change mechanism.

Unmounting Volumes

The first method of announcing a disk change is to call ***rawFsVolUnmount( )*** prior to removing the disk. This call flushes all modified file descriptor buffers if possible (see *Synchronizing Volumes*, p.214) and also marks any open file descriptors as obsolete. The next I/O operation remounts the disk. Calling ***ioctl( )*** with **FIOUNMOUNT** is equivalent to using ***rawFsVolUnmount( )***. Any open file descriptor to the device can be used in the ***ioctl( )*** call.

Attempts to use obsolete file descriptors for further I/O operations produce an **S_rawFsLib_FD_OBSOLETE** error. To free an obsolete descriptor, use ***close( )***, as usual. This frees the descriptor even though it produces the same error.

ISRs must not call ***rawFsVolUnmount( )*** directly, because the call can pend while the device becomes available. The ISR can instead give a semaphore that prompts a task to unmount the volume. (Note that ***rawFsReadyChange( )*** can be called directly from ISRs; see *Announcing Disk Changes with Ready-Change*, p.213.)

When ***rawFsVolUnmount( )*** is called, it attempts to write buffered data out to the disk. Its use is therefore inappropriate for situations where the disk-change notification does not occur until a new disk is inserted, because the old buffered data would be written to the new disk. In this case, use ***rawFsReadyChange( )***, which is described in *Announcing Disk Changes with Ready-Change*, p.213.

If ***rawFsVolUnmount( )*** is called after the disk is physically removed, the data flushing portion of its operation fails. However, the file descriptors are still marked as obsolete, and the disk is marked as requiring remounting. An error is *not* returned by ***rawFsVolUnmount( )***; to avoid lost data in this situation, explicitly synchronize the disk before removing it (see *Synchronizing Volumes*, p.214).

Announcing Disk Changes with Ready-Change

The second method of announcing that a disk change is taking place is with the *ready-change* mechanism. A change in the disk's ready-status is interpreted by **rawFsLib** to indicate that the disk must be remounted during the next I/O call.

There are three ways to announce a ready-change:

- By calling ***rawFsReadyChange*( )** directly.
- By calling ***ioctl*( )** with **FIODISKCHANGE**.
- By having the device driver set the **bd_readyChanged** field in the **BLK_DEV** structure to TRUE; this has the same effect as notifying **rawFsLib** directly.

The ready-change announcement does not cause buffered data to be flushed to the disk. It merely marks the volume as needing remounting. As a result, data written to files can be lost. This can be avoided by synchronizing the disk before asserting ready-change. The combination of synchronizing and asserting ready-change provides all the functionality of ***rawFsVolUnmount*( )** except for marking file descriptors as obsolete.

Ready-change can be used in ISRs, because it does not attempt to flush data or perform other operations that could cause delay.

The block device driver status-check routine (identified by the **bd_statusChk** field in the **BLK_DEV** structure) is useful for asserting ready-change for devices that only detect a disk change after the new disk is inserted. This routine is called at the beginning of each ***open*( )** or ***creat*( )**, before the file system checks for ready-change.

Disks with No Change Notification

If it is not possible for a ready-change to be announced each time the disk is changed, close all file descriptors for the volume before changing the disk.

Synchronizing Volumes

When a disk is *synchronized*, all buffered data that is modified is written to the physical device so that the disk is up to date. For the rawFs file system, the only such data is that contained in open file descriptor buffers.

To avoid loss of data, synchronize a disk before removing it. You may need to explicitly synchronize a disk, depending on when (or if) the ***rawFsVolUnmount*( )** call is issued.

When ***rawFsVolUnmount*( )** is called, an attempt is made to synchronize the device before unmounting. If this disk is still present and writable at the time of the call, synchronization takes place automatically; there is no need to synchronize the disk explicitly.

However, if the ***rawFsVolUnmount*( )** call is made after a disk is removed, it is obviously too late to synchronize, and ***rawFsVolUnmount*( )** discards the buffered data. Therefore, make a separate ***ioctl*( )** call with the **FIOSYNC** function before removing the disk. (For example, this could be done in response to an operator command.) Any open file descriptor to the device can be used during the ***ioctl*( )** call. This call writes all modified file descriptor buffers for the device out to the disk.

4.4.7 I/O Control Functions Supported by rawFsLib

The rawFs file system supports the ***ioctl*( )** functions shown in Table 4-7. The functions listed are defined in the header file **ioLib.h**. For more information, see the manual entries for **rawFsLib** and for ***ioctl*( )** in **ioLib**.

Table 4-7 **I/O Control Functions Supported by rawFsLib**

Function	Decimal Value	Description
FIODISKCHANGE	13	Announce a media change.
FIODISKFORMAT	5	Format the disk (device driver function).
FIODISKINIT	6	Initialize a rawFs file system on a disk volume (not required).
FIOFLUSH	2	Same as **FIOSYNC**.
FIOGETNAME	18	Get the file name of the *fd*.
FIONREAD	1	Get the number of unread bytes on the device.
FIOSEEK	7	Set the current byte offset on the device.
FIOSYNC	21	Write out all modified file descriptor buffers.
FIOUNMOUNT	39	Unmount a disk volume.
FIOWHERE	8	Return the current byte position on the device.

4.5 Tape File System: tapeFs

The tapeFs library, **tapeFsLib**, provides basic services for tape devices that do not use a standard file or directory structure on tape. The tape volume is treated much like a raw device where the entire volume is a large file. Any data organization on this large file is the responsibility of a higher-level layer.

4.5.1 Tape Organization

The tapeFs file system imposes no organization of the data on the tape volume. It maintains no directory information; there is no division of the tape area into specific files; and no file names are used. An ***open*( )** operation on the tapeFs device specifies only the device name; no additional file names are allowed.

The entire tape area is available to any file descriptor open for the device. All read and write operations to the tape use a location offset relative to the current location of the tape head. When a file is configured as a rewind device and first opened, tape operations begin at the beginning-of-medium (BOM); see *Initializing a Device for Use with the tapeFs File System*, p. 217. Thereafter, all operations occur relative to where the tape head is located at that instant of time. No location information, as such, is maintained by tapeFs.

4.5.2 Using the tapeFs File System

Before tapeFs can be used, it must be configured by defining **INCLUDE_TAPEFS** in the BSP file **config.h**. (See *8.5 Configuring VxWorks*, p. 337.) Note that the tape file system must be configured with SCSI-2 enabled. See *Configuring SCSI Drivers*, p. 129 for configuration details.

Once the tape file system has been configured, you must initialize it and then define a tape device. Once the device is initialized, the physical tape device is available to the tape file system and normal I/O system operations can be performed.

Initializing the tapeFs File System

The tapeFs library, **tapeFsLib**, is initialized by calling ***tapeFsInit*( )**. Each tape file system can handle multiple tape devices. However, each tape device is allowed only one file descriptor. Thus you cannot open two files on the same tape device.

The ***tapeFsInit*( )** routine also makes an entry for the tapeFs file system in the I/O system driver table (with ***iosDrvInstall*( )**). This entry specifies function pointers to carry out tapeFs file operations on devices that use the tapeFs file system. The driver number assigned to the tapeFs file system is placed in a global variable, **tapeFsDrvNum**.

When initializing a tape device, ***tapeFsInit*( )** is called automatically if ***tapeFsDevInit*( )** is called; thus, the tape file system does not require explicit initialization.

Initializing a Device for Use with the tapeFs File System

Once the tapeFs file system has been initialized, the next step is to create one or more devices that can be used with it. This is done using the sequential device creation routine, ***scsiSeqDevCreate*( )**. The driver routine returns a pointer to a sequential device descriptor structure, **SEQ_DEV**. The **SEQ_DEV** structure describes the physical aspects of the device and specifies the routines in the device driver that tapeFs can call. For more information on sequential devices, see the manual entry for ***scsiSeqDevCreate*( )**, *Configuring SCSI Drivers*, p.129, *3.9.4 Block Devices*, p.158, and Example 3-6.

Immediately after its creation, the sequential device has neither a name nor a file system associated with it. To initialize a sequential device for use with tapeFs, call ***tapeFsDevInit*( )** to assign a name and declare a file system. Its parameters are the volume name, for identifying the device; a pointer to **SEQ_DEV**, the sequential device descriptor structure; and a pointer to an initialized tape configuration structure **TAPE_CONFIG.** This structure has the following form:

```
typedef struct  /* TAPE_CONFIG tape device config structure */
    {
    int blkSize;            /* block size; 0 => var. block size */
    BOOL rewind;            /* TRUE => a rewind device; FALSE => no rewind */
    int numFileMarks;       /* not used */
    int density;            /* not used */
    } TAPE_CONFIG;
```

In the preceding definition of **TAPE_CONFIG**, only two fields, **blkSize** and **rewind**, are currently in use. If **rewind** is TRUE, then a tape device is rewound to the beginning-of-medium (BOM) upon closing a file with ***close*( )**. However, if **rewind** is FALSE, then closing a file has no effect on the position of the read/write head on the tape medium.

For more information on initializing a tapeFs device, see the online reference for ***tapeFsDevInit*( )** under VxWorks Reference Manual>Libraries.

The **blkSize** field specifies the block size of the physical tape device. Having set the block size, each read or write operation has a transfer unit of **blkSize**. Tape devices can perform fixed or variable block transfers, a distinction also captured in the **blkSize** field.

Fixed Block and Variable Block Devices

A tape file system can be created for fixed block size transfers or variable block size transfers, depending on the capabilities of the underlying physical device. The type of data transfer (fixed block or variable block) is usually decided when the tape device is being created in the file system, that is, before the call to ***tapeFsDevInit*( )**. A block size of zero represents variable block size data transfers.

Once the block size has been set for a particular tape device, it is usually not modified. To modify the block size, use the ***ioctl*( )** functions **FIOBLKSIZESET** and **FIOBLKSIZEGET** to set and get the block size on the physical device.

Note that for fixed block transfers, the tape file system buffers a block of data. If the block size of the physical device is changed after a file is opened, the file should first be closed and then re-opened in order for the new block size to take effect.

Example 4-4 **Tape Device Configuration**

There are many ways to configure a tape device. In this code example, a tape device is configured with a block size of 512 bytes and the option to rewind the device at the end of operations.

```
/* global variables assigned elsewhere */

SCSI_PHYS_DEV *   pScsiPhysDev;

/* local variable declarations */

TAPE_VOL_DESC *  pTapeVol;
SEQ_DEV  *       pSeqDev;
TAPE_CONFIG      pTapeConfig;

/* initialization code */

pTapeConfig.blkSize  = 512;
pTapeConfig.rewind   = TRUE;
pSeqDev    = scsiSeqDevCreate (pScsiPhysDev);
pTapeVol   = tapeFsDevInit ("/tape1", pSeqDev, pTapeConfig);
```

The ***tapeFsDevInit*( )** call assigns the specified name to the device and enters the device in the I/O system device table (with ***iosDevAdd*( )**). The return value of this routine is a pointer to a volume descriptor structure that contains volume-specific configuration and state information.

Mounting Volumes

A tape volume is *mounted* automatically during the ***open*( )** operation. There is no specific mount operation, that is, the mount is implicit in the ***open*( )** operation.

⚠ **CAUTION:** Because device names are recognized by the I/O system using simple substring matching, file systems should not use a slash (**/**) alone as a name; unexpected results may occur.

Modes of Operation

The tapeFs tape volumes can be operated in only one of two modes: read-only (**O_RDONLY**) or write-only (**O_WRONLY**). There is no read-write mode. The mode of operation is defined when the file is opened using ***open*( )**.

File I/O

To begin I/O to a tapeFs device, the device is first opened using ***open*( )**. Data on the tapeFs device is written and read using the standard I/O routines ***write*( )** and ***read*( )**. For more information, see *3.7.6 Block Devices*, p.127.

End-of-file markers can be written using ***ioctl*( )** with the **MTWEOF** function. For more information, see *I/O Control Functions Supported by tapeFsLib*, p.220.

Changing Tapes

The tapeFs file system should be notified when removable media are changed (for example, when tapes are swapped). The ***tapeFsVolUnmount*( )** routine controls the mechanism to unmount a tape volume.

A tape should be unmounted before it is removed. Prior to unmounting a tape volume, an open file descriptor must be closed. Closing an open file flushes any buffered data to the tape, thus synchronizing the file system with the data on the tape. To flush or synchronize data, call ***ioctl*( )** with the **FIOFLUSH** or **FIOSYNC** functions, prior to closing the file descriptor.

After closing any open file, call ***tapeFsVolUnmount*( )** before removing the tape. Once a tape has been unmounted, the next I/O operation must remount the tape using ***open*( )**.

Interrupt handlers must not call ***tapeFsVolUnmount( )*** directly, because it is possible for the call to pend while the device becomes available. The interrupt handler can instead give a semaphore that prompts a task to unmount the volume.

I/O Control Functions Supported by tapeFsLib

The tapeFs file system supports the ***ioctl( )*** functions shown in Table 4-8. The functions listed are defined in the header files **ioLib.h**, **seqIo.h**, and **tapeFsLib.h.** For more information, see the reference entries for **tapeFsLib**, **ioLib**, and ***ioctl( )***.

Table 4-8 **I/O Control Functions Supported by tapeFsLib**

Function	Value	Meaning
FIOFLUSH	2	Write out all modified file descriptor buffers.
FIOSYNC	21	Same as **FIOFLUSH**.
FIOBLKSIZEGET	1001	Get the actual block size of the tape device by issuing a driver command to it. Check this value with that set in the **SEQ_DEV** data structure.
FIOBLKSIZESET	1000	Set the block size of the tape device on the device and in the **SEQ_DEV** data structure.
MTIOCTOP	1005	Perform a UNIX-like **MTIO** operation to the tape device. The type of operation and operation count is set in an **MTIO** structure passed to the ***ioctl( )*** routine. The **MTIO** operations are defined in Table 4-9.

The **MTIOCTOP** operation is compatible with the UNIX **MTIOCTOP** operation. The argument passed to ***ioctl( )*** with **MTIOCTOP** is a pointer to an **MTOP** structure that contains the following two fields:

```
typedef struct mtop
    {
    short mt_op;   /* operation */
    int  mt_count; /* number of operations */
    } MTOP;
```

The **mt_op** field contains the type of **MTIOCTOP** operation to perform. These operations are defined in Table 4-9. The **mt_count** field contains the number of times the operation defined in **mt_op** should be performed.

Table 4-9 **MTIOCTOP Operations**

Function	Value	Meaning
MTWEOF	0	Write an end-of-file record or "file mark."
MTFSF	1	Forward space over file mark.
MTBSF	2	Backward space over file mark.
MTFSR	3	Forward space over data block.
MTBSR	4	Backward space over data block.
MTREW	5	Rewind the tape device to the beginning-of-medium.
MTOFFL	6	Rewind and put the drive offline.
MTNOP	7	No operation, sets status in the **SEQ_DEV** structure only.
MTRETEN	8	Re-tension the tape (cartridge tape only).
MTERASE	9	Erase the entire tape.
MTEOM	10	Position tape to end-of-media.
MTNBSF	11	Backward space file to beginning-of-medium.

4.6 CD-ROM File System: cdromFs

The cdromFs library, **cdromFsLib**, lets applications read any CD-ROM that is formatted in accordance with ISO 9660 file system standards. After initializing cdromFs and mounting it on a CD-ROM block device, you can access data on that device using the standard POSIX I/O calls: ***open*( )**, ***close*( )**, ***read*( )**, ***ioctl*( )**, ***readdir*( )**, and ***stat*( )**. The ***write*( )** call always returns an error.

The cdromFs utility supports multiple drives, multiple open files, and concurrent file access. When you specify a pathname, cdromFS accepts both "/" and "\". However, the backslash is not recommended because it might not be supported in future releases.

The strict ISO 9660 specification allows only uppercase file names consisting of 8 characters plus a 3-character suffix.

CdromFs provides access to CD-ROM file systems using any standard **BLK_DEV** structure. The basic initialization sequence is similar to installing a dosFs file system on a SCSI device.

Before cdromFs can be used, it must be configured by defining **INCLUDE_CDROMFS** in **config.h**. (See *8.5 Configuring VxWorks*, p.337.) For information on using cdromFs, see the online reference for **cdromFsLib** under VxWorks Reference Manual>Libraries.

4.7 The Target Server File System: TSFS

The Target Server File System (TSFS) is a full-featured VxWorks file system, but the files operated on by using the file system are actually located on the host. TSFS uses a WDB driver to transfer requests from the I/O system to the target server. The target server reads the request and executes it using the host file system. Thus when you open a file with TSFS, the file being opened is actually on the host. Future ***read*( )** and ***write*( )** calls on the file descriptor obtained from the ***open*( )** call actually read from and write to the opened host file.

The TSFS VIO driver is oriented toward file I/O rather than toward console operations as is the Tornado 1.0 VIO driver. TSFS provides all the I/O features that **netDrv** provides, without requiring any target resource beyond what is already configured to support communication between target and target server. It is possible to access host files randomly without copying the entire file to the target, to load an object module from a virtual file source, and to supply the file name to routines such as ***ld*( )** and ***copy*( )**.

How It Works

Two steps are required to configure TSFS. First, TSFS must be included in your VxWorks image. This creates a new file system entry, **/tgtsvr**. Then the target server must be configured for TSFS, which involves assigning a root directory on your host to TSFS. For example, you could set the TSFS root to **c:\windview\logs**.

Having done this, opening the file **/tgtsvr/eventLog.wvr** from the target causes **c:\windview\logs\eventLog.wvr** to be opened on the host by the target server. A new file descriptor representing that file is returned to the caller on the target.

Each I/O request, including ***open*( )**, is synchronous; the calling target task is blocked until the operation is complete. This provides flow control not available in the console VIO implementation. In addition, there is no need for WTX protocol requests to be issued to associate the VIO channel with a particular host file; the information is contained in the name of the file.

Consider a ***read*( )** call. The driver transmits the ID of the file (previously established by an ***open*( )** call), the address of the buffer to receive the file data, and the desired length of the read to the target server. The target server responds by issuing the equivalent ***read*( )** call on the host and transfers the data read to the target program. The return value of ***read*( )** and any **errno** that might arise are also relayed to the target, so that the file appears to be local in every way. For detailed information on the supported routines and ioctl requests, see the online reference for **wdbTsfsDrv** under VxWorks Reference Manual>Libraries.

Socket Support

TSFS sockets are operated on in a similar way to other TSFS files, using ***open*( )**, ***close*( )**, ***read*( )**, ***write*( )**, and ***ioctl*( )**. To open a TSFS socket use one of the following forms of filename:

```
"TCP:hostIP:port"
"TCP:hostname:port"
```

The *flags* and *permissions* arguments are ignored. The following examples show how to use these filenames:

```
fd = open("/tgtsvr/TCP:phobos:6164"0,0)    /* open socket and connect  */
                                           /* to server phobos         */

fd = open("/tgtsvr/TCP:150.50.50.50:6164",0,0)  /* open socket and     */
                                                /*connect to server    */
                                                /* 150.50.50.50        */
```

The result of this ***open*( )** call is to open a TCP socket on the host and connect it to the target server socket at *hostname* or *hostIP* awaiting connections on *port*. The resultant socket is non-blocking. Use ***read*( )** and ***write*( )** to read and write to the TSFS socket. Because the socket is non-blocking, the ***read*( )** call returns immediately with an error and the appropriate **errno** if there is no data available to read from the socket. Ioctls specific to TSFS sockets are discussed in the online reference for **wdbTsfsDrv** under VxWorks Reference Manual>Libraries. This socket configuration allows WindView to use the socket facility without requiring **sockLib** and the networking modules on the target.

Error Handling

Errors can arise at various points within TSFS and are reported back to the original caller on the target, along with an appropriate error code. The error code returned is the VxWorks **errno** which most closely matches the error experienced on the host. If a WDB error is encountered, a WDB error message is returned rather than a VxWorks **errno**.

Security Considerations

While TSFS has much in common with **netDrv**, the security considerations are different. With TSFS, the host file operations are done on behalf of the user that launched the target server. The user name given to the target as a boot parameter has no effect. In fact, none of the boot parameters have any effect on the access privileges of TSFS.

In this environment, it is less clear to the user what the privilege restrictions to TSFS actually are, since the user ID and host machine that start the target server may vary from invocation to invocation. In any case, any Tornado tool that connects to a target server which is supporting TSFS has access to any file with the same authorizations as the user that started that target server. For this reason, the target server is locked by default when TSFS is started.

The options which have been added to the target server startup routine to control target access to host files using TSFS include:

-R set the root of TSFS

For example, specifying **-R /tftpboot** prepends this string to all TSFS file names received by the target server, so that **/tgtsvr/etc/passwd** maps to **/tftpboot/etc/passwd**. If **-R** is not specified, TSFS is not activated and no TSFS requests from the target will succeed. Restarting the target server without specifying **-R** disables TSFS.

-RW make TSFS read-write

The target server interprets this option to mean that modifying operations (including file create and delete or write) are authorized. If **-RW** is not specified, the default is read only and no file modification are allowed.

WARNING: When you specify **-RW** the target server is locked (reserved to the user who started it). The target server owner can unlock it, but then any Tornado tool that attached to it has exactly the same file access permissions as the target server owner. A target server started on UNIX is automatically owned by the user ID that started it. A target server started on Windows is assigned to the variable **WIND_UID**, which must be set as described in *Setting WIND_UID on Windows Hosts*, p.225.

Setting WIND_UID on Windows Hosts

The variable **WIND_UID** must be set to use TSFS with WindView on Windows hosts. There are two ways to set it:

- Use the **System Properties** dialog box, accessible through the **Control Panel**, to set the value of **WIND_UID**. This technique makes the value available to all tools in your environment.
- Type a unique number or string at the DOS prompt:

  ```
  % set WIND_UID=num
  ```

  If you choose this option, you must set **WIND_UID** before starting both Tornado and the target server because both must have **WIND_UID** set to the same value. Note that this method sets **WIND_UID** only for tools that are started from this DOS prompt.

NOTE: If you have an environment that mixes Windows and UNIX hosts, you may want to set **WIND_UID** to your UNIX user ID number. This will allow you to attach the Tornado session on your Windows host to a target server running on your UNIX host.

For more information on **WIND_UID**, see the *Tornado User's Guide (Windows version): Target Server.*

5
C++ Development

Basic Support and the Optional Component Wind Foundation Classes

5.1 Introduction

In the Tornado environment, C++ development support consists of the GNU C++ toolchain, run-time support, the Standard Template Library (STL), exception handling, Run-Time Type Identification (RTTI), and the Iostream library. In addition, Wind River Systems offers an optional product, the Wind Foundation Classes, providing several additional class libraries to extend VxWorks functionality.

This chapter discusses basic application development using C++ and provides references to relevant information in other Wind River documentation. In addition, the Iostream library and the Wind Foundation Classes are documented here.

The Standard Template Library provides support for "generic" programming. Two template instantiation strategies are supported. Templates may be instantiated in every translation unit that uses them, or the compiler can determine where to instantiate them. The STL is VxWorks thread safe at the class level.

Exception handling is available for use in your application code. The GNU Iostream library does not throw without specific enabling. The STL throws only in some methods in the basic_string class.

The Iostream library provides support for formatted I/O in C++. The C++ language definition (like C) does not include special input and output statements, relying instead on standard library facilities. The Iostream library provides C++ capabilities analogous to the C functions offered by the *stdio* library. The principal differences are that the Iostream library gives you enhanced type security and can be extended to support your own class definitions. The Iostream library is thread safe at the object level.

The Wind Foundation Classes consist of a group of libraries (some of which are industry standard) that provide a broad range of C++ classes to extend VxWorks functionality in several important ways. They are called *Foundation* classes because they provide basic services which are fundamental to many programming tasks, and which can be used in almost every application domain. For information about how to install the Wind Foundation Classes, see *Tornado Getting Started*.

The Wind Foundation Classes consist of the following libraries:

- VxWorks Wrapper Class library
- Tools.h++ library from Rogue Wave Software

5.2 C++ Development Under Tornado

Basic C++ support is bundled with the Tornado development environment. VxWorks provides header files containing C++ safe declarations for all routines and the necessary run-time support. The standard Tornado interactive development tools such as the debugger, the shell, and the incremental loader include C++ support.

5.2.1 Tools Support

WindSh

Tornado supports both C and C++ as development languages. WindSh can interpret simple C++ expressions. To exercise C++ facilities that are missing from the C-expression interpreter, you can compile and download routines that encapsulate the special C++ syntax. See the *Tornado User's Guide: Tornado Tools Reference* or the HTML online reference for WindSh C++ options.

Demangling

When C++ functions are compiled, the class membership (if any) and the type and number of the function's arguments are encoded in the function's linkage name. This is called *name mangling* or *mangling*. The debugging and system information routines in WindSh can print C++ function names in demangled or mangled representations.

The default representation is **gnu**. In addition, **arm** and **none** (no demangling) are available options. To select an alternate mode, modify the Tcl variable **shDemangleStyle**. For instance:

```
-> ?set shDemangleStyle none
```

Overloaded Function Names

When you invoke an overloaded function, WindSh prints the matching functions' signatures and prompts you for the desired function. For more information on how WindSh handles overloaded function names, including an example, see the *Tornado User's Guide: Shell*.

Debugger

The Tornado debugger supports debugging of C++ class member functions including stepping through constructors and templates. For details, see the *Tornado User's Guide: Tornado Tools Reference* and *Debugging with GDB*.

5.2.2 Programming Issues

Making C++ Entry Points Accessible to C Code

If you want to reference a (non-overloaded, global) C++ symbol from your C code you will need to give it C linkage by prototyping it using **extern "C"**:

```
#ifdef __cplusplus
extern "C" void myEntryPoint ();
#else
void myEntryPoint ();
#endif
```

You can also use this syntax to make C symbols accessible to C++ code. VxWorks C symbols are automatically available to C++ because the VxWorks header files use this mechanism for declarations.

5.2.3 Compiling C++ Applications

The Tornado project tool fully supports C++. The recommended way to configure and compile C++ applications is to use the project tool. The information below may be useful for understanding the C++ environment but unless you have a particular reason to use manual methods, you should use the methods explained in the *Tornado User's Guide: Projects*.

For details on the GNU compiler and on the associated tools, see the *GNU ToolKit User's Guide*.

When compiling C++ modules with the GNU compiler, invoke **cc***arch* (just as for C source) on any source file with a C++ suffix (such as **.cpp**). Compiling C++ applications in the VxWorks environment involves the following steps:

1. Each C++ source file is compiled into object code for your target architecture, just as for C applications. For example, to compile for a 68K target:

```
cc68k -fno-builtin -I$WIND_BASE/target/h -nostdinc -O2 \
    -DCPU=MC68040 -c foo.cpp
cc68k -fno-builtin -I$WIND_BASE/target/h -nostdinc -O2 \
    -DCPU=MC68040 -c bar.cpp
```

2. The objects are munched (see *5.2.5 Munching C++ Application Modules*, p.232). In our example:

```
nm68k foo.o bar.o | wtxtcl $WIND_BASE/host/src/hutils/munch.tcl \
    -asm 68k > ctdt.c
cc68k -c ctdt.c
```

3. The objects are linked with the compiled munch output. (They may be partially linked using **-r** for downloadable applications or statically linked with a VxWorks BSP for bootable applications.) If you are using the GNU tools, invoke the linker from the compiler driver as follows:

```
cc68k -r ctdt.o foo.o bar.o -o linkedObjs.o
```

   Here we have linked two objects modules, **foo.o** and **bar.o**, to give a downloadable object, **linkedObjs.o**. Using cc*arch* rather than ld*arch* performs template instantiation if you use the **-frepo** option. (see *5.2.7 Template Instantiation*, p.234).

NOTE: If you use a Wind River Systems makefile to build your application, munching is handled by **make**.

WARNING: In the linking step, **-r** is used to specify partial linking. A partially linked file is still relocatable, and is suitable for downloading and linking using the VxWorks module loader. The *GNU ToolKit User's Guide: Using ld* describes a **-Ur** option for resolving references to C++ constructors. That option is for native development, not for cross-development. Do not use **-Ur** with C++ modules for VxWorks.

5.2.4 Configuration Constants

By default VxWorks kernels contain the C++ run-time, basic Iostream functionality and support for the Standard Template Library. You may add/remove C++ components by including any of the following macros:

INCLUDE_CPLUS
Includes all basic C++ run-time support in VxWorks. This enables you to download and run compiled and munched C++ modules. It does not configure any of the Wind Foundation Class libraries into VxWorks.

INCLUDE_CPLUS_STL
Includes support for the standard template library.

INCLUDE_CPLUS_STRING
Includes the basic components of the string type library.

INCLUDE_CPLUS_IOSTREAMS
Includes the basic components of the Iostream library.

INCLUDE_CPLUS_COMPLEX
Includes the basic components of the complex type library.

INCLUDE_CPLUS_IOSTREAMS_FULL
Includes the full Iostream library; this implies **INCLUDE_CPLUS_IOSTREAMS**.

INCLUDE_CPLUS_STRING_IO
Includes string I/O function; this implies **INCLUDE_CPLUS_STRING** and **INCLUDE_CPLUS_IOSTREAMS**.

INCLUDE_CPLUS_COMPLEX_IO
Includes I/O for complex number objects; this implies **INCLUDE_CPLUS_IOSTREAMS** and **INCLUDE_CPLUS_COMPLEX**.

To include one or more of the Wind Foundation Classes, include one or more of the following constants:

INCLUDE_CPLUS_VXW
Includes the VxWorks Wrapper Class library.

INCLUDE_CPLUS_TOOLS
Includes Rogue Wave's Tools.h++ class library.

For more information on configuring VxWorks, see the *Tornado User's Guide: Projects*.

5.2.5 Munching C++ Application Modules

Modules written in C++ must undergo an additional host processing step before being downloaded to a VxWorks target. This extra step (called *munching*, by convention) initializes support for static objects and ensures that when the module is downloaded to VxWorks, the C++ run-time support is able to call the correct constructors and destructors in the correct order for all static objects.

The following commands will compile **hello.cpp**, then munch **hello.o**, resulting in the munched file **hello.out** suitable for loading by the Tornado module loader:

```
cc68k -IinstallDir/target/h -DCPU=MC68020 -nostdinc -fno-builtin \
        -c hello.cpp
nm68k hello.o | wtxtcl installDir/host/src/hutils/munch.tcl \
        -asm 68k > ctdt.c
cc68k -c ctdt.c
ld68k -r -o hello.out hello.o ctdt.o
```

NOTE: You can substitute the actual name of your *installDir* or use **$WIND_BASE** (UNIX) or **%WIND_BASE%** (Windows).

CAUTION: The *GNU ToolKit User's Guide: Using ld* describes a **-Ur** option for resolving references to C++ constructors. That option is for native development, not for cross-development. Do not use **-Ur** with C++ modules for VxWorks.

5.2.6 Static Constructors and Destructors

After munching, downloading, and linking, the static constructors and destructors must be called.

Calling Static Constructors and Destructors Interactively

VxWorks provides two strategies for calling static constructors and destructors interactively:

automatic
: Static *constructors* are called as a side effect of downloading. Static *destructors* are called as a side effect of unloading.

manual
: Static constructors and destructors are called indirectly by invoking ***cplusCtors*( )** and ***cplusDtors*( )**.

Use ***cplusXtorSet*( )** to change the strategy; see its entry in the **windsh** reference entry for details. To report on the current strategy, call ***cplusStratShow*( )**.

Under the automatic strategy, which is the default, static constructors are called immediately after a successful download. If the automatic strategy is set *before* a module is downloaded, that module's static constructors are called before the module loader returns to its caller. Under the automatic strategy, the module unloader calls a module's static destructors before actually unloading the module.

The manual strategy causes static constructors to be called as a result of invoking ***cplusCtors*( )**. Refer to the entries for ***cplusCtors*( )** and ***cplusDtors*( )** in the **windsh** reference for more information. To invoke all currently-loaded static constructors or destructors, manual mode can be used with no argument. Manual mode can also be used to call static constructors and destructors explicitly on a module-by-module basis.

Constructors and Destructors in System Startup and Shutdown

When you create bootable VxWorks applications, call static constructors during system initialization. Modify the ***usrRoot*( )** routine in **usrConfig.c** to include a call to ***cplusCtorsLink*( )**. This calls all static constructors linked with your system.

To modify **usrConfig.c** to call ***cplusCtorsLink*( )**, locate the C++ initialization sections:

```
#ifdef INCLUDE_CPLUS           /* C++ product */
    cplusLibInit ();
#endif

#ifdef INCLUDE_CPLUS_MIN       /* C++ product */
    cplusLibMinInit ();
#endif
```

Next, add ***cplusCtorsLink*( )** to one or both sections, depending on your system requirements. In the following example, ***cplusCtorsLink*( )** is called only when minimal C++ is configured:

```
#ifdef INCLUDE_CPLUS_MIN       /* C++ product */
    cplusLibMinInit ();
    cplusCtorsLink ();
#endif
```

⚠ **CAUTION:** Static objects are not initialized until the call to ***cplusCtorsLink*( )**. Thus, if your application uses static objects in ***usrRoot*( )**, call ***cplusCtorsLink*( )** before using them.

For ***cplusCtorsLink*( )** to work correctly, you must perform the munch operation on the fully-linked VxWorks image rather than on individual modules.

A corresponding routine, ***cplusDtorsLink*( )**, is provided to call all static destructors. This routine is useful in systems that have orderly shutdown procedures. Include a call to ***cplusDtorsLink*( )** at the point in your code where it is appropriate to call all static destructors that were initially linked with your system.

The ***cplusCtorsLink*( )** and ***cplusDtorsLink*( )** routines do not call static constructors and destructors for modules that are downloaded after system initialization. If your system uses the module downloader, follow the procedures described in *Calling Static Constructors and Destructors Interactively*, p.233.

5.2.7 Template Instantiation

Our C++ toolchain supports three distinct template instantiation strategies. The simplest (and the one that is used by default in VxWorks makefiles) is *implicit instantiation*. In this case code for each template gets emitted in every module that needs it. For this to work the body of a template must be available in each module that uses it. Typically this is done by including template function bodies along with their declarations in a header file. The disadvantage of implicit instantiation is that it may lead to code duplication and larger application size.

The second approach is to explicitly instantiate any templates you require using the syntax found in Example 5-1. In this case you should compile with **-fno-implicit-templates**. This scheme allows you the most control over where templates get instantiated and avoids code bloat.

-frepo

This approach combines the simplicity of implicit instantiation with the smaller footprint obtained by instantiating templates by hand. It works by manipulating a database of template instances for each module.

The compiler will generate files with the extension **.rpo**; these files list all the template instantiations used in the corresponding object files which could be instantiated there. The link wrapper **collect2** then updates the **.rpo** files to tell the compiler where to place those instantiations and rebuilds any affected object files. The link-time overhead is negligible after the first pass, as the compiler continues to place the instantiations in the same files.

Procedure

The header file for a template must contain the template body. If template bodies are currently stored in **.cpp** files, the line **#include** *theTemplate***.cpp** must be added to *theTemplate***.h**.

A full build with the **-frepo** option is required to create the **.rpo** files that tell the compiler which templates to instantiate. The link step should be driven from **cc***arch* rather than **ld***arch*.

Subsequently individual modules can be compiled as usual (but with the **-frepo** option and no other template flags).

When a new template instance is required the relevant part of the project must be rebuilt to update the **.rpo** files.

Loading Order

The Tornado tools' dynamic linking ability requires that the module containing a symbol definition be downloaded before a module that references it. For instance, in the example below you should download **PairA.o** before downloading **PairB.o**. (You could also prelink them and download the linked object).

Example

This example uses a standard VxWorks BSP makefile (for concreteness, we assume a 68K target).

Example 5-1 **Sample Makefile**

```
make PairA.o PairB.o ADDED_C++FLAGS=-frepo

/* dummy link step to instantiate templates */
cc68k -r -o Pair PairA.o PairB.o
```

```
/* In this case the template Pair<int>::Sum(void)
 * will be instantiated in PairA.o.
 */

//Pair.h

template <class T> class Pair
{
public:
    Pair (T _x, T _y);
    T Sum ();

protected:
    T x, y;
};

template <class T>
Pair<T>::Pair (T _x, T _y) : x (_x), y(_y)
{
}

template <class T>
T Pair<T>::Sum ()
{
    return x + y;
}
// PairA.cpp
#include "Pair.h"

int Add (int x, int y)
{
    Pair <int> Two (x, y);
    return Two.Sum ();
}

// PairB.cpp
#include "Pair.h"

int Double (int x)
{
Pair <int> Two (x, x);
return Two.Sum ();
}
```

5.3 C++ Language and Library Support

In this section we describe some of the VxWorks-specific aspects of our C++ implementation. To learn more about the C++ language and the Standard libraries consult any standard C++ reference (a good one is Stroustrup, *The C++ Programming Language*, Third Edition). For documentation on the GNU implementation of the Iostream library see

5.3.1 Language Features

We support many but not all of the new language features contained in the recently approved ANSI C++ Standard. Tornado 2.0 has support for exception handling and run-time type information, as well as improved template support. We do not yet support the namespace feature although the compiler will accept (and ignore) references to the **std** namespace.

Exception Handling

Our C++ compiler supports multithread safe exception handling by default. To turn off exception handling support use the **-fno-exceptions** compiler flag.

Using Exceptions

You may have code which was designed around the pre-exception model of C++ compilation. Your calls to **new** may check the returned pointer for a failure value of zero, for example. If you are worried that the exception handling enhancements in this release will not compile your code correctly, you could adhere to the following simple rules:

- Use new (nothrow).
- Do not explicitly turn on exceptions in your Iostream objects.
- Do not use string objects or wrap them in "try { } catch (...) { }" blocks.

These rules derive from the following observations:

- The GNU Iostream does not throw unless **IO_THROW** is defined when the library is built and exceptions are explicitly enabled for the particular Iostream object in use. The default is no exceptions. Exceptions have to be explicitly turned on for each iostate flag that wants to throw.
- The STL does not throw except in some methods in the **basic_string** class (of which string is a specialization).

Exception Handling Overhead

To support destruction of automatic objects during stack-unwinding the compiler must insert house-keeping code into any function that creates an automatic (stack based) object with a destructor.

Below are some of the costs of exception handling as measured on a PowerPC 604 target (BSP mv2604); counts are in executed instructions. 1,235 instructions are executed to execute a "throw 1" and the associated "catch (...)". There are 14 "extra" instructions to register and deregister automatic variables and temporary objects with destructors and 29 "extra" instructions per non-inlined function for exception-handling setup if any exception handling is used in the function. Finally, the implementation executes 947 "extra" instructions upon encountering the first exception-handling construct (try, catch, throw, or registration of an auto variable or temporary).

```
                            first time   normal case
void test()  {          // 3+29         3+29
    throw 1;            // 1235         1235     total time to printf
}

void doit() {           // 3+29+947     3+29
    try {               // 22           22
        test();         // 1            1
    } catch (...) {
        printf("Hi\n");
    }
}

struct A { ~A( ) { } };

void local_var ( ) {   //               3+29
    A a;               //               14
}                     //              4
```

-fno-exceptions can be used to turn exception handling off. Doing so will reduce the overheads back to classical C++.

Unhandled Exceptions

As required by the Standard, an uncaught exception will eventually lead to a call to ***terminate*( )**. The default behavior of this function is to suspend the offending task and log a warning message to the console. You may install your own termination handler by calling ***set_terminate*( )** (defined in the header file **exception**).

Run-Time Type Information (RTTI)

This feature is turned on by default and adds a small overhead to any C++ program containing classes with virtual functions. If you do not need this feature you may turn it off using **-fno-rtti**.

5.3.2 Standard Template Library (STL)

The Standard Template library consists of a small run-time component (which may be configured into your kernel by selecting **INCLUDE_CPLUS_STL** for inclusion in the project facility VxWorks view) and a set of header files.

Our STL port is VxWorks thread safe at the class level. This means that the client has to provide explicit locking if two tasks want to use the same container object. (For example, this could be done by using a semaphore; for details, see *2.4.3 Semaphores*, p.47.) However two different objects of the same STL container class may be accessed concurrently.

Iostream Library

This library is configured into VxWorks by selecting **INCLUDE_CPLUS_IOSTREAMS** for inclusion in the project facility VxWorks view; see *5.2.4 Configuration Constants*, p.231.

The Iostream library header files reside in the standard VxWorks header file directory, *installDir*/**target/h**. To use this library, include one or more of the header files after the **vxWorks.h** header in the appropriate modules of your application. The most frequently used header file is **iostream.h**, but others are available; see a C++ reference such as Stroustrup for information.

The standard Iostream objects (**cin**, **cout**, **cerr**, and **clog**) are global: that is, they are not private to any given task. They are correctly initialized regardless of the number of tasks or modules that reference them and they may safely be used across multiple tasks that have the same definitions of stdin, stdout, and stderr. However they cannot safely be used in the case that different tasks have different standard i/o file-descriptors; in this case, the responsibility for mutual exclusion rests with the application.

The effect of private standard Iostream objects can be simulated by creating a new Iostream object of the same class as the standard Iostream object (for example, **cin** is an **istream_withassign**), and assigning to it a new **filebuf** object tied to the appropriate file descriptor. The new **filebuf** and Iostream objects are private to the calling task, ensuring that no other task can accidentally corrupt them.

```
ostream my_out (new filebuf (1));            /* 1 == STDOUT */
istream my_in (new filebuf (0), &my_out);    /* 0 == STDIN;
                                              * TIE to my_out */
```

For complete details on the Iostreams library, see the online manual *The GNU C++ Iostream Library*.

String and Complex Number Classes

These classes are part of the new Standard C++ library. They may be configured into the kernel by selecting **INCLUDE_CPLUS_STRING** and **INCLUDE_CPLUS_COMPLEX** for inclusion in the project facility VxWorks view. You may optionally include I/O facilities for these classes by selecting **INCLUDE_CPLUS_STRING_IO** and **INCLUDE_CPLUS_COMPLEX_IO**.

NOTE: Tornado 2.0 C++ support does not include support for multi-byte strings. This includes certain classes which are part of the tools.h++ portion of the Wind Foundation Classes.

5.4 Example

Example 5-2 exercises various C++ features including the Standard Template Library, user defined templates, Run-Time Type Identification, and exception handling. To try it out, create a project containing **factory.cpp** and **factory.h** and build and download **linkedObjs.o**. At the shell type:

```
-> testFactory
```

Full documentation on what you should except to see is given in the source code.

Example 5-2 **Code Factory Example**

```
/* factory.cpp - implements an object factory */

/* Copyright 1993-1998 Wind River Systems, Inc. */

/*
```

```
modification history
--------------------
01a,05oct98,sn   wrote
*/

/*
DESCRIPTION

We implement an "object factory". The first step is to give
classes human-readable names by registering them with a
"global class registry". Then objects of a named type may be
created and registered with an "object registry".

This gives us an opportunity to exercise various C++ features:

* Standard Template Library
    A "map" is used as the basis for the various registries.
* User defined templates
    The class registry and object registry are both based on a
    generic registry type.
* Run Time Type Checking
    We provide a function to determine the type of a registered
    object using "dynamic_cast".
* Exception Handling
    If we attempt to cast to the "wrong" type we have to handle a
    C++ exception.

We provide a C interface to facilitate easy testing from the Wind Shell.

Here is an example test run (you can run this whole test through the
function testFactory()):

-> classRegistryShow
Showing Class Registry ...
Name    Address
=========================================================
blue_t  0x6b1c7a0
green_t 0x6b1c790
red_t   0x6b1c7b0

-> objectRegistryShow
Showing Object Registry ...
Name    Address
=========================================================

-> objectCreate "green_t", "bob"
Creating an object called 'bob' of type 'green_t'

-> objectCreate "red_t", "bill"
Creating an object called 'bill' of type 'red_t'

-> objectRegistryShow
Showing Object Registry ...
Name    Address
=========================================================
bill    0x6b1abf8
```

```
bob     0x6b1ac18

-> objectTypeShowByName "bob"
Looking up object 'bob'
Attempting to ascertain type of object at 0x6b1ac18
Attempting a dynamic_cast to red_t ...
dynamic_cast threw an exception ... caught here!
Attempting a dynamic_cast to blue_t ...
dynamic_cast threw an exception ... caught here!
Attempting a dynamic_cast to green_t ...
Cast to green_t succeeded!
green.

*/

/* includes */
#include "factory.h"

/* locals */

/* pointer to the global class registry */
LOCAL class_registry_t* pClassRegistry;

/* pointer to the global object registry */
LOCAL object_registry_t* pObjectRegistry;

/************************************************************************
*
* testFactory - an example test run
*
*/
void testFactory ()
{
    cout << "classRegistryShow ()" << endl;
    classRegistryShow ();
    cout << "objectRegistryShow ()" << endl;
    objectRegistryShow ();
    cout << "objectCreate (\"green_t\", \"bob\")" << endl;
    objectCreate ("green_t", "bob");
    cout << "objectCreate (\"red_t\", \"bill\")" << endl;
    objectCreate ("red_t", "bill");
    cout << "objectRegistryShow ()" << endl;
    objectRegistryShow ();
    cout << "objectTypeShowByName (\"bob\")" << endl;
    objectTypeShowByName ("bob");
}

/************************************************************************
*
* class_registry_t::create - create an object of type className
*
* Look up 'className' in this registry. If it exists then
* create an object of this type by using the registered class factory;
* otherwise return NULL.
*
* RETURNS : pointer to new object of type className or NULL.
```

```
*/

object_t* class_registry_t::create
    (
    string className
    )
    {
    object_factory_t* pFactory = lookup (className);
    if (pFactory != NULL)
        {
        return lookup (className)-> create ();
        }
    else
        {
        cout << "No such class in Class Registry. " << endl;
        return NULL;
        }
    }

/***************************************************************************
*
* classRegistryGet - get a reference to the global class registry
*
* Create and populate a new class registry if necessary.
*
* RETURNS : a reference to the global class registry
*/

LOCAL class_registry_t& classRegistryGet ()
    {
    if (pClassRegistry == NULL)
        {
        pClassRegistry = new class_registry_t;
        pClassRegistry -> insert ("red_t", new red_factory_t);
        pClassRegistry -> insert ("blue_t", new blue_factory_t);
        pClassRegistry -> insert ("green_t", new green_factory_t);
        }
    return *pClassRegistry;
    }

/***************************************************************************
*
* objectRegistryGet - get a reference to the global object registry
*
* Create a new object registry if necessary.
*
* RETURNS : a reference to the global object registry
*/

LOCAL object_registry_t& objectRegistryGet ()
    {
    if (pObjectRegistry == NULL)
        {
        pObjectRegistry = new object_registry_t;
        }
    return *pObjectRegistry;
    }

/***************************************************************************
*
* objectCreate - create an object of a given type
*
* Use the class factory registered in the global class registry
* under 'className' to create a new object. Register this object
* in the global object registry under 'object name'.
*
* RETURNS : object of type className
*/

object_t* objectCreate
    (
    char* className,
    char* objectName
    )
    {
    cout << "Creating an object called '" << objectName << "'"
         << " of type '" << className << "'" << endl;
    object_t* pObject = classRegistryGet().create (className);
    if (pObject != NULL)
        {
        objectRegistryGet().insert(objectName, pObject);
        }
    else
        {
        cout << "Could not create object. Sorry. " << endl;
        }
    return pObject;
    }

/***************************************************************************
*
* isRed
* isBlue   - is anObject a reference to an object of the specified type?
* isGreen
*
* Try a dynamic_cast. If this succeeds then return TRUE. If it fails
* then catch the resulting exception and return FALSE.
*
* RETURNS : TRUE or FALSE
*/

/* isRed */

LOCAL BOOL isRed (object_t& anObject)
    {
    try
        {
        cout << "Attempting a dynamic_cast to red_t ..." << endl;
        dynamic_cast<red_t&> (anObject);
        cout << "Cast to red_t succeeded!" << endl;
        return TRUE;
        }
    catch (exception)
        {
        cout << "dynamic_cast threw an exception ... caught here!" << endl;
        return FALSE;
        }
    }

/* isBlue */

LOCAL BOOL isBlue (object_t& anObject)
    {
    try
        {
        cout << "Attempting a dynamic_cast to blue_t ..." << endl;
        dynamic_cast<blue_t&> (anObject);
        cout << "Cast to blue_t succeeded!" << endl;
        return TRUE;
        }
    catch (exception)
        {
        cout << "dynamic_cast threw an exception ... caught here!" << endl;
        return FALSE;
        }
    }

/* isGreen */

LOCAL BOOL isGreen (object_t& anObject)
    {
    try
        {
        cout << "Attempting a dynamic_cast to green_t ..." << endl;
        dynamic_cast<green_t&> (anObject);
        cout << "Cast to green_t succeeded!" << endl;
        return TRUE;
        }
    catch (exception)
        {
        cout << "dynamic_cast threw an exception ... caught here!" << endl;
        return FALSE;
        }
    }


/**************************************************************************
*
* objectTypeShow - ascertain the type of an object
*
* Use dynamic type checking to determine the type of an object.
*
* RETURNS : N/A
*/

LOCAL void objectTypeShow (object_t* pObject)
    {
    cout << "Attempting to ascertain type of object at " << "0x" << hex
```

```
         << (int) pObject << endl;
    if (isRed (*pObject))
        {
        cout << "red." << endl;
        }
    else if (isBlue (*pObject))
        {
        cout << "blue." << endl;
        }
    else if (isGreen (*pObject))
        {
        cout << "green." << endl;
        }
    }

/**************************************************************************
*
* objectTypeShowByName - ascertain the type of a registered object
*
* Lookup 'objectName' in the global object registry and
* print the type of the associated object.
*
* RETURNS : N/A
*/

void objectTypeShowByName
    (
    char* objectName
    )
    {
    cout << "Looking up object '" << objectName << "'" << endl;
    object_t *pObject = objectRegistryGet ().lookup (objectName);
    if (pObject != NULL)
        {
        objectTypeShow (pObject);
        }
    else
        {
        cout << "No such object in the Object Registry." << endl;
        }

    }

/**************************************************************************
*
* objectRegistryShow - show contents of global object registry
*
* RETURNS : N/A
*/

void objectRegistryShow ()
    {
    cout << "Showing Object Registry ..." << endl;
    objectRegistryGet ().list ();
    }
```

```
/**************************************************************************
*
* classRegistryShow - show contents of global class registry
*
* RETURNS : N/A
*/

void classRegistryShow ()
    {
    cout << "Showing Class Registry ..." << endl;
    classRegistryGet ().list ();
    }
```

```
/* factory.h - class declarations for the object factory */

/* Copyright 1993-1998 Wind River Systems, Inc. */

/*
modification history
--------------------
01a,05oct98,sn   wrote
*/

#include <vxWorks.h>
#include <iostream.h>
#include <string>
#include <typeinfo>
#include <map>

/*
 * object_t hierarchy
 *
 *             object_t
 *                 |
 *    +------------+-----------+
 *    |            |           |
 *  red_t        blue_t       green_t
 *
 */

struct object_t
    {
    virtual void method () {}
    };

struct red_t : object_t
    {
    };

struct blue_t : object_t
    {
    };
```

```
struct green_t : object_t
    {
    };

/*
 * object_factory_t hierarchy
 *
 *
 *                   object_factory_t
 *                        |
 *    +-------------------+-------------------+
 *    |                   |                   |
 *  red_factory_t      blue_factory_t     green_factory_t

 */

struct object_factory_t
    {
    virtual object_t* create () = 0;
    };

struct red_factory_t : object_factory_t
    {
    red_t* create () { return new red_t; }
    };

struct blue_factory_t : object_factory_t
    {
    blue_t* create () { return new blue_t; }
    };

struct green_factory_t : object_factory_t
    {
    green_t* create () { return new green_t; }
    };

/*
 * registry_t<T> - a registry of objects of type T
 *
 * The registry maps user readable names to pointers to objects.
 *
 */

template <class T> class registry_t
    {
private:
    typedef map <string, T*> map_t;
    map_t registry;
public:
    void insert (string objectName, T* pObject);
    T* lookup (string objectName);
    void list ();
    };
```

```
/* object_registry_t - a registry of objects derived from object_t */

typedef registry_t <object_t> object_registry_t;

/* class_registry_t - a registry of object factories ('classes') */

class class_registry_t : public registry_t <object_factory_t>
    {
public:
    object_t* create (string className) ;
    };

/*
 * template method definitions
 *
 * It is common to put template method definitions in header
 * files so that they may be instantiated whenever necessary.
 *
 */

/*************************************************************************
*
* registry_t<T>::insert - register an object
*
* Register object pointed to by pObject under 'objectName'.
*
* RETURNS : N/A
*/

template <class T>
void registry_t<T>::insert
    (
    string objectName,
    T* pObject
    )
    {
    registry [objectName] = pObject;
    }

/*************************************************************************
*
* registry_t<T>::lookup - lookup an object by name
*
* Lookup 'objectName' in this registry and return a pointer
* to the corresponding object.
*
* RETURNS : a pointer to an object or NULL
*/

template <class T>
T* registry_t<T>::lookup
    (
    string objectName
    )
    {
    return registry [objectName];
    }

/**************************************************************************
*
* registry_t<T>::list - list objects in this registry
*
* RETURNS : N/A
*/

template <class T>
void registry_t<T>::list ()
    {
    cout << "Name \t" << "Address" << endl;
    cout << "=================================================" << endl;
    for (map_t::iterator i = registry.begin ();
         i != registry.end (); ++i)
        {
        cout << i -> first << " \t"
             << "0x" << hex << (int) i -> second << endl;
        }
    }

/* function declarations */

/* objectCreate - create an object of a given type */
object_t* objectCreate (char* className, char* objectName);

/* objectTypeShowByName - ascertain the type of a registered object */
void objectTypeShowByName (char* objectName);

/* objectRegistryShow - show contents of global object registry */
void objectRegistryShow ();

/* classRegistryShow - show contents of global class registry */
void classRegistryShow ();
```

5.5 Wind Foundation Classes

The Wind Foundation Classes include three libraries:

– VxWorks Wrapper Class library
– Tools.h++ library from Rogue Wave Software

The VxWorks Wrapper Class library provides a thin C++ interface to several standard VxWorks modules. The Tools.h++ foundation class library from Rogue Wave Software supports a variety of C++ features.

⚠ **CAUTION:** In order to prevent dependency conflicts between VxWorks libraries and Rogue Wave libraries, all VxWorks libraries, including the VxWorks Wrapper Class Library, should be included before all Rogue Wave libraries, including the Tools.h++ library.

5.5.1 VxWorks Wrapper Class Library

The classes in this library are called *wrapper* classes because each class encapsulates, or *wraps*, the interfaces for some portion of standard VxWorks functionality. Select **INCLUDE_CPLUS_VXW** for inclusion in the project facility VxWorks view to configure this library into VxWorks; see *5.2.4 Configuration Constants*, p.231.

The VxWorks Wrapper Class library header files reside in the standard VxWorks header file directory, *installDir***/target/h**. The classes and their corresponding header files are shown in Table 5-1. To use one of these classes, include the corresponding header file in the appropriate modules of your application.

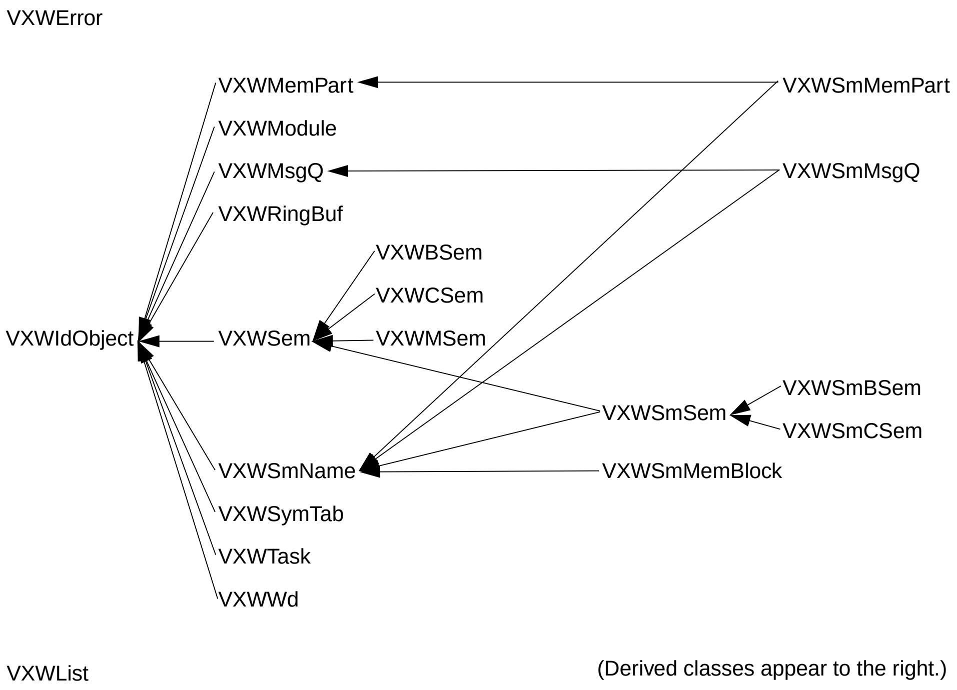
Table 5-1 **Header Files for VxWorks Wrapper Classes**

Header File	Description
vxwLoadLib.h	Object module loader and unloader (wraps **loadLib**, **unldLib**, **moduleLib**)
vxwLstLib.h	Linked lists (wraps **lstLib**)
vxwMemPartLib.h	Memory partitions (wraps **memLib**)
vxwMsgQLib.h	Message queues (wraps **msgQLib**)
vxwRngLib.h	Ring buffers (wraps **rngLib**)
vxwSemLib.h	Semaphores (wraps **semLib**)
vxwSmLib.h	Shared memory objects (adds support for shared memory semaphores, message queues, and memory partitions)
vxwSymLib.h	Symbol tables (wraps **symLib**)
vxwTaskLib.h	Tasks (wraps **taskLib**, **envLib**, **errnoLib**, **sigLib**, and **taskVarLib**)
vxwWdLib.h	Watchdog timers (wraps **wdLib**)

The VxWorks Wrapper Classes are designed to provide C++ language bindings to VxWorks modules that are inherently object-oriented, but for which only C bindings have previously been available. Figure 5-1 shows the inheritance relationships for all of the VxWorks Wrapper Classes. The classes are named to correspond with the VxWorks features that they wrap. For example, **VXWMsgQ** is the class of message queues, and provides a C++ interface to **msgQLib**.

⚠ **CAUTION:** The classes **VXWError** and **VXWIdObject** are used internally by the VxWorks Wrapper Classes. They are listed in Figure 5-1 for completeness only. These two classes are not intended for direct use by applications.

Figure 5-1 **Wrapper-Class Inheritance**



Example 5-3 **Watchdog Timers**

To illustrate the way in which the wrapper classes provide C++ language bindings for VxWorks objects, the following example exhibits methods in the watchdog timer class, **VXWWd**. See *2.6 Watchdog Timers*, p.90 for general information about watchdog timers.

```
    /* Create a watchdog timer and set it to go off in 3 seconds. */

    /* includes */

    #include "vxWorks.h"
    #include "logLib.h"
    #include "vxwWdLib.h"

    /* defines */

    #define  SECONDS (3)

    task (void)
        {
        /* Create watchdog */

[1]     VXWWd myWatchDog;

        /* Set timer to go off in SECONDS - printing a message to stdout */

[2]     if (myWatchDog.start (sysClkRateGet( ) * SECONDS, logMsg,
                    int ("Watchdog timer just expired\n")) == ERROR)
        return (ERROR);

        while (TIMER_NEEDED)
            {
            /* ... */
            }
[3]     }
```

A notable difference from the C interface is that the wrapper classes allow you to manipulate watchdog timers as objects rather than through an object ID. Line [1] creates and names a watchdog object; C++ automatically calls the **VXWWd** constructor, implicitly invoking the C routine ***wdCreate*( )** to create a watchdog timer.

Line [2] in the example illustrates how to use a method from the wrapper classes. The example invokes the method ***start*( )** for the instance **myWatchDog** of the class **VXWWd** to call the timer. Because this method is invoked on a specific object, the argument list for the method ***start*( )** does not require an argument to identify which timer to start (unlike ***wdStart*( )**, the corresponding C routine).

Finally, because **myWatchDog** is a local object, exiting from the routine ***task*( )** on line [3] automatically calls the destructor for the **VXWWd** watchdog class. This implicit call to the destructor deallocates the watchdog object, and if the timer was still running removes it from the system timer queues. Thus, for objects declared on the stack, it is not necessary to call a routine equivalent to the C routine ***wdDelete*( )**. (However, if an object is created dynamically with the operator **new**, you must delete it explicitly with the operator **delete**, once your application no longer needs the object.)

For details of the wrapper classes and on each of the wrapper class functions, see the *VxWorks Reference Manual*.

5.5.2 Tools.h++ Library

Tools.h++ is an industry-standard foundation class library from Rogue Wave Software which supports the following features:

– A complete set of collection classes
– Template based classes
– Persistent store facility
– File classes and file space manager
– B-tree disk retrieval
– Multi-thread safety
– Multi-byte and wide character strings
– Localized string collation
– Parse and format times, dates, and currency in multiple locales
– Support for multiple time zones and daylight savings rules
– Support for localized messages
– Localized I/O streams

This library is configured into VxWorks by selecting **INCLUDE_CPLUS_TOOLS** for inclusion in the project facility VxWorks view; see *5.2.4 Configuration Constants*, p.231.

The Tools.h++ library header files reside in the VxWorks header file directory *installDir***/target/h/rw**. To use this library, **#include** one or more of these header files after the **#include "vxWorks.h"** statement and after the **#include** statements for all other VxWorks libraries in the appropriate modules of your application. For a list of all the header files and details on this library, see Rogue Wave's *Tools.h++ Introduction and Reference Manual*.

6
Shared-Memory Objects
Optional Component VxMP

6.1 Introduction

VxMP is an optional VxWorks component that provides shared-memory objects dedicated to high-speed synchronization and communication between tasks running on separate CPUs. For information on how to install VxMP, see *Tornado Getting Started*.

Shared-memory objects are a class of system objects that can be accessed by tasks running on different processors. They are called *shared-memory* objects because the object's data structures must reside in memory accessible by all processors. Shared-memory objects are an extension of local VxWorks objects. *Local objects* are only available to tasks on a single processor. VxMP supplies three kinds of shared-memory objects:

- shared semaphores (binary and counting)
- shared message queues
- shared-memory partitions (system- and user-created partitions)

Shared-memory objects provide the following advantages:

- A transparent interface that allows shared-memory objects to be manipulated with the same routines that are used for manipulating local objects.
- High-speed inter-processor communication—no unnecessary packet passing is required.
- The shared memory can reside either in dual-ported RAM or on a separate memory board.

The components of VxMP consist of the following: a name database (**smNameLib**), shared semaphores (**semSmLib**), shared message queues (**msgQSmLib**), and a shared-memory allocator (**smMemLib**).

This chapter presents a detailed description of each shared-memory object and internal considerations. It then describes configuration and troubleshooting.

6.2 Using Shared-Memory Objects

VxMP provides a transparent interface that makes it easy to execute code using shared-memory objects on both a multiprocessor system and a single-processor system. After an object is created, tasks can operate on shared objects with the same routines used to operate on their corresponding local objects. For example, shared semaphores, shared message queues, and shared-memory partitions have the same syntax and interface as their local counterparts. Routines such as ***semGive*( )**, ***semTake*( )**, ***msgQSend*( )**, ***msgQReceive*( )**, ***memPartAlloc*( )**, and ***memPartFree*( )** operate on both local and shared objects. Only the create routines are different. This allows an application to run in either a single-processor or a multiprocessor environment with only minor changes to system configuration, initialization, and object creation.

All shared-memory objects can be used on a single-processor system. This is useful for testing an application before porting it to a multiprocessor configuration. However, for objects that are used only locally, local objects always provide the best performance.

After the shared-memory facilities are initialized (see *6.4 Configuration*, p.279 for initialization differences), all processors are treated alike. Tasks on any CPU can create and use shared-memory objects. No processor has priority over another from a shared-memory object's point of view.[1]

Systems making use of shared memory can include a combination of supported architectures. This enables applications to take advantage of different processor types and still have them communicate. However, on systems where the processors have different byte ordering, you must call the macros **ntohl** and **htonl** to byte-swap the application's shared data (see *VxWorks Network Programmer's Guide: TCP/IP Under VxWorks*).

1. Do not confuse this type of priority with the CPU priorities associated with VMEbus access.

When an object is created, an *object ID* is returned to identify it. For tasks on different CPUs to access shared-memory objects, they must be able to obtain this ID. An object's ID is the same regardless of the CPU. This allows IDs to be passed using shared message queues, data structures in shared memory, or the name database.

Throughout the remainder of this chapter, system objects under discussion refer to shared objects unless otherwise indicated.

6.2.1 Name Database

The *name database* allows the association of any value to any name, such as a shared-memory object's ID with a unique name. It can communicate or *advertise* a shared-memory block's address and object type. The name database provides name-to-value and value-to-name translation, allowing objects in the database to be accessed either by name or by value. While other methods exist for advertising an object's ID, the name database is a convenient method for doing this.

Typically the task that creates an object also advertises the object's ID by means of the name database. By adding the new object to the database, the task associates the object's ID with a name. Tasks on other processors can look up the name in the database to get the object's ID. After the task has the ID, it can use it to access the object.

For example, task **t1** on CPU 1 creates an object. The object ID is returned by the creation routine and entered in the name database with the name **myObj**. For task **t2** on CPU 0 to operate on this object, it first finds the ID by looking up the name **myObj** in the name database.

This same technique can be used to advertise a shared-memory address. For example, task **t1** on CPU 0 allocates a chunk of memory and adds the address to the database with the name **mySharedMem**. Task **t2** on CPU 1 can find the address of this shared memory by looking up the address in the name database using **mySharedMem**.

Tasks on different processors can use an agreed-upon name to get a newly created object's value. See Table 6-1 for a list of name service routines. Note that retrieving an ID from the name database need occur only one time for each task, and usually occurs during application initialization.

The name database service routines automatically convert to or from network-byte order; do not call ***htonl*( )** or ***ntohl*( )** explicitly for values from the name database.

The object types listed in Table 6-2 are defined in **smNameLib.h**.

Table 6-1 **Name Service Routines**

Routine	Functionality
***smNameAdd*( )**	Add a name to the name database.
***smNameRemove*( )**	Remove a name from the name database.
***smNameFind*( )**	Find a shared symbol by name.
***smNameFindByValue*( )**	Find a shared symbol by value.
***smNameShow*( )**	Display the name database to the standard output device; automatically included if **INCLUDE_SM_OBJ** is selected.

Table 6-2 **Shared-Memory Object Types**

Constant	Hex Value
T_SM_SEM_B	0
T_SM_SEM_C	1
T_SM_MSG_Q	2
T_SM_PART_ID	3
T_SM_BLOCK	4

The following example shows the name database as displayed by ***smNameShow*( )**, which is automatically included if **INCLUDE_SM_OBJ** is selected for inclusion in the project facility VxWorks view. The parameter to ***smNameShow*( )** specifies the level of information displayed; in this case, 1 indicates that all information is shown. For additional information on ***smNameShow*( )**, see its reference entry.

```
-> smNameShow 1
value = 0 = 0x0
```

The output is sent to the standard output device, and looks like the following:

```
Name in Database Max : 100 Current : 5 Free : 95
Name                   Value           Type
----------------- ------------- -------------
myMemory             0x3835a0       SM_BLOCK
myMemPart            0x3659f9       SM_PART_ID
myBuff               0x383564       SM_BLOCK
mySmSemaphore        0x36431d       SM_SEM_B
myMsgQ               0x365899      SM_MSG_Q
```

6.2.2 Shared Semaphores

Like local semaphores, *shared semaphores* provide synchronization by means of atomic updates of semaphore state information. See *2. Basic OS* in this manual and the reference entry for **semLib** for a complete discussion of semaphores. Shared semaphores can be given and taken by tasks executing on any CPU with access to the shared memory. They can be used for either synchronization of tasks running on different CPUs or mutual exclusion for shared resources.

To use a shared semaphore, a task creates the semaphore and advertises its ID. This can be done by adding it to the name database. A task on any CPU in the system can use the semaphore by first getting the semaphore ID (for example, from the name database). When it has the ID, it can then take or give the semaphore.

In the case of employing shared semaphores for mutual exclusion, typically there is a system resource that is shared between tasks on different CPUs and the semaphore is used to prevent concurrent access. Any time a task requires exclusive access to the resource, it takes the semaphore. When the task is finished with the resource, it gives the semaphore.

For example, there are two tasks, **t1** on CPU 0 and **t2** on CPU 1. Task **t1** creates the semaphore and advertises the semaphore's ID by adding it to the database and assigning the name **myMutexSem**. Task **t2** looks up the name **myMutexSem** in the database to get the semaphore's ID. Whenever a task wants to access the resource, it first takes the semaphore by using the semaphore ID. When a task is done using the resource, it gives the semaphore.

In the case of employing shared semaphores for synchronization, assume a task on one CPU must notify a task on another CPU that some event has occurred. The task being synchronized pends on the semaphore waiting for the event to occur. When the event occurs, the task doing the synchronizing gives the semaphore.

For example, there are two tasks, **t1** on CPU 0 and **t2** on CPU 1. Both **t1** and **t2** are monitoring robotic arms. The robotic arm that is controlled by **t1** is passing a physical object to the robotic arm controlled by **t2**. Task **t2** moves the arm into position but must then wait until **t1** indicates that it is ready for **t2** to take the object. Task **t1** creates the shared semaphore and advertises the semaphore's ID by adding it to the database and assigning the name **objReadySem**. Task **t2** looks up the name **objReadySem** in the database to get the semaphore's ID. It then takes the semaphore by using the semaphore ID. If the semaphore is unavailable, **t2** pends, waiting for **t1** to indicate that the object is ready for **t2**. When **t1** is ready to transfer control of the object to **t2**, it gives the semaphore, readying **t2** on CPU1.

There are two types of shared semaphores, binary and counting. Shared semaphores have their own create routines and return a **SEM_ID**. Table 6-3 lists the create routines. All other semaphore routines, except ***semDelete*( )**, operate transparently on the created shared semaphore.

Table 6-3 **Shared Semaphore Create Routines**

Create Routine	Description
***semBSmCreate*( )**	Create a shared binary semaphore.
***semCSmCreate*( )**	Create a shared counting semaphore.

The use of shared semaphores and local semaphores differs in several ways:

- The shared semaphore queuing order specified when the semaphore is created must be FIFO. Figure 6-1 shows two tasks executing on different CPUs, both trying to take the same semaphore. Task 1 executes first, and is put at the front of the queue because the semaphore is unavailable (empty). Task 2 (executing on a different CPU) tries to take the semaphore after task 1's attempt and is put on the queue behind task 1.
- Shared semaphores *cannot* be given from interrupt level.
- Shared semaphores cannot be deleted. Attempts to delete a shared semaphore return **ERROR** and set **errno** to **S_smObjLib_NO_OBJECT_DESTROY**.

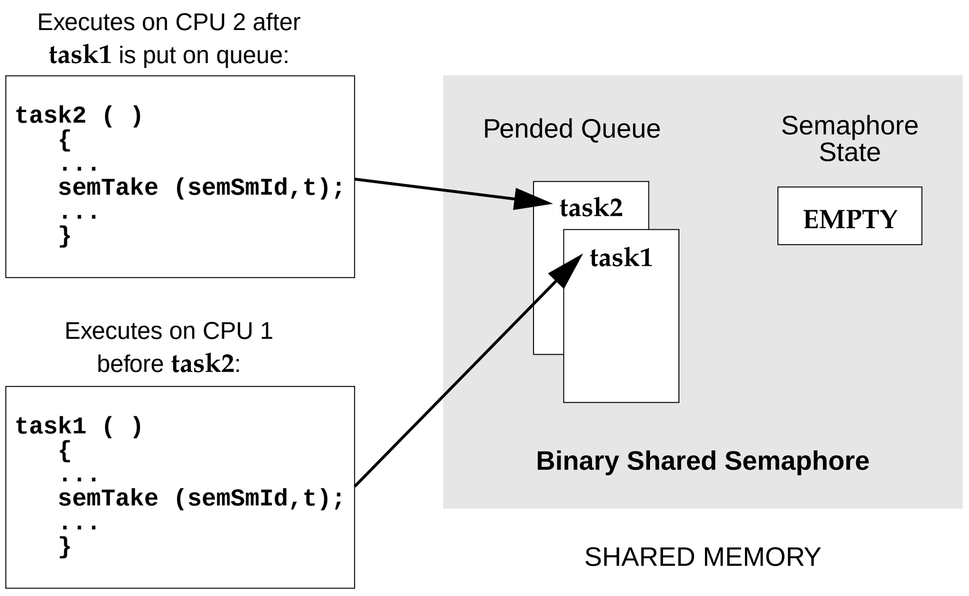
Use ***semInfo*( )** to get the shared task control block of tasks pended on a shared semaphore. Use ***semShow*( )**, if **INCLUDE_SEM_SHOW** is included in the project facility VxWorks view, to display the status of the shared semaphore and a list of pended tasks. The following example displays detailed information on the shared semaphore **mySmSemaphoreId** as indicated by the second argument (0 = summary, 1 = details):

```
-> semShow mySmSemaphoreId, 1
value = 0 = 0x0
```

The output is sent to the standard output device, and looks like the following:

```
Semaphore Id     : 0x36431d
Semaphore Type   : SHARED BINARY
Task Queuing     : FIFO
Pended Tasks     : 2
State            : EMPTY
TID            CPU Number      Shared TCB
------------- ------------- --------------
0xd0618            1           0x364204
0x3be924           0           0x36421c
```

Figure 6-1 **Shared Semaphore Queues**


Executes on CPU 2 after **task1** is put on queue:
task2 ( ) { ... semTake (semSmId,t); ... }
Executes on CPU 1 before **task2**:
task1 ( ) { ... semTake (semSmId,t); ... }
Pended Queue
Semaphore State
task2
task1
EMPTY
Binary Shared Semaphore
SHARED MEMORY

Example 6-1 **Shared Semaphores**

The following code example depicts two tasks executing on different CPUs and using shared semaphores. The routine ***semTask1( )*** creates the shared semaphore, initializing the state to full. It adds the semaphore to the name database (to enable the task on the other CPU to access it), takes the semaphore, does some processing, and gives the semaphore. The routine ***semTask2( )*** gets the semaphore ID from the database, takes the semaphore, does some processing, and gives the semaphore.

```
/* semExample.h - shared semaphore example header file */

#define SEM_NAME "mySmSemaphore"

/* semTask1.c - shared semaphore example */

/* This code is executed by a task on CPU #1 */

#include "vxWorks.h"
#include "semLib.h"
#include "semSmLib.h"
#include "smNameLib.h"
```

```
#include "stdio.h"
#include "taskLib.h"
#include "semExample.h"

/************************************************************************
*
* semTask1 - shared semaphore user
*/

STATUS semTask1 (void)
    {
    SEM_ID semSmId;

    /* create shared semaphore */

    if ((semSmId = semBSmCreate (SEM_Q_FIFO, SEM_FULL)) == NULL)
        return (ERROR);

    /* add object to name database */

    if (smNameAdd (SEM_NAME, semSmId, T_SM_SEM_B) == ERROR)
        return (ERROR);

    /* grab shared semaphore and hold it for awhile */

    semTake (semSmId, WAIT_FOREVER);

    /* normally do something useful */

    printf ("Task1 has the shared semaphore\n");
    taskDelay (sysClkRateGet () * 5);
    printf ("Task1 is releasing the shared semaphore\n");

    /* release shared semaphore */

    semGive (semSmId);

    return (OK);
    }
```

```
/* semTask2.c - shared semaphore example */

/* This code is executed by a task on CPU #2. */

#include "vxWorks.h"
#include "semLib.h"
#include "semSmLib.h"

#include "smNameLib.h"
#include "stdio.h"
#include "semExample.h"
```

```
/************************************************************************
*
* semTask2 - shared semaphore user
*/

STATUS semTask2 (void)
    {
    SEM_ID semSmId;
    int    objType;

    /* find object in name database */

    if (smNameFind (SEM_NAME, (void **) &semSmId, &objType, WAIT_FOREVER)
        == ERROR)
        return (ERROR);

    /* take the shared semaphore */

    printf ("semTask2 is now going to take the shared semaphore\n");
    semTake (semSmId, WAIT_FOREVER);

    /* normally do something useful */

    printf ("Task2 got the shared semaphore!!\n");

    /* release shared semaphore */

    semGive (semSmId);

    printf ("Task2 has released the shared semaphore\n");

    return (OK);
    }
```

6.2.3 Shared Message Queues

Shared message queues are FIFO queues used by tasks to send and receive variable-length messages on any of the CPUs that have access to the shared memory. They can be used either to synchronize tasks or to exchange data between tasks running on different CPUs. See *2. Basic OS* in this manual and the reference entry for **msgQLib** for a complete discussion of message queues.

To use a shared message queue, a task creates the message queue and advertises its ID. A task that wants to send or receive a message with this message queue first gets the message queue's ID. It then uses this ID to access the message queue.

For example, consider a typical server/client scenario where a server task **t1** (on CPU 1) reads requests from one message queue and replies to these requests with a different message queue. Task **t1** creates the request queue and advertises its ID by adding it to the name database assigning the name **requestQue**. If task **t2** (on

CPU 0) wants to send a request to **t1**, it first gets the message queue ID by looking up the name **requestQue** in the name database. Before sending its first request, task **t2** creates a reply message queue. Instead of adding its ID to the database, it advertises the ID by sending it as part of the request message. When **t1** receives the request from the client, it finds in the message the ID of the queue to use when replying to that client. Task **t1** then sends the reply to the client by using this ID.

To pass messages between tasks on different CPUs, first create the message queue by calling ***msgQSmCreate*( )**. This routine returns a **MSG_Q_ID**. This ID is used for sending and receiving messages on the shared message queue.

Like their local counterparts, shared message queues can send both urgent or normal priority messages.

The use of shared message queues and local message queues differs in several ways:

- The shared message queue task queueing order specified when a message queue is created must be FIFO. Figure 6-2 shows two tasks executing on different CPUs, both trying to receive a message from the same shared message queue. Task 1 executes first, and is put at the front of the queue because there are no messages in the message queue. Task 2 (executing on a different CPU) tries to receive a message from the message queue after task 1's attempt and is put on the queue behind task 1.
- Messages *cannot* be sent on a shared message queue at interrupt level. (This is true even in **NO_WAIT** mode.)
- Shared message queues cannot be deleted. Attempts to delete a shared message queue return **ERROR** and sets **errno** to **S_smObjLib_NO_OBJECT_DESTROY**.

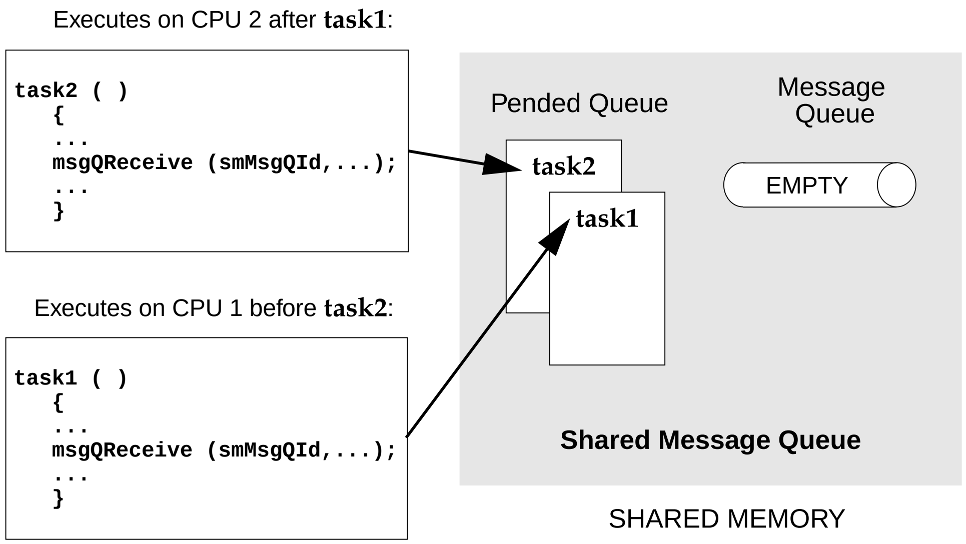
To achieve optimum performance with shared message queues, align send and receive buffers on 4-byte boundaries.

To display the status of the shared message queue as well as a list of tasks pended on the queue, select **INCLUDE_MSG_Q_SHOW** for inclusion in the project facility VxWorks view and call ***msgQShow*( )**. The following example displays detailed information on the shared message queue 0x7f8c21 as indicated by the second argument (0 = summary display, 1 = detailed display).

```
-> msgQShow 0x7f8c21, 1
value = 0 = 0x0
```

The output is sent to the standard output device, and looks like the following:

Figure 6-2 **Shared Message Queues**


Executes on CPU 2 after task1:
task2 ( )
{
...
msgQReceive (smMsgQId,...);
...
}
Executes on CPU 1 before task2:
task1 ( )
{
...
msgQReceive (smMsgQId,...);
...
}
Pended Queue
task2
task1
Message Queue
EMPTY
Shared Message Queue
SHARED MEMORY

```
Message Queue Id  : 0x7f8c21
Task Queuing      : FIFO
Message Byte Len  : 128
Messages Max      : 10
Messages Queued   : 0
Receivers Blocked : 1
Send timeouts     : 0
Receive timeouts  : 0
Receivers blocked :
TID           CPU Number          Shared TCB
---------- -------------------- --------------
0xd0618           1               0x1364204
```

Example 6-2 **Shared Message Queues**

In the following code example, two tasks executing on different CPUs use shared message queues to pass data to each other. The server task creates the request message queue, adds it to the name database, and reads a message from the queue. The client task gets the **smRequestQId** from the name database, creates a reply message queue, bundles the ID of the reply queue as part of the message, and sends the message to the server. The server gets the ID of the reply queue and uses it to send a message back to the client. This technique requires the use of the network byte-order conversion macros ***htonl*( )** and ***ntohl*( )**, because the numeric queue ID is passed over the network in a data field.

```
/* msgExample.h - shared message queue example header file */

#define MAX_MSG     (10)
#define MAX_MSG_LEN (100)
#define REQUEST_Q   "requestQue"

typedef struct message
    {
    MSG_Q_ID replyQId;
    char     clientRequest[MAX_MSG_LEN];
    } REQUEST_MSG;
```

```
/* server.c - shared message queue example server */

/* This file contains the code for the message queue server task. */

#include "vxWorks.h"
#include "msgQLib.h"
#include "msgQSmLib.h"
#include "stdio.h"
#include "smNameLib.h"
#include "msgExample.h"
#include "netinet/in.h"

#define REPLY_TEXT "Server received your request"

/************************************************************************
*
* serverTask - receive and process a request from a shared message queue
*/

STATUS serverTask (void)
    {
    MSG_Q_ID    smRequestQId;  /* request shared message queue */
    REQUEST_MSG request;       /* request text */

    /* create a shared message queue to handle requests */

    if ((smRequestQId = msgQSmCreate (MAX_MSG, sizeof (REQUEST_MSG),
        MSG_Q_FIFO)) == NULL)
        return (ERROR);

    /* add newly created request message queue to name database */

    if (smNameAdd (REQUEST_Q, smRequestQId, T_SM_MSG_Q) == ERROR)
        return (ERROR);

    /* read messages from request queue */

    FOREVER
```

```
        {
        if (msgQReceive (smRequestQId, (char *) &request, sizeof (REQUEST_MSG),
            WAIT_FOREVER) == ERROR)
            return (ERROR);

        /* process request - in this case simply print it */

        printf ("Server received the following message:\n%s\n",
            request.clientRequest);

        /* send a reply using ID specified in client's request message */

        if (msgQSend ((MSG_Q_ID) ntohl ((int) request.replyQId),
            REPLY_TEXT, sizeof (REPLY_TEXT),
            WAIT_FOREVER, MSG_PRI_NORMAL) == ERROR)
            return (ERROR);
        }
    }
```

```
/* client.c - shared message queue example client */

/* This file contains the code for the message queue client task. */

#include "vxWorks.h"
#include "msgQLib.h"
#include "msgQSmLib.h"
#include "smNameLib.h"
#include "stdio.h"
#include "msgExample.h"
#include "netinet/in.h"

/************************************************************************
*
* clientTask - sends request to server and reads reply
*/

STATUS clientTask
    (
    char * pRequestToServer  /* request to send to the server */
                             /* limited to 100 chars */
    )
    {
    MSG_Q_ID    smRequestQId; /* request message queue */
    MSG_Q_ID  smReplyQId;   /* reply message queue */
    REQUEST_MSG request;      /* request text */
    int         objType;      /* dummy variable for smNameFind */
    char        serverReply[MAX_MSG_LEN]; /*buffer for server's reply */

    /* get request queue ID using its name */

    if (smNameFind (REQUEST_Q, (void **) &smRequestQId, &objType,
        WAIT_FOREVER) == ERROR)
        return (ERROR);
    /* create reply queue, build request and send it to server */

    if ((smReplyQId = msgQSmCreate (MAX_MSG, MAX_MSG_LEN,
        MSG_Q_FIFO)) == NULL)
        return (ERROR);

    request.replyQId = (MSG_Q_ID) htonl ((int) smReplyQId);

    strcpy (request.clientRequest, pRequestToServer);

    if (msgQSend (smRequestQId, (char *) &request, sizeof (REQUEST_MSG),
        WAIT_FOREVER, MSG_PRI_NORMAL) == ERROR)
        return (ERROR);

    /* read reply and print it */

    if (msgQReceive (request.replyQId, serverReply, MAX_MSG_LEN,
        WAIT_FOREVER) == ERROR)
        return (ERROR);

    printf ("Client received the following message:\n%s\n", serverReply);

    return (OK);
    }
```

6.2.4 Shared-Memory Allocator

The *shared-memory allocator* allows tasks on different CPUs to allocate and release variable size chunks of memory that are accessible from all CPUs with access to the shared-memory system. Two sets of routines are provided: low-level routines for manipulating user-created shared-memory partitions, and high-level routines for manipulating a shared-memory partition dedicated to the shared-memory system pool. (This organization is similar to that used by the local-memory manager, **memPartLib**.)

Shared-memory blocks can be allocated from different partitions. Both a shared-memory system partition and user-created partitions are available. User-created partitions can be created and used for allocating data blocks of a particular size. Memory fragmentation is avoided when fixed-sized blocks are allocated from user-created partitions dedicated to a particular block size.

Shared-Memory System Partition

To use the shared-memory system partition, a task allocates a shared-memory block and advertises its address. One way of advertising the ID is to add the address to the name database. The routine used to allocate a block from the shared-memory system partition returns a local address. Before the address is advertised to tasks on other CPUs, this local address must be converted to a global address. Any task that must use the shared memory must first get the address of the memory block and convert the global address to a local address. When the task has the address, it can use the memory.

However, to address issues of mutual exclusion, typically a shared semaphore is used to protect the data in the shared memory. Thus in a more common scenario, the task that creates the shared memory (and adds it to the database) also creates a shared semaphore. The shared semaphore ID is typically advertised by storing it in a field in the shared data structure residing in the shared-memory block. The first time a task must access the shared data structure, it looks up the address of the memory in the database and gets the semaphore ID from a field in the shared data structure. Whenever a task must access the shared data, it must first take the semaphore. Whenever a task is finished with the shared data, it must give the semaphore.

For example, assume two tasks executing on two different CPUs must share data. Task **t1** executing on CPU 1 allocates a memory block from the shared-memory system partition and converts the local address to a global address. It then adds the global address of the shared data to the name database with the name **mySharedData**. Task **t1** also creates a shared semaphore and stores the ID in the first field of the data structure residing in the shared memory. Task **t2** executing on CPU 2 looks up the name **mySharedData** in the name database to get the address of the shared memory. It then converts this address to a local address. Before accessing the data in the shared memory, **t2** gets the shared semaphore ID from the first field of the data structure residing in the shared-memory block. It then takes the semaphore before using the data and gives the semaphore when it is done using the data.

User-Created Partitions

To make use of user-created shared-memory partitions, a task creates a shared-memory partition and adds it to the name database. Before a task can use the shared-memory partition, it must first look in the name database to get the partition ID. When the task has the partition ID, it can access the memory in the shared-memory partition.

For example, task **t1** creates a shared-memory partition and adds it to the name database using the name **myMemPartition**. Task **t2** executing on another CPU wants to allocate memory from the new partition. Task **t2** first looks up

myMemPartition in the name database to get the partition ID. It can then allocate memory from it, using the ID.

Using the Shared-Memory System Partition

The shared-memory system partition is analogous to the system partition for local memory. Table 6-4 lists routines for manipulating the shared-memory system partition.

Table 6-4 **Shared-Memory System Partition Routines**

Routine	Functionality
***smMemMalloc*( )**	Allocate a block of shared system memory.
***smMemCalloc*( )**	Allocate a block of shared system memory for an array.
***smMemRealloc*( )**	Resize a block of shared system memory.
***smMemFree*( )**	Free a block of shared system memory.
***smMemShow*( )**	Display usage statistics of the shared-memory system partition on the standard output device; this routine is automatically included if **INCLUDE_SM_OBJ** is selected for inclusion in the project facility VxWorks view.
***smMemOptionsSet*( )**	Set the debugging options for the shared-memory system partition.
***smMemAddToPool*( )**	Add memory to the shared-memory system pool.
***smMemFindMax*( )**	Find the size of the largest free block in the shared-memory system partition.

Routines that return a pointer to allocated memory return a local address (that is, an address suitable for use from the local CPU). To share this memory across processors, this address must be converted to a global address before it is advertised to tasks on other CPUs. Before a task on another CPU uses the memory, it must convert the global address to a local address. Macros and routines are provided to convert between local addresses and global addresses; see the header file **smObjLib.h** and the reference entry for **smObjLib**.

Example 6-3 **Shared-Memory System Partition**

The following code example uses memory from the shared-memory system partition to share data between tasks on different CPUs. The first member of the data structure is a shared semaphore that is used for mutual exclusion. The send task creates and initializes the structure, then the receive task accesses the data and displays it.

```
/* buffProtocol.h - simple buffer exchange protocol header file */

#define BUFFER_SIZE   200           /* shared data buffer size */
#define BUFF_NAME     "myMemory"    /* name of data buffer in database */

typedef struct shared_buff
    {
    SEM_ID semSmId;
    char   buff [BUFFER_SIZE];
    } SHARED_BUFF;
```

```
/* buffSend.c - simple buffer exchange protocol send side */

/* This file writes to the shared memory. */

#include "vxWorks.h"
#include "semLib.h"
#include "semSmLib.h"
#include "smNameLib.h"
#include "smObjLib.h"
#include "stdio.h"
#include "buffProtocol.h"

/************************************************************************
*
* buffSend - write to shared semaphore protected buffer
*
*/

STATUS buffSend (void)
    {
    SHARED_BUFF * pSharedBuff;
    SEM_ID        mySemSmId;

    /* grab shared system memory */

    pSharedBuff = (SHARED_BUFF *) smMemMalloc (sizeof (SHARED_BUFF));
    /*
     * Initialize shared buffer structure before adding to database. The
     * protection semaphore is initially unavailable and the receiver blocks.
     */

    if ((mySemSmId = semBSmCreate (SEM_Q_FIFO, SEM_EMPTY)) == NULL)
        return (ERROR);
    pSharedBuff->semSmId = (SEM_ID) htonl ((int) mySemSmId);

    /*
     * Convert address of shared buffer to a global address and add to
     * database.
     */

    if (smNameAdd (BUFF_NAME, (void *) smObjLocalToGlobal (pSharedBuff),
                    T_SM_BLOCK) == ERROR)
        return (ERROR);

    /* put data into shared buffer */

    sprintf (pSharedBuff->buff,"Hello from sender\n");

    /* allow receiver to read data by giving protection semaphore */

    if (semGive (mySemSmId) != OK)
        return (ERROR);

    return (OK);
    }
```

```
/* buffReceive.c - simple buffer exchange protocol receive side */

/* This file reads the shared memory. */

#include "vxWorks.h"
#include "semLib.h"
#include "semSmLib.h"
#include "smNameLib.h"
#include "smObjLib.h"
#include "stdio.h"
#include "buffProtocol.h"

/************************************************************************
*
* buffReceive - receive shared semaphore protected buffer
*/

STATUS buffReceive (void)
    {
    SHARED_BUFF * pSharedBuff;
    SEM_ID        mySemSmId;
    int           objType;
    /* get shared buffer address from name database */

    if (smNameFind (BUFF_NAME, (void **) &pSharedBuff,
                     &objType, WAIT_FOREVER) == ERROR)
        return (ERROR);

    /* convert global address of buff to its local value */

    pSharedBuff = (SHARED_BUFF *) smObjGlobalToLocal (pSharedBuff);

    /* convert shared semaphore ID to host (local) byte order */

    mySemSmId = (SEM_ID) ntohl ((int) pSharedBuff->semSmId);

    /* take shared semaphore before reading the data buffer */

    if (semTake (mySemSmId,WAIT_FOREVER) != OK)
        return (ERROR);

    /* read data buffer and print it */

    printf ("Receiver reading from shared memory: %s\n", pSharedBuff->buff);

    /* give back the data buffer semaphore */

    if (semGive (mySemSmId) != OK)
        return (ERROR);

    return (OK);
    }
```

Using User-Created Partitions

Shared-memory partitions have a separate create routine, ***memPartSmCreate*( )**, that returns a **MEM_PART_ID**. After a user-defined shared-memory partition is created, routines in **memPartLib** operate on it transparently. Note that the address of the shared-memory area passed to ***memPartSmCreate*( )** (or ***memPartAddToPool*( )**) must be the global address.

Example 6-4 **User-Created Partition**

This example is similar to Example 6-3, which uses the shared-memory system partition. This example creates a user-defined partition and stores the shared data in this new partition. A shared semaphore is used to protect the data.

```
/* memPartExample.h - shared memory partition example header file */

#define CHUNK_SIZE      (2400)
#define MEM_PART_NAME   "myMemPart"
#define PART_BUFF_NAME  "myBuff"
#define BUFFER_SIZE     (40)

typedef struct shared_buff
    {
    SEM_ID semSmId;
    char   buff [BUFFER_SIZE];
    } SHARED_BUFF;
```

```
/* memPartSend.c - shared memory partition example send side */

/* This file writes to the user-defined shared memory partition. */

#include "vxWorks.h"
#include "memLib.h"
#include "semLib.h"
#include "semSmLib.h"
#include "smNameLib.h"
#include "smObjLib.h"
#include "smMemLib.h"
#include "stdio.h"
#include "memPartExample.h"

/*********************************************************************
*
* memPartSend - send shared memory partition buffer
*/

STATUS memPartSend (void)
    {
    char *          pMem;
    PART_ID         smMemPartId;
    SEM_ID          mySemSmId;
    SHARED_BUFF *   pSharedBuff;

    /* allocate shared system memory to use for partition */

    pMem = smMemMalloc (CHUNK_SIZE);

    /* Create user defined partition using the previously allocated
     * block of memory.
     * WARNING: memPartSmCreate uses the global address of a memory
     * pool as first parameter.
     */
    if ((smMemPartId = memPartSmCreate (smObjLocalToGlobal (pMem), CHUNK_SIZE))
          == NULL)
        return (ERROR);

    /* allocate memory from partition */

    pSharedBuff = (SHARED_BUFF *) memPartAlloc ( smMemPartId,
                sizeof (SHARED_BUFF));
    if (pSharedBuff == 0)
        return (ERROR);

    /* initialize structure before adding to database */

    if ((mySemSmId = semBSmCreate (SEM_Q_FIFO, SEM_EMPTY)) == NULL)
        return (ERROR);
    pSharedBuff->semSmId = (SEM_ID) htonl ((int) mySemSmId);

    /* enter shared partition ID in name database */

    if (smNameAdd (MEM_PART_NAME, (void *) smMemPartId, T_SM_PART_ID) == ERROR)
        return (ERROR);

    /* convert shared buffer address to a global address and add to database */

    if (smNameAdd (PART_BUFF_NAME, (void *) smObjLocalToGlobal(pSharedBuff),
                   T_SM_BLOCK) == ERROR)
        return (ERROR);

    /* send data using shared buffer */

    sprintf (pSharedBuff->buff,"Hello from sender\n");

    if (semGive (mySemSmId) != OK)
        return (ERROR);

    return (OK);
    }
```

```
/* memPartReceive.c - shared memory partition example receive side */

/* This file reads from the user-defined shared memory partition. */

#include "vxWorks.h"
#include "memLib.h"
#include "stdio.h"
#include "semLib.h"
#include "semSmLib.h"
#include "stdio.h"
#include "memPartExample.h"
```

```
/************************************************************************
*
* memPartReceive - receive shared memory partition buffer
*
* execute on CPU 1 - use a shared semaphore to protect shared memory
*
*/

STATUS memPartReceive (void)
    {
    SHARED_BUFF * pBuff;
    SEM_ID        mySemSmId;
    int           objType;

    /* get shared buffer address from name database */

    if (smNameFind (PART_BUFF_NAME, (void **) &pBuff, &objType,
                    WAIT_FOREVER) == ERROR)
        return (ERROR);

    /* convert global address of buffer to its local value */

    pBuff = (SHARED_BUFF *) smObjGlobalToLocal (pBuff);

    /* Grab shared semaphore before using the shared memory */

    mySemSmId = (SEM_ID) ntohl ((int) pBuff->semSmId);
    semTake (mySemSmId,WAIT_FOREVER);
    printf ("Receiver reading from shared memory: %s\n", pBuff->buff);
    semGive (mySemSmId);

    return (OK);
    }
```

Side Effects of Shared-Memory Partition Options

Like their local counterparts, shared-memory partitions (both system- and user-created) can have different options set for error handling; see the reference entries for ***memPartOptionsSet*( )** and ***smMemOptionsSet*( )**.

If the **MEM_BLOCK_CHECK** option is used in the following situation, the system can get into a state where the memory partition is no longer available. If a task attempts to free a bad block and a bus error occurs, the task is suspended. Because shared semaphores are used internally for mutual exclusion, the suspended task still has the semaphore, and no other task has access to the memory partition. By default, shared-memory partitions are created without the **MEM_BLOCK_CHECK** option.

6.3 Internal Considerations

6.3.1 System Requirements

The shared-memory region used by shared-memory objects must be visible to all CPUs in the system. Either dual-ported memory on the master CPU (CPU 0) or a separate memory board can be used. The shared-memory objects' anchor must be in the same address space as the shared-memory region. Note that the memory does *not* have to appear at the same address for all CPUs.

⚠ **CAUTION:** Boards that make use of VxMP must support hardware test-and-set (indivisible read-modify-write cycle). PowerPC is an exception; see *F. PowerPC*.

All CPUs in the system must support indivisible read-modify-write cycle across the (VME) bus. The indivisible RMW is used by the spin-lock mechanism to gain exclusive access to internal shared data structures; see *6.3.2 Spin-lock Mechanism*, p.277 for details. Because all the boards must support a hardware test-and-set, the constant **SM_TAS_TYPE** must be set to **SM_TAS_HARD** on the Parameters tab of the project facility VxWorks view.

CPUs must be notified of any event that affects them. The preferred method is for the CPU initiating the event to interrupt the affected CPU. The use of interrupts is dependent on the capabilities of the hardware. If interrupts cannot be used, a polling scheme can be employed, although this generally results in a significant performance penalty.

The maximum number of CPUs that can use shared-memory objects is 20 (CPUs numbered 0 through 19). The practical maximum is usually a smaller number that depends on the CPU, bus bandwidth, and application.

6.3.2 Spin-lock Mechanism

Internal shared-memory object data structures are protected against concurrent access by a *spin-lock mechanism*. The spin-lock mechanism is a loop where an attempt is made to gain exclusive access to a resource (in this case an internal data structure). An indivisible hardware read-modify-write cycle (hardware test-and-set) is used for this mutual exclusion. If the first attempt to take the lock fails, multiple attempts are made, each with a decreasing random delay between one attempt and the next. The average time it takes between the original attempt to take the lock and the first retry is 70 microseconds on an MC68030 at 20MHz. Operating time for the spin-lock cycle varies greatly because it is affected by the processor cache, access time to shared memory, and bus traffic. If the lock is not obtained after the maximum number of tries specified by **SM_OBJ_MAX_TRIES** (defined in the Params tab of the properties window for shared memory objects in the VxWorks view), **errno** is set to **S_smObjLib_LOCK_TIMEOUT**. If this error occurs, set the maximum number of tries to a higher value. Note that any failure to take a spin-lock prevents proper functioning of shared-memory objects. In most cases, this is due to problems with the shared-memory configuration; see *6.5.2 Troubleshooting Techniques*, p.286.

6.3.3 Interrupt Latency

For the duration of the spin-lock, interrupts are disabled to avoid the possibility of a task being preempted while holding the spin-lock. As a result, the interrupt latency of each processor in the system is increased. However, the interrupt latency added by shared-memory objects is constant for a particular CPU.

6.3.4 Restrictions

Unlike local semaphores and message queues, shared-memory objects cannot be used at interrupt level. No routines that use shared-memory objects can be called from ISRs. An ISR is dedicated to handle time-critical processing associated with an external event; therefore, using shared-memory objects at interrupt time is not appropriate. On a multiprocessor system, run event-related time-critical processing on the CPU where the time-related interrupt occurred.

Note that shared-memory objects are allocated from dedicated shared-memory pools, and cannot be deleted.

When using shared-memory objects, the maximum number of each object type must be specified on the Params tab of the properties window; see *6.4.3 Initializing the Shared-Memory Objects Package*, p.280. If applications are creating more than the specified maximum number of objects, it is possible to run out of memory. If this happens, the shared object creation routine returns an error and **errno** is set to **S_memLib_NOT_ENOUGH_MEM**. To solve this problem, first increase the maximum number of shared-memory objects of corresponding type; see Table 6-5 for a list of the applicable configuration constants. This decreases the size of the shared-memory system pool because the shared-memory pool uses the remainder of the shared memory. If this is undesirable, increase both the number of the corresponding shared-memory objects and the size of the overall shared-memory region, **SM_OBJ_MEM_SIZE**. See *6.4 Configuration*, p.279 for a discussion of the constants used for configuration.

6.3.5 Cache Coherency

When dual-ported memory is used on some boards without MMU or bus snooping mechanisms, the data cache must be disabled for the shared-memory region on the master CPU. If you see the following error message, make sure that the constant **INCLUDE_CACHE_ENABLE** is not selected for inclusion in the VxWorks view:

```
usrSmObjInit - cache coherent buffer not available. Giving up.
```

6.4 Configuration

To include shared-memory objects in VxWorks, select **INCLUDE_SM_OBJ** for inclusion in the project facility VxWorks view. Most of the configuration is already done automatically from ***usrSmObjInit*( )** in **usrConfig.c**. However, you may also need to modify some values in the Params tab of the properties window to reflect your configuration; these are described in this section.

6.4.1 Shared-Memory Objects and Shared-Memory Network Driver

Shared-memory objects and the shared-memory network[2] use the same memory region, anchor address, and interrupt mechanism. Configuring the system to use shared-memory objects is similar to configuring the shared-memory network driver. For a more detailed description of configuring and using the shared-memory network, see *VxWorks Network Programmer's Guide: Data Link Layer Network Components*. If the default value for the shared-memory anchor address is modified, the anchor must be on a 256-byte boundary.

One of the most important aspects of configuring shared-memory objects is computing the address of the shared-memory anchor. The shared-memory anchor is a location accessible to all CPUs on the system, and is used by both VxMP and the shared-memory network driver. The anchor stores a pointer to the shared-memory header, a pointer to the shared-memory packet header (used by the shared-memory network driver), and a pointer to the shared-memory object header.

2. Also known as the *backplane network*.

The address of the anchor is defined in the Params tab of the Properties window with the constant **SM_ANCHOR_ADRS**. If the processor is booted with the shared-memory network driver, the anchor address is the same value as the boot device (**sm=***anchorAddress*). The shared-memory object initialization code uses the value from the boot line instead of the constant. If the shared-memory network driver is not used, modify the definition of **SM_ANCHOR_ADRS** as appropriate to reflect your system.

Two types of interrupts are supported and defined by **SM_INT_TYPE**: mailbox interrupts and bus interrupts (see *VxWorks Network Programmer's Guide: Data Link Layer Network Components*). Mailbox interrupts (**SM_INT_MAILBOX**) are the preferred method, and bus interrupts (**SM_INT_BUS**) are the second choice. If interrupts cannot be used, a polling scheme can be employed (**SM_INT_NONE**), but this is much less efficient.

When a CPU initializes its shared-memory objects, it defines the interrupt type as well as three interrupt arguments. These describe how the CPU is notified of events. These values can be obtained for any attached CPU by calling ***smCpuInfoGet*( )**.

The default interrupt method for a target is defined by **SM_INT_TYPE**, **SM_INT_ARG1**, **SM_INT_ARG2**, and **SM_INT_ARG3** on the Params tab.

6.4.2 Shared-Memory Region

Shared-memory objects rely on a shared-memory region that is visible to all processors. This region is used to store internal shared-memory object data structures and the shared-memory system partition.

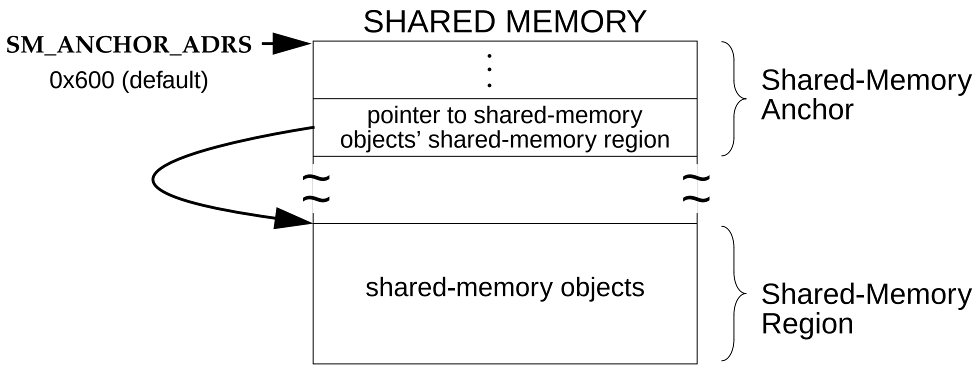
The shared-memory region is usually in dual-ported RAM on the master, but it can also be located on a separate memory card. The shared-memory region address is defined when configuring the system as an offset from the shared-memory anchor address, **SM_ANCHOR_ADRS**, as shown in Figure 6-3.

6.4.3 Initializing the Shared-Memory Objects Package

Shared-memory objects are initialized by default in the routine ***usrSmObjInit*( )** in *installDir***/target/src/config/usrSmObj.c**. The configuration steps taken for the master CPU differ slightly from those taken for the slaves.

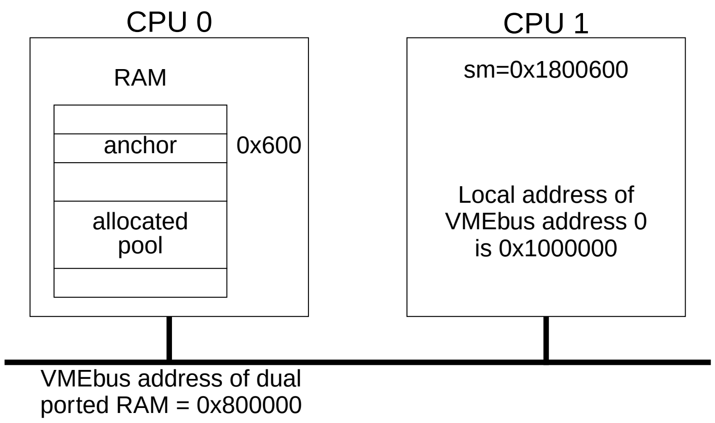
The address for the shared-memory pool must be defined. If the memory is off-board, the value must be calculated (see Figure 6-5).

Figure 6-3 **Shared-Memory Layout**



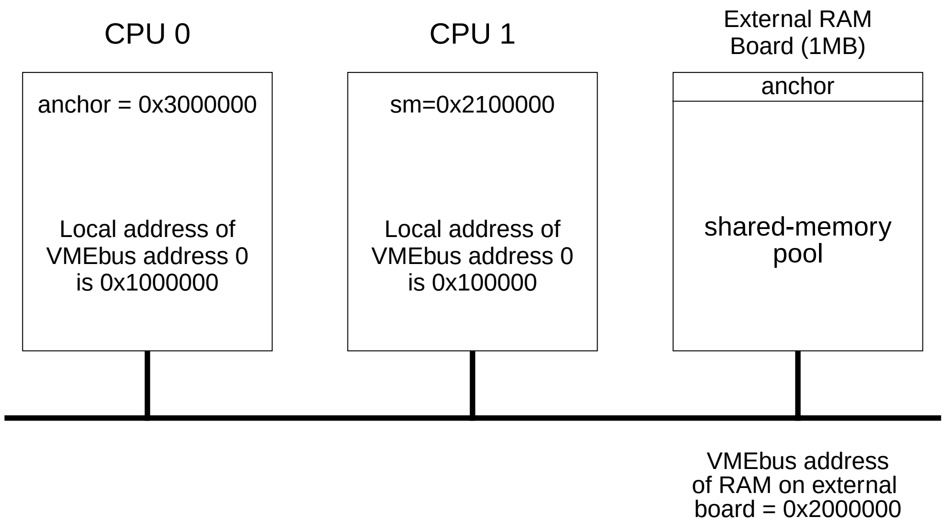
The example configuration in Figure 6-4 uses the shared memory in the master CPU's dual-ported RAM. On the Params tab of the properties window for the master, **SM_OFF_BOARD** is FALSE and **SM_ANCHOR_ADRS** is 0x600. **SM_OBJ_MEM_ADRS** is set to **NONE**, because on-board memory is used (it is malloc'ed at run-time); **SM_OBJ_MEM_SIZE** is set to 0x20000. For the slave, the board maps the base of the VME bus to the address 0x1000000. **SM_OFF_BOARD** is TRUE and the anchor address is 0x1800600. This is calculated by taking the VMEbus address (0x800000) and adding it to the anchor address (0x600). Many boards require further address translation, depending on where the board maps VME memory. In this example, the anchor address for the slave is 0x1800600, because the board maps the base of the VME bus to the address 0x1000000.

Figure 6-4 **Example Configuration: Dual-Ported Memory**


CPU 0
RAM
anchor
0x600
allocated pool
CPU 1
sm=0x1800600
Local address of VMEbus address 0 is 0x1000000
VMEbus address of dual ported RAM = 0x800000

In the example configuration in Figure 6-5, the shared memory is on a separate memory board. On the Params tab for the master, **SM_OFF_BOARD** is TRUE, **SM_ANCHOR_ADRS** is 0x3000000, **SM_OBJ_MEM_ADRS** is set to **SM_ANCHOR_ADRS**, and **SM_OBJ_MEM_SIZE** is set to 0x100000. For the slave board, **SM_OFF_BOARD** is TRUE and the anchor address is 0x2100000. This is calculated by taking the VMEbus address of the memory board (0x2000000) and adding it to the local VMEbus address (0x100000).

Figure 6-5 **Example Configuration: an External Memory Board**


CPU 0
CPU 1
External RAM Board (1MB)
anchor = 0x3000000
sm=0x2100000
anchor
Local address of VMEbus address 0 is 0x1000000
Local address of VMEbus address 0 is 0x100000
shared-memory pool
VMEbus address of RAM on external board = 0x2000000

Some additional configuration are sometimes required to make the shared memory non-cacheable, because the shared-memory pool is accessed by all processors on the backplane. By default, boards with an MMU have the MMU turned on. With the MMU on, memory that is off-board must be made non-cacheable. This is done using the data structure **sysPhysMemDesc** in **sysLib.c**. This data structure must contain a virtual-to-physical mapping for the VME address space used for the shared-memory pool, and mark the memory as non-cacheable. (Most BSPs include this mapping by default.) See *7.3 Virtual Memory Configuration*, p.290 in this manual for additional information.

⚠ **CAUTION:** For the MC68030, if the MMU is off, data caching must be turned off globally; see the reference entry for **cacheLib**.

When shared-memory objects are initialized, the memory size as well as the maximum number of each object type must be specified. The master processor specifies the size of memory using the constant **SM_OBJ_MEM_SIZE**. Symbolic constants are used to set the maximum number of different objects. These constants are specified on the Params tab of the properties window. See Table 6-5 for a list of these constants.

Table 6-5 **Configuration Constants for Shared-Memory Objects**

Symbolic Constant	Default Value	Description
SM_OBJ_MAX_TASK	40	Maximum number of tasks using shared-memory objects.
SM_OBJ_MAX_SEM	30	Maximum number of shared semaphores (counting and binary).
SM_OBJ_MAX_NAME	100	Maximum number of names in the name database.
SM_OBJ_MAX_MSG_Q	10	Maximum number of shared message queues.
SM_OBJ_MAX_MEM_PART	4	Maximum number of user-created shared-memory partitions.

If the size of the objects created exceeds the shared-memory region, an error message is displayed on CPU 0 during initialization. After shared memory is configured for the shared objects, the remainder of shared memory is used for the shared-memory system partition.

The routine ***smObjShow*( )** displays the current number of used shared-memory objects and other statistics, as follows:

```
-> smObjShow
value = 0 = 0x0
```

The routine is automatically included if **INCLUDE_SM_OBJ** is selected for inclusion in the project facility VxWorks view. The output of ***smObjShow*( )** is sent to the standard output device, and looks like the following:

```
Shared Mem Anchor Local Addr : 0x600
Shared Mem Hdr Local Addr    : 0x363ed0
Attached CPU                 : 2
Max Tries to Take Lock       : 0
Shared Object Type      Current      Maximum      Available
------------------      -------      -------      ---------
Tasks                         1           40             39
Binary Semaphores             3           30             27
```

```
Counting Semaphores           0          30            27
Messages Queues               1          10             9
Memory Partitions             1           4             3
Names in Database             5         100            95
```

⚠ **CAUTION:** If the master CPU is rebooted, it is necessary to reboot all the slaves. If a slave CPU is to be rebooted, it must not have tasks pended on a shared-memory object.

6.4.4 Configuration Example

The following example shows the configuration for a multiprocessor system with three CPUs. The master is CPU 0, and shared memory is configured from its dual-ported memory. This application has 20 tasks using shared-memory objects, and uses 12 message queues and 20 semaphores. The maximum size of the name database is the default value (100), and only one user-defined memory partition is required. On CPU 0, the shared-memory pool is configured to be on-board. This memory is allocated from the processor's system memory. On CPU 1 and CPU 2, the shared-memory pool is configured to be off-board. Table 6-6 shows the values set on the Params tab of the properties window for **INCLUDE_SM_OBJECTS** in the project facility.

Table 6-6 **Configuration Settings for Three CPU System**

CPU	Symbolic Constant	Value
Master (**CPU 0**)	**SM_OBJ_MAX_TASK**	20
	SM_OBJ_MAX_SEM	20
	SM_OBJ_MAX_NAME	100
	SM_OBJ_MAX_MSG_Q	12
	SM_OBJ_MAX_MEM_PART	1
	SM_OFF_BOARD	**FALSE**
	SM_MEM_ADRS	NONE
	SM_MEM_SIZE	0x10000
	SM_OBJ_MEM_ADRS	NONE

Table 6-6 **Configuration Settings for Three CPU System**

CPU	Symbolic Constant	Value
	SM_OBJ_MEM_SIZE	0x10000
Slaves (**CPU 1**, **CPU 2**)	**SM_OBJ_MAX_TASK**	20
	SM_OBJ_MAX_SEM	20
	SM_OBJ_MAX_NAME	100
	SM_OBJ_MAX_MSG_Q	12
	SM_OBJ_MAX_MEM_PART	1
	SM_OFF_BOARD	**TRUE**
	SM_ANCHOR_ADRS	(char *) 0xfb800000
	SM_MEM_ADRS	**SM_ANCHOR_ADRS**
	SM_MEM_SIZE	0x80000
	SM_OBJ_MEM_ADRS	(**SM_MEM_ADRS** + **SM_MEM_SIZE**)
	SM_OBJ_MEM_SIZE	0x80000

Note that for the slave CPUs, the value of **SM_OBJ_MEM_SIZE** is not actually used.

6.4.5 Initialization Steps

Initialization is performed by default in ***usrSmObjInit*( )**, in *installDir*/**target/src/config/usrSmObj.c**. On the master CPU, the initialization of shared-memory objects consists of the following:

1. Setting up the shared-memory objects header and its pointer in the shared-memory anchor, with ***smObjSetup*( )**.
2. Initializing shared-memory object parameters for this CPU, with ***smObjInit*( )**.
3. Attaching the CPU to the shared-memory object facility, with ***smObjAttach*( )**.

On slave CPUs, only steps 2 and 3 are required.

The routine ***smObjAttach*( )** checks the setup of shared-memory objects. It looks for the *shared-memory heartbeat* to verify that the facility is running. The shared-memory heartbeat is an unsigned integer that is incremented once per second by the master CPU. It indicates to the slaves that shared-memory objects are initialized, and can be used for debugging. The heartbeat is the first field in the shared-memory object header; see *6.5 Troubleshooting*, p.286.

6.5 Troubleshooting

Problems with shared-memory objects can be due to a number of causes. This section discusses the most common problems and a number of troubleshooting tools. Often, you can locate the problem by rechecking your hardware and software configurations.

6.5.1 Configuration Problems

Refer to the following list to confirm that your system is properly configured:

- Be sure to verify that the constant **INCLUDE_SM_OBJ** is selected for inclusion in the project facility VxWorks view for each processor using VxMP.
- Be sure the anchor address specified is the address seen by the CPU. This can be defined with the constant **SM_ANCHOR_ADRS** in the Params tab of the properties window or at boot time (**sm=**) if the target is booted with the shared-memory network.
- If there is heavy bus traffic relating to shared-memory objects, bus errors can occur. Avoid this problem by changing the bus arbitration mode or by changing relative CPU priorities on the bus.
- If ***memAddToPool*( )**, ***memPartSmCreate*( )**, or ***smMemAddToPool*( )** fail, check that any address you are passing to these routines is in fact a global address.

6.5.2 Troubleshooting Techniques

Use the following techniques to troubleshoot any problems you encounter:

- The routine ***smObjTimeoutLogEnable*( )** enables or disables the printing of an error message indicating that the maximum number of attempts to take a spin-lock has been reached. By default, message printing is enabled.
- The routine ***smObjShow*( )** displays the status of the shared-memory objects facility on the standard output device. It displays the maximum number of tries a task took to get a spin-lock on a particular CPU. A high value can indicate that an application might run into problems due to contention for shared-memory resources.

- The shared-memory heartbeat can be checked to verify that the master CPU has initialized shared-memory objects. The shared-memory heartbeat is in the first 4-byte word of the shared-memory object header. The offset to the header is in the sixth 4-byte word in the shared-memory anchor. (See *VxWorks Network Programmer's Guide: Data Link Layer Network Components*.)

  Thus, if the shared-memory anchor were located at 0x800000:

  ```
  [VxWorks Boot]: d 0x800000
  800000: 8765 4321 0000 0001 0000 0000 0000 002c *.eC!...........,*
  800010: 0000 0000 0000 0170 0000 0000 0000 0000 *...p............*
  800020: 0000 0000 0000 0000 0000 0000 0000 0000 *................*
  ```

  The offset to the shared-memory object header is 0x170. To view the shared-memory object header display 0x800170:

  ```
  [VxWorks Boot]: d 0x800170
  800170: 0000 0050 0000 0000 0000 0bfc 0000 0350 *...P...........P*
  ```

  In the preceding example, the value of the shared-memory heartbeat is 0x50. Display this location again to ensure that the heartbeat is alive; if its value has changed, shared-memory objects are initialized.

- The global variable **smIfVerbose**, when set to 1 (TRUE), causes shared-memory interface error messages to print to the console, along with additional details of shared-memory operations. This variable enables you to get run-time information from the device driver level that would be unavailable at the debugger level. The default setting for **smIfVerbose** is 0 (FALSE). That can be reset programmatically or from the shell.

7
Virtual Memory Interface
Basic Support and Optional Component VxVMI

7.1 Introduction

VxWorks provides two levels of virtual memory support. The basic level is bundled with VxWorks and provides caching on a per-page basis. The full level is unbundled, and requires the optional component, VxVMI. VxVMI provides write protection of text segments and the VxWorks exception vector table, and an architecture-independent interface to the CPU's memory management unit (MMU). For information on how to install VxVMI, see *Tornado Getting Started*.

This chapter contains the following sections:

- The first describes the basic level of support.
- The second describes configuration, and is applicable to both levels of support.
- The third and fourth parts apply only to the optional component, VxVMI:
  - The third is for general use, discussing the write protection implemented by VxVMI.
  - The fourth describes a set of routines for manipulating the MMU. VxVMI provides low-level routines for interfacing with the MMU in an architecture-independent manner, allowing you to implement your own virtual memory systems.

7.2 Basic Virtual Memory Support

For systems with an MMU, VxWorks allows you to perform DMA and interprocessor communication more efficiently by rendering related buffers noncacheable. This is necessary to ensure that data is not being buffered locally when other processors or DMA devices are accessing the same memory location. Without the ability to make portions of memory noncacheable, caching must be turned off globally (resulting in performance degradation) or buffers must be flushed/invalidated manually.

Basic virtual memory support is included by selecting **INCLUDE_MMU_BASIC** in the project facility VxWorks view; see *7.3 Virtual Memory Configuration*, p.290. It is also possible to allocate noncacheable buffers using ***cacheDmaMalloc*( )**; see the reference entry for **cacheLib**.

7.3 Virtual Memory Configuration

The following discussion of configuration applies to both bundled and unbundled virtual memory support.

In the project facility, define the constants in Table 7-1 to reflect your system configuration.

Table 7-1 **MMU Configuration Constants**

Constant	**Description**
INCLUDE_MMU_BASIC	Basic MMU support without VxVMI option.
INCLUDE_MMU_FULL	Full MMU support with the VxVMI option.
INCLUDE_PROTECT_TEXT	Text segment protection (requires full MMU support).
INCLUDE_PROTECT_VEC_TABLE	Exception vector table protection (requires full MMU support).

The appropriate default page size for your processor (4 KB or 8KB) is defined by **VM_PAGE_SIZE** in your BSP. If you must change this value for some reason, redefine **VM_PAGE_SIZE** in **config.h**. (See *8. Configuration and Build*.)

To make memory noncacheable, it must have a virtual-to-physical mapping. The data structure **PHYS_MEM_DESC** in **vmLib.h** defines the parameters used for mapping physical memory. Each board's memory map is defined in **sysLib.c** using **sysPhysMemDesc** (which is declared as an array of **PHYS_MEM_DESC**). In addition to defining the initial state of the memory pages, the **sysPhysMemDesc** structure defines the virtual addresses used for mapping virtual-to-physical memory. For a discussion of page states, see *Page States*, p.294.

Modify the **sysPhysMemDesc** structure to reflect your system configuration. For example, you may need to add the addresses of interprocessor communication buffers not already included in the structure. Or, you may need to map and make noncacheable the VMEbus addresses of the shared-memory data structures. Most board support packages have a section of VME space defined in **sysPhysMemDesc**; however, this may not include all the space required by your system configuration.

I/O devices and memory not already included in the structure must also be mapped and made noncacheable. In general, off-board memory regions are specified as noncacheable; see *VxWorks Network Programmer's Guide: Data Link Layer Network Components*.

CAUTION: The regions of memory defined in **sysPhysMemDesc** must be page-aligned, and must span complete pages. In other words, the first three fields (virtual address, physical address, and length) of a **PHYS_MEM_DESC** structure must all be even multiples of **VM_PAGE_SIZE**. Specifying elements of **sysPhysMemDesc** that are not page-aligned leads to crashes during VxWorks initialization.

The following example configuration consists of multiple CPUs using the shared-memory network. A separate memory board is used for the shared-memory pool. Because this memory is not already mapped, it must be added to **sysPhysMemDesc** for all the boards on the network. The memory starts at 0x4000000 and must be made noncacheable, as shown in the following code excerpt:

```
/* shared memory */
{
(void *) 0x4000000,         /* virtual address */
(void *) 0x4000000,         /* physical address */
0x20000,             /* length */
/* initial state mask */
VM_STATE_MASK_VALID | VM_STATE_MASK_WRITABLE |VM_STATE_MASK_CACHEABLE,
/* initial state */
VM_STATE_VALID | VM_STATE_WRITABLE | VM_STATE_CACHEABLE_NOT
}
```

For MC680*x*0 boards, the virtual address *must* be the same as the physical address. For other boards, the virtual and physical addresses are the same as a matter of convention.

7.4 General Use

This section describes VxVMI's general use and configuration for write-protecting text segments and the exception vector table.

VxVMI uses the MMU to prevent portions of memory from being overwritten. This is done by write-protecting pages of memory. Not all target hardware supports write protection; see the architecture appendices in this manual for further information. For most architectures, the page size is 8KB. An attempt to write to a memory location that is write-protected causes a bus error.

When VxWorks is loaded, all text segments are write-protected; see *7.3 Virtual Memory Configuration*, p.290. The text segments of additional object modules loaded using ***ld*( )** are automatically marked as read-only. When object modules are loaded, memory to be write-protected is allocated in page-size increments. No additional steps are required to write-protect application code.

During system initialization, VxWorks write-protects the exception vector table. The only way to modify the interrupt vector table is to use the routine ***intConnect*( )**, which write-enables the exception vector table for the duration of the call.

To include write-protection, select the following in the project facility VxWorks view:

INCLUDE_MMU_FULL
INCLUDE_PROTECT_TEXT
INCLUDE_PROTECT_VEC_TABLE

7.5 Using the MMU Programmatically

This section describes the facilities provided for manipulating the MMU programmatically using low-level routines in **vmLib**. You can make data private to a task or code segment, make portions of memory noncacheable, or write-protect portions of memory. The fundamental structure used to implement virtual memory is the *virtual memory context* (VMC).

For a summary of the VxVMI routines, see the reference entry for **vmLib**.

7.5.1 Virtual Memory Contexts

A virtual memory context (**VM_CONTEXT**, defined in **vmLib**) is made up of a translation table and other information used for mapping a virtual address to a physical address. Multiple virtual memory contexts can be created and swapped in and out as desired.

Global Virtual Memory

Some system objects, such as text segments and semaphores, must be accessible to all tasks in the system regardless of which virtual memory context is made current. These objects are made accessible by means of *global virtual memory*. Global virtual memory is created by mapping all the physical memory in the system (the mapping is defined in **sysPhysMemDesc**) to the identical address in the virtual memory space. In the default system configuration, this initially gives a one-to-one relationship between physical memory and global virtual memory; for example, virtual address 0x5000 maps to physical address 0x5000. On some architectures, it is possible to use **sysPhysMemDesc** to set up virtual memory so that the mapping of virtual-to-physical addresses is not one-to-one; see *7.3 Virtual Memory Configuration*, p.290 for additional information.

Global virtual memory is accessible from all virtual memory contexts. Modifications made to the global mapping in one virtual memory context appear in all virtual memory contexts. Before virtual memory contexts are created, add all global memory with ***vmGlobalMap*( )**. Global memory that is added after virtual memory contexts are created may not be available to existing contexts.

Initialization

Global virtual memory is initialized by ***vmGlobalMapInit*( )** in ***usrMmuInit*( )**, which is called from ***usrRoot*( )**. The routine ***usrMmuInit*( )** is in *installDir***/target/src/config/usrMmuInit.c**, and creates global virtual memory using **sysPhysMemDesc**. It then creates a default virtual memory context and makes the default context current. Optionally, it also enables the MMU.

Page States

Each virtual memory page (typically 8KB) has a state associated with it. A page can be valid/invalid, writable/nonwritable, or cacheable/noncacheable. See Table 7-2 for the associated constants.

Table 7-2 **State Flags**

Constant	Description
VM_STATE_VALID	Valid translation
VM_STATE_VALID_NOT	Invalid translation
VM_STATE_WRITABLE	Writable memory
VM_STATE_WRITABLE_NOT	Read-only memory
VM_STATE_CACHEABLE	Cacheable memory
VM_STATE_CACHEABLE_NOT	Noncacheable memory

Validity
: A valid state indicates the virtual-to-physical translation is true. When the translation tables are initialized, global virtual memory is marked as valid. All other virtual memory is initialized as invalid.

Writability
: Pages can be made read-only by setting the state to nonwritable. This is used by VxWorks to write-protect all text segments.

Cacheability
: The caching of memory pages can be prevented by setting the state flags to noncacheable. This is useful for memory that is shared between processors (including DMA devices).

Change the state of a page with the routine ***vmStateSet*( )**. In addition to specifying the state flags, a state mask must describe which flags are being changed; see Table 7-3. Additional architecture-dependent states are specified in **vmLib.h**.

Table 7-3 **State Masks**

Constant	Description
VM_STATE_MASK_VALID	Modify valid flag
VM_STATE_MASK_WRITABLE	Modify write flag
VM_STATE_MASK_CACHEABLE	Modify cache flag

7.5.2 Private Virtual Memory

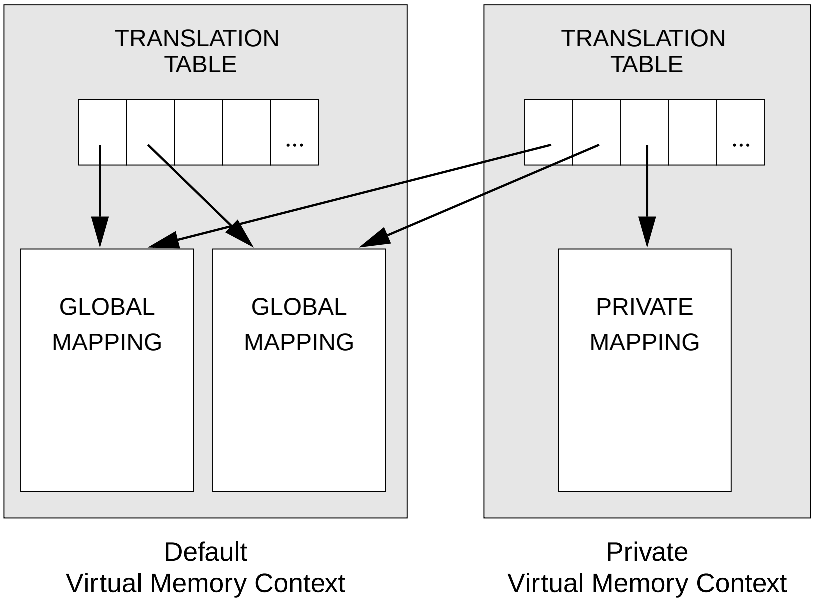
Private virtual memory can be created by creating a new virtual memory context. This is useful for protecting data by making it inaccessible to other tasks or by limiting access to specific routines. Virtual memory contexts are not automatically created for tasks, but can be created and swapped in and out in an application-specific manner.

At system initialization, a default context is created. All tasks use this default context. To create private virtual memory, a task must create a new virtual memory context using ***vmContextCreate*( )**, and make it current. All virtual memory contexts share the global mappings that are created at system initialization; see Figure 7-1. Only the valid virtual memory in the current virtual memory context (including global virtual memory) is accessible. Virtual memory defined in other virtual memory contexts is not accessible. To make another memory context current, use ***vmCurrentSet*( )**.

To create a new virtual-to-physical mapping, use ***vmMap*( )**; both the physical and virtual address must be determined in advance. The physical memory (which must be page aligned) can be obtained using ***valloc*( )**. The easiest way to determine the virtual address is to use ***vmGlobalInfoGet*( )** to find a virtual page that is not a global mapping. With this scheme, if multiple mappings are required, a task must keep track of its own private virtual memory pages to guarantee it does not map the same non-global address twice.

When physical pages are mapped into new sections of the virtual space, the physical page is accessible from two different virtual addresses (a condition known as *aliasing*): the newly mapped virtual address and the virtual address equal to the physical address in the global virtual memory. This can cause problems for some architectures, because the cache may hold two different values

Figure 7-1 **Global Mappings of Virtual Memory**



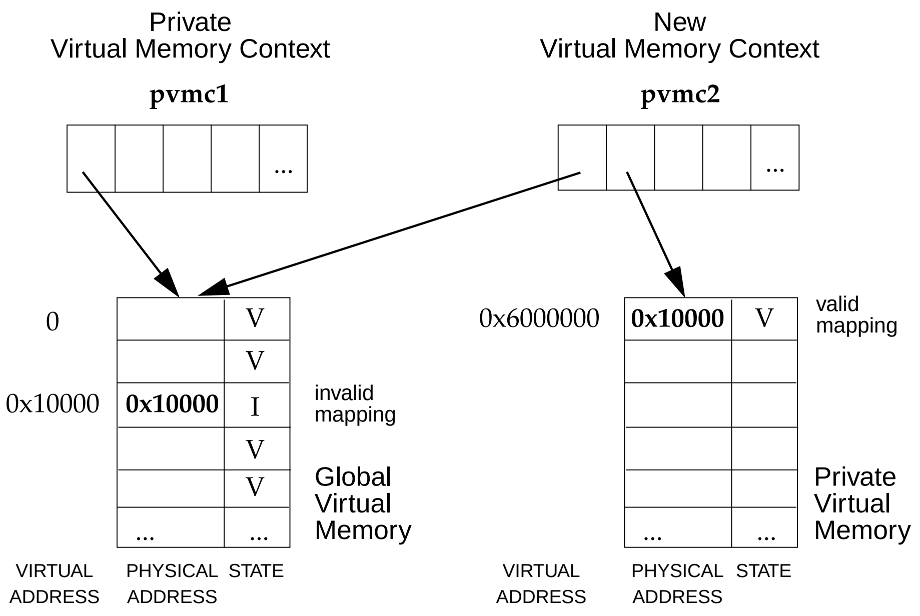
for the same underlying memory location. To avoid this, invalidate the virtual page (using ***vmStateSet*( )**) in the global virtual memory. This also ensures that the data is accessible only when the virtual memory context containing the new mapping is current.

Figure 7-2 depicts two private virtual memory contexts. The new context (**pvmc2**) maps virtual address 0x6000000 to physical address 0x10000. To prevent access to this address from outside of this virtual context (**pvmc1**), the corresponding physical address (0x10000) must be set to invalid. If access to the memory is made using address 0x10000, a bus error occurs because that address is now invalid.

Example 7-1 **Private Virtual Memory Contexts**

In the following code example, private virtual memory contexts are used for allocating memory from a task's private memory partition. The setup routine, ***contextSetup*( )**, creates a private virtual memory context that is made current during a context switch. The virtual memory context is stored in the field **spare1** in the task's TCB. Switch hooks are used to save the old context and install the task's private context. Note that the use of switch hooks increases the context switch time. A user-defined memory partition is created using the private virtual memory

Figure 7-2 **Mapping Private Virtual Memory**



context. The partition ID is stored in **spare2** in the tasks TCB. Any task wanting a private virtual memory context must call ***contextSetup*( )**. A sample task to test the code is included.

```
/* contextExample.h - header file for vm contexts used by switch hooks */

#define NUM_PAGES (3)
```

```
/* context.c - use context switch hooks to make task private context current */

#include "vxWorks.h"
#include "vmLib.h"
#include "semLib.h"
#include "taskLib.h"
#include "taskHookLib.h"
#include "memLib.h"
#include "contextExample.h"

void privContextSwitch (WIND_TCB *pOldTask, WIND_TCB *pNewTask);
```

```
/***********************************************************************
*
* initContextSetup - install context switch hook
*
*/

STATUS initContextSetup ( )
    {
    /* Install switch hook */

    if (taskSwitchHookAdd ((FUNCPTR) privContextSwitch) == ERROR)
        return (ERROR);

    return (OK);
    }

/***********************************************************************
*
* contextSetup - initialize context and create separate memory partition
*
* Call only once for each task that wants a private context.
*
* This could be made into a create-hook routine if every task on the
* system needs a private context. To use as a create hook, the code for
* installing the new virtual memory context should be replaced by simply
* saving the new context in spare1 of the task's TCB.
*/

STATUS contextSetup (void)
    {
    VM_CONTEXT_ID pNewContext;
    int pageSize;
    int pageBlkSize;
    char * pPhysAddr;
    char * pVirtAddr;
    UINT8 * globalPgBlkArray;
    int newMemSize;
    int index;
    WIND_TCB * pTcb;

    /* create context */

    pNewContext = vmContextCreate();

    /* get page and page block size */

    pageSize = vmPageSizeGet ();
    pageBlkSize = vmPageBlockSizeGet ();
    newMemSize = pageSize * NUM_PAGES;

    /* allocate physical memory that is page aligned */

    if ((pPhysAddr = (char *) valloc (newMemSize)) == NULL)
        return (ERROR);
    /* Select virtual address to map. For this example, since only one page
     * block is used per task, simply use the first address that is not a
     * global mapping. vmGlobalInfoGet( ) returns a boolean array where each
     * element corresponds to a block of virtual memory.
     */

    globalPgBlkArray = vmGlobalInfoGet();
    for (index = 0; globalPgBlkArray[index] == TRUE; index++)
        ;
    pVirtAddr = (char *) (index * pageBlkSize);

    /* map physical memory to new context */

    if (vmMap (pNewContext, pVirtAddr, pPhysAddr, newMemSize) == ERROR)
        {
        free (pPhysAddr);
        return (ERROR);
        }

    /*
     * Set state in global virtual memory to be invalid - any access to
     * this memory must be done through new context.
     */

    if (vmStateSet(pNewContext, pPhysAddr, newMemSize, VM_STATE_MASK_VALID,
                   VM_STATE_VALID_NOT) == ERROR)
        return (ERROR);

    /* get tasks TCB */

    pTcb = taskTcb (taskIdSelf());

    /* change virtual memory contexts */

    /*
     * Stash the current vm context in the spare TCB field -- the switch
     * hook will install this when this task gets swapped out.
     */

    pTcb->spare1 = (int) vmCurrentGet();

    /* install new tasks context */

    vmCurrentSet (pNewContext);

    /* create new memory partition and store id in task’s TCB */

    if ((pTcb->spare2 = (int) memPartCreate (pVirtAddr,newMemSize)) == NULL)
        return (ERROR);

    return (OK);
    }
```

```
/*******************************************************************
*
* privContextSwitch - routine to be executed on a context switch
*
* If old task had private context, save it. If new task has private
* context, install it.
*/

void privContextSwitch
    (
    WIND_TCB *pOldTcb,
    WIND_TCB *pNewTcb
    )

    {
    VM_CONTEXT_ID pContext = NULL;

    /* If previous task had private context, save it--reset previous context. */

    if (pOldTcb->spare1)
        {
        pContext = (VM_CONTEXT_ID) pOldTcb->spare1;
        pOldTcb->spare1 = (int) vmCurrentGet ();

        /* restore old context */

        vmCurrentSet (pContext);
        }

    /*
     * If next task has private context, map new context and save previous
     * context in task's TCB.
     */

    if (pNewTcb->spare1)
        {
        pContext = (VM_CONTEXT_ID) pNewTcb->spare1;
        pNewTcb->spare1 = (int) vmCurrentGet();

        /* install new tasks context */

        vmCurrentSet (pContext);
        }
    }
```

```
/* taskExample.h - header file for testing VM contexts used by switch hook */

/* This code is used by the sample task. */

#define MAX (10000000)
```

```
typedef struct myStuff {
    int stuff;
    int myStuff;
    } MY_DATA;
```

```
/* testTask.c - task code to test switch hooks */

#include "vxWorks.h"
#include "memLib.h"
#include "taskLib.h"
#include "stdio.h"
#include "vmLib.h"
#include "taskExample.h"

IMPORT char *string = "test\n";

MY_DATA *pMem;

/************************************************************************
*
* testTask - allocate private memory and use it
*
* Loop forever, modifying memory and printing out a global string. Use this
* in conjunction with testing from the shell. Since pMem points to private
* memory, the shell should generate a bus error when it tries to read it.
* For example:
*     -> sp testTask
*     -> d pMem
*/

STATUS testTask (void)
    {
    int val;
    WIND_TCB *myTcb;

    /* install private context */

    if (contextSetup () == ERROR)
        return (ERROR);

    /* get TCB */

    myTcb = taskTcb (taskIdSelf ());

    /* allocate private memory */

    if ((pMem = (MY_DATA *) memPartAlloc((PART_ID) myTcb->spare2,
         sizeof (MY_DATA))) == NULL)
        return (ERROR);
    /*
     * Forever, modify data in private memory and display string in
     * global memory.
     */

    FOREVER
        {
        for (val = 0; val <= MAX; val++)
            {
            /* modify structure */

            pMem->stuff = val;
            pMem->myStuff = val / 2;

            /* make sure can access global virtual memory */

            printf (string);

            taskDelay (sysClkRateGet() * 10);
            }
        }
    return (OK);
    }

/*************************************************************************
*
* testVmContextGet - return a task's virtual memory context stored in TCB
*
* Used with vmContextShow()1 to display a task's virtual memory context.
* For example, from the shell, type:
*   -> tid = sp (testTask)
*   -> vmContextShow (testVmContextGet (tid))
*/

VM_CONTEXT_ID testVmContextGet
    (
    UINT tid
    )
    {
    return ((VM_CONTEXT_ID) ((taskTcb (tid))->spare1));
    }
```

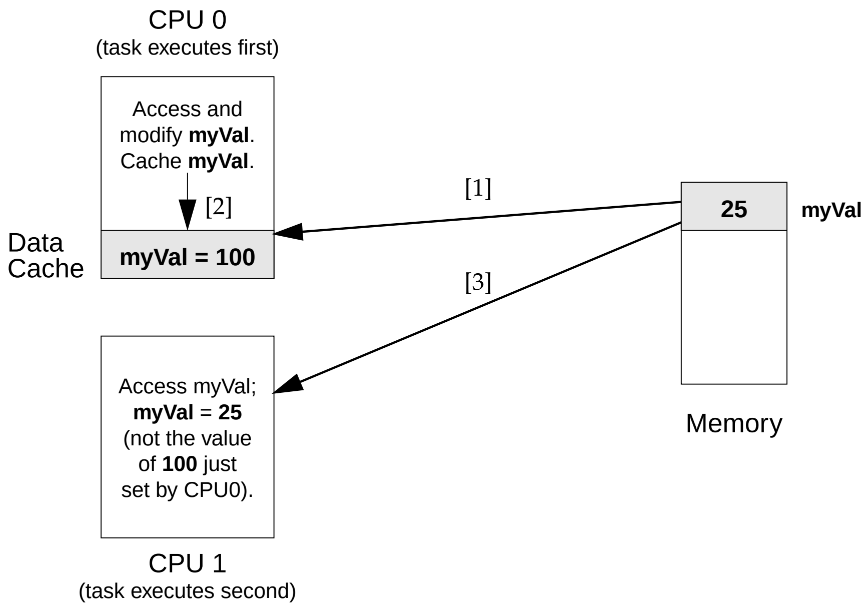
7.5.3 Noncacheable Memory

Architectures that do not support bus snooping must disable the memory caching that is used for interprocessor communication (or by DMA devices). If multiple

1. This routine is *not* built in to the Tornado shell. To use it from the Tornado shell, you must define **INCLUDE_MMU_FULL_SHOW** in your VxWorks configuration; see the *Tornado User's Guide: Projects*. When invoked this routine's output is sent to the standard output device.

processors are reading from and writing to a memory location, you must guarantee that when the CPU accesses the data, it is using the most recent value. If caching is used in one or more CPUs in the system, there can be a local copy of the data in one of the CPUs' data caches. In the example in Figure 7-3, a system with multiple CPUs share data, and one CPU on the system (CPU 0) caches the shared data. A task on CPU 0 reads the data [1] and then modifies the value [2]; however, the new value may still be in the cache and not flushed to memory when a task on another CPU (CPU 1) accesses it [3]. Thus the value of the data used by the task on CPU 1 is the old value and does not reflect the modifications done by the task on CPU 0; that value is still in CPU 0's data cache [2].

Figure 7-3 **Example of Possible Problems with Data Caching**


CPU 0
(task executes first)
Access and modify **myVal**. Cache **myVal**.
[2]
Data Cache
myVal = 100
[1]
[3]
25
myVal
Memory
Access myVal; **myVal** = **25** (not the value of **100** just set by CPU0).
CPU 1
(task executes second)

To disable caching on a page basis, use ***vmStateSet*( )**; for example:

```
vmStateSet (pContext, pSData, len, VM_STATE_MASK_CACHEABLE, VM_STATE_CACHEABLE_NOT)
```

To allocate noncacheable memory, see the reference entry for ***cacheDmaMalloc*( )**.

7.5.4 Nonwritable Memory

Memory can be marked as nonwritable. Sections of memory can be write-protected using ***vmStateSet*( )** to prevent inadvertent access.

One use of this is to restrict modification of a data object to a particular routine. If a data object is global but read-only, tasks can read the object but not modify it. Any task that must modify this object must call the associated routine. Inside the routine, the data is made writable for the duration of the routine, and on exit, the memory is set to **VM_STATE_WRITABLE_NOT**.

Example 7-2 **Nonwritable Memory**

In this code example, to modify the data structure pointed to by **pData**, a task must call ***dataModify*( )**. This routine makes the memory writable, modifies the data, and sets the memory back to nonwritable. If a task tries to read the memory, it is successful; however, if it tries to modify the data outside of ***dataModify*( )**, a bus error occurs.

```
/* privateCode.h - header file to make data writable from routine only */

#define MAX 1024

typedef struct myData
    {
    char stuff[MAX];
    int moreStuff;
    } MY_DATA;
```

```
/* privateCode.c - uses VM contexts to make data private to a code segment */

#include "vxWorks.h"
#include "vmLib.h"
#include "semLib.h"
#include "privateCode.h"

MY_DATA * pData;
SEM_ID dataSemId;
int pageSize;

/***********************************************************************
*
* initData - allocate memory and make it nonwritable
*
```

```
* This routine initializes data and should be called only once.
*
*/

STATUS initData (void)
    {
    pageSize = vmPageSizeGet();

    /* create semaphore to protect data */

    dataSemId = semBCreate (SEM_Q_PRIORITY, SEM_EMPTY);

    /* allocate memory = to a page */

    pData = (MY_DATA *) valloc (pageSize);

    /* initialize data and make it read-only */

    bzero (pData, pageSize);
    if (vmStateSet (NULL, pData, pageSize, VM_STATE_MASK_WRITABLE,
            VM_STATE_WRITABLE_NOT) == ERROR)
                {
                semGive (dataSemId);
                return (ERROR);
                }

    /* release semaphore */

    semGive (dataSemId);
    return (OK);
    }

/*********************************************************************
*
* dataModify - modify data
*
* To modify data, tasks must call this routine, passing a pointer to
* the new data.
* To test from the shell use:
*     -> initData
*     -> sp dataModify
*     -> d pData
*     -> bfill (pdata, 1024, 'X')
*/

STATUS dataModify
    (
    MY_DATA * pNewData
    )
    {

    /* take semaphore for exclusive access to data */

    semTake (dataSemId, WAIT_FOREVER);

    /* make memory writable */
    if (vmStateSet (NULL, pData, pageSize, VM_STATE_MASK_WRITABLE,
            VM_STATE_WRITABLE) == ERROR)
                {
                semGive (dataSemId);
                return (ERROR);
                }

    /* update data*/

    bcopy (pNewData, pData, sizeof(MY_DATA));

    /* make memory not writable */

    if (vmStateSet (NULL, pData, pageSize, VM_STATE_MASK_WRITABLE,
            VM_STATE_WRITABLE_NOT) == ERROR)
                {
                semGive (dataSemId);
                return (ERROR);
                }

    semGive (dataSemId);

    return (OK);
    }
```

7.5.5 Troubleshooting

If **INCLUDE_MMU_FULL_SHOW** is included in the project facility VxWorks view, you can use ***vmContextShow*( )** to display a virtual memory context on the standard output device. In the following example, the current virtual memory context is displayed. Virtual addresses between 0x0 and 0x59fff are write protected; 0xff800000 through 0xffbfffff are noncacheable; and 0x2000000 through 0x2005fff are private. All valid entries are listed and marked with a *V+*. Invalid entries are not listed.

```
-> vmContextShow 0
value = 0 = 0x0
```

The output is sent to the standard output device, and looks like the following:

```
VIRTUAL ADDR   BLOCK LENGTH   PHYSICAL ADDR   STATE
0x0            0x5a000        0x0             W- C+ V+ (global)
0x5a000        0x1f3c000      0x5a000         W+ C+ V+ (global)
0x1f9c000      0x2000         0x1f9c000       W+ C+ V+ (global)
0x1f9e000      0x2000         0x1f9e000       W- C+ V+ (global)
0x1fa0000      0x2000         0x1fa0000       W+ C+ V+ (global)
0x1fa2000      0x2000         0x1fa2000       W- C+ V+ (global)
0x1fa4000      0x6000         0x1fa4000       W+ C+ V+ (global)
0x1faa000      0x2000         0x1faa000       W- C+ V+ (global)
0x1fac000      0xa000         0x1fac000       W+ C+ V+ (global)
0x1fb6000      0x2000         0x1fb6000       W- C+ V+ (global)
```

```
0x1fb8000     0x36000       0x1fb8000      W+ C+ V+ (global)
0x1fee000     0x2000        0x1fee000      W- C+ V+ (global)
0x1ff0000     0x2000        0x1ff0000      W+ C+ V+ (global)
0x1ff2000     0x2000        0x1ff2000      W- C+ V+ (global)
0x1ff4000     0x2000        0x1ff4000      W+ C+ V+ (global)
0x1ff6000     0x2000        0x1ff6000      W- C+ V+ (global)
0x1ff8000     0x2000        0x1ff8000      W+ C+ V+ (global)
0x1ffa000     0x2000        0x1ffa000      W- C+ V+ (global)
0x1ffc000     0x4000        0x1ffc000      W+ C+ V+ (global)
0x2000000     0x6000        0x1f96000      W+ C+ V+
0xff800000    0x400000      0xff800000     W- C- V+ (global)
0xffe00000    0x20000       0xffe00000     W+ C+ V+ (global)
0xfff00000    0xf0000       0xfff00000     W+ C- V+ (global)
```

7.5.6 Precautions

Memory that is marked as global cannot be remapped using ***vmMap*( )**. To add to global virtual memory, use ***vmGlobalMap*( )**. For further information on adding global virtual memory, see *7.5.2 Private Virtual Memory*, p.295.

Performances of MMUs vary across architectures; in fact, some architectures may cause the system to become non-deterministic. For additional information, see the architecture-specific documentation for your hardware.

8
Configuration and Build

8.1 Introduction

The Tornado distribution includes a VxWorks system image for each target shipped. The *system image* is a binary module that can be booted and run on a target system. The system image consists of all desired system object modules linked together into a single non-relocatable object module with no unresolved external references.

In most cases, you will find the supplied system image entirely adequate for initial development. However, later in the cycle you may want to tailor its configuration to reflect your application requirements.

In order to tailor the system image, you will need to understand the BSP structure and the VxWorks initialization process. These topics are discussed in the following sections:

- *8.2 The Board Support Package (BSP)*, p.310
- *8.3 VxWorks Initialization Timeline*, p.313

In addition, this chapter describes in detail the manual cross-development procedures used to create and run VxWorks systems and applications as well as how to configure the system image by directly editing configuration files.

The following topics are included:

- How to build, load, run, and unload VxWorks applications manually.
- VxWorks configuration files and configuration options and parameters.
- How to include manually generated configuration files in the project facility.
- Some of the common alternative configurations of VxWorks.

- Rebuilding VxWorks system images, bootable applications, and ROM images using manual methods.

WARNING: Use of the project facility for configuring and building applications is largely independent of the methods used prior to Tornado 2.0 (which included manually editing the configuration file **config.h**). The project facility provides the recommended and simpler means for configuration and build, although the manual method may still be used as described in this chapter.

To avoid confusion and errors, the two methods should not be used together for the same project. The one exception is for any configuration macro that is not exposed through the project facility GUI (which may be the case, for example, for some BSP driver parameters). In this case, a configuration file must be edited, and the project facility will implement the change in the subsequent build.

Note that the project facility overrides any changes made to a macro in **config.h** which is also exposed through the project facility. If you are using the project facility, only edit macros in config.h which can not be configured through the project facility.

VxWorks has been ported to numerous development and target systems, and can support many different hardware configurations. Some of the cross-development procedures discussed in this chapter depend somewhat on the specific system and configuration you are running. The procedures in this chapter are presented in generic form, and may differ slightly on your particular system.

For information specific to an architecture family, see the corresponding appendix in this manual. Information specific to particular target boards is provided with each BSP.

8.2 The Board Support Package (BSP)

The directory *installDir***/target/config/***bspname* contains the *Board Support Package (BSP)*, which consists of files for the particular hardware used to run VxWorks, such as a VME board with serial lines, timers, and other devices. The files include: **Makefile**, **sysLib.c**, **sysSerial.c**, **sysALib.s**, **romInit.s**, *bspname***.h**, and **config.h**.

Wind River Systems BSPs conform to a standard, introduced with BSP Version 1.1. The standard is fully described in the *Tornado BSP Developer's Kit for VxWorks*.

The System Library

The file **sysLib.c** provides the board-level interface on which VxWorks and application code can be built in a hardware-independent manner. The functions addressed in this file include:

- Initialization functions
  - initialize the hardware to a known state
  - identify the system
  - initialize drivers, such as SCSI or custom drivers
- Memory/address space functions
  - get the on-board memory size
  - make on-board memory accessible to external bus (optional)
  - map local and bus address spaces
  - enable/disable cache memory
  - set/get nonvolatile RAM (NVRAM)
  - define the board's memory map (optional)
  - virtual-to-physical memory map declarations for processors with MMUs
- Bus interrupt functions
  - enable/disable bus interrupt levels
  - generate bus interrupts
- Clock/timer functions
  - enable/disable timer interrupts
  - set the periodic rate of the timer
- Mailbox/location monitor functions (optional)
  - enable mailbox/location monitor interrupts

The **sysLib** library does not support every feature of every board: some boards may have additional features, others may have fewer, others still may have the same features with a different interface. For example, some boards provide some **sysLib** functions by means of hardware switches, jumpers, or PALs, instead of by software-controllable registers.

The configuration modules **usrConfig.c** and **bootConfig.c** in **config/all** are responsible for invoking this library's routines at the appropriate time. Device drivers can use some of the memory mapping routines and bus functions.

Virtual Memory Mapping

For boards with MMU support, the data structure **sysPhysMemDesc** defines the virtual-to-physical memory map. This table is typically defined in **sysLib.c**, although some BSPs place it in a separate file, **memDesc.c**. It is declared as an array of the data structure **PHYS_MEM_DESC**. No two entries in this descriptor can overlap; each entry must be a unique memory space.

The **sysPhysMemDesc** array should reflect your system configuration, and you may encounter a number of reasons for changing the MMU memory map, for example: the need to change the size of local memory or the size of the VME master access space, or because the address of the VME master access space has been moved. For information on virtual memory mapping, as well as an example of how to modify **sysPhysMemDesc**, see *7.3 Virtual Memory Configuration*, p.290.

⚠ **CAUTION:** A bus error can occur if you try to access memory that is not mapped.

The Serial Driver

The file **sysSerial.c** provides board-specific initialization for the on-board serial ports. The actual serial I/O driver is in the *installDir*/**target/src/drv/sio** directory. The library **ttyDrv** uses the serial I/O driver to provide terminal operations for VxWorks.

BSP Initialization Modules

The following files initialize the BSP:

- The file **romInit.s** contains assembly-level initialization routines.
- The file **sysALib.s** contains initialization and system-specific assembly-level routines.

BSP Documentation

The file **target.nr** in the *installDir*/**target/config/***bspname* directory is the source of the online reference entry for target-specific information. (For information on how to view these reference entries, see *Tornado Getting Started*.) The **target.nr** file describes the supported board variations, the relevant jumpering, and supported devices. It also includes an ASCII representation of the board layout with an indication of board jumpers (if applicable) and the location of the ROM sockets.

8.3 VxWorks Initialization Timeline

This section covers the initialization sequence for VxWorks in a typical development configuration. The steps are described in sequence of execution. This is not the only way VxWorks can be bootstrapped on a particular processor. There are often more efficient or robust techniques unique to a particular processor or hardware; consult your hardware's documentation.

For final production, the sequence can be revisited to include diagnostics or to remove some of the generic operations that are required for booting a development environment, but that are unnecessary for production. This description can provide only an approximate guide to the processor initialization sequence and does not document every exception to this time-line.

The early steps of the initialization sequence are slightly different for ROM-based versions of VxWorks; for information, see *8.6.3 Initialization Sequence for ROM-Based VxWorks*, p.349.

For a summary of the initialization time-line, see Table 8-1. The following sections describe the initialization in detail by routine name. For clarity, the sequence is divided into a number of main steps or function calls. The key routines are listed in the headings and are described in chronological order.

The VxWorks Entry Point: *sysInit*( )

The first step in starting a VxWorks system is to load a system image into main memory. This usually occurs as a download from the development host, under the control of the VxWorks boot ROM. Next, the boot ROM transfers control to the VxWorks startup entry point, ***sysInit*( )**. This entry point is configured by **RAM_LOW_ADRS** in the makefile and in **config.h**. The VxWorks memory layout is different for each architecture; for details, see the appendix that describes your architecture.

The entry point, ***sysInit*( )**, is in the system-dependent assembly language module, **sysALib.s**. It locks out all interrupts, invalidates caches if applicable, and initializes processor registers (including the C stack pointer) to default values. It also disables tracing, clears all pending interrupts, and invokes ***usrInit*( )**, a C subroutine in the **usrConfig.c** module. For some targets, ***sysInit*( )** also performs some minimal system-dependent hardware initialization, enough to execute the remaining initialization in ***usrInit*( )**. The initial stack pointer, which is used only by ***usrInit*( )**, is set to occupy an area below the system image but above the vector table (if any).

The Initial Routine: usrInit( )

The ***usrInit*( )** routine (in **usrConfig.c**) saves information about the boot type, handles all the initialization that must be performed before the kernel is actually started, and then starts the kernel execution. It is the first C code to run in VxWorks. It is invoked in supervisor mode with all hardware interrupts locked out.

Many VxWorks facilities cannot be invoked from this routine. Because there is no task context as yet (no TCB and no task stack), facilities that require a task context cannot be invoked. This includes any facility that can cause the caller to be preempted, such as semaphores, or any facility that uses such facilities, such as ***printf*( )**. Instead, the ***usrInit*( )** routine does only what is necessary to create an initial task, ***usrRoot*( )**. This task then completes the startup.

The initialization in ***usrInit*( )** includes the following:

Cache Initialization

The code at the beginning of ***usrInit*( )** initializes the caches, sets the mode of the caches and puts the caches in a safe state. At the end of ***usrInit*( )**, the instruction and data caches are enabled by default.

Zeroing Out the System *bss* Segment

The C and C++ languages specify that all uninitialized variables must have initial values of 0. These uninitialized variables are put together in a segment called *bss*. This segment is not actually loaded during the bootstrap, because it is known to be zeroed out. Because ***usrInit*( )** is the first C code to execute, it clears the section of memory containing *bss* as its very first action. While the VxWorks boot ROMs clear all memory, VxWorks does not assume that the boot ROMs are used.

Initializing Interrupt Vectors

The exception vectors must be set up before enabling interrupts and starting the kernel. First, ***intVecBaseSet*( )** is called to establish the vector table base address.

NOTE: There are exceptions to this in some architectures; see the appendix that describes your architecture for details.

After ***intVecBaseSet*( )** is called, the routine ***excVecInit*( )** initializes all exception vectors to default handlers that safely trap and report exceptions caused by program errors or unexpected hardware interrupts.

Initializing System Hardware to a Quiescent State

System hardware is initialized by calling the system-dependent routine ***sysHwInit*( )**. This mainly consists of resetting and disabling hardware devices that can cause interrupts after interrupts are enabled (when the kernel is started). This is important because the VxWorks ISRs (for I/O devices, system clocks, and so on), are not connected to their interrupt vectors until the system initialization is completed in the ***usrRoot*( )** task. However, do not attempt to connect an interrupt handler to an interrupt during the ***sysHwInit*( )** call, because the memory pool is not yet initialized.

Initializing the Kernel

The ***usrInit*( )** routine ends with calls to two kernel initialization routines:

***usrKernelInit*( )** (defined in **usrKernel.c**)
calls the appropriate initialization routines for each of the specified optional kernel facilities (see Table 8-1 for a list).

***kernelInit*( )** (part of **kernelLib.c**)
initiates the multitasking environment and never returns. It takes the following parameters:

– The application to be spawned as the "root" task, typically ***usrRoot*( )**.

– The stack size.

– The start of usable memory; that is, the memory after the main text, data, and *bss* of the VxWorks image. All memory after this area is added to the system memory pool, which is managed by **memPartLib**. Allocation for dynamic module loading, task control blocks, stacks, and so on, all come out of this region. See *Initializing the Memory Pool*, p.316.

– The top of memory as indicated by ***sysMemTop*( )**. If a contiguous block of memory is to be preserved from normal memory allocation, pass ***sysMemTop*( )** less the reserved memory.

– The interrupt stack size. The interrupt stack corresponds to the largest amount of stack space any interrupt-level routine uses, plus a safe margin for the nesting of interrupts.

– The interrupt lock-out level. For architectures that have a *level* concept, it is the maximum level. For architectures that do not have a level concept, it is the mask to disable interrupts. See the appendix that describes your architecture for details.

***kernelInit*( )** calls ***intLockLevelSet*( )**, disables round-robin mode, and creates an interrupt stack if supported by the architecture. It then creates a root stack and TCB from the top of the memory pool, spawns the root task, ***usrRoot*( )**, and terminates the ***usrInit*( )** thread of execution. At this time, interrupts are enabled; it is critical that all interrupt sources are disabled and pending interrupts cleared.

Initializing the Memory Pool

VxWorks includes a memory allocation facility, in the module **memPartLib**, that manages a pool of available memory. The ***malloc*( )** routine allows callers to obtain variable-size blocks of memory from the pool. Internally, VxWorks uses ***malloc*( )** for dynamic allocation of memory. In particular, many VxWorks facilities allocate data structures during initialization. Therefore, the memory pool must be initialized before any other VxWorks facilities are initialized.

Note that the Tornado target server manages a portion of target memory to support downloading of object modules and other development functions. VxWorks makes heavy use of ***malloc*( )**, including allocation of space for loaded modules, allocation of stacks for spawned tasks, and allocation of data structures on initialization. You are also encouraged to use ***malloc*( )** to allocate any memory your application requires. Therefore, it is recommended that you assign to the VxWorks memory pool all unused memory, unless you must reserve some fixed absolute memory area for a particular application use.

The memory pool is initialized by ***kernelInit*( )**. The parameters to ***kernelInit*( )** specify the start and end address of the initial memory pool. In the default ***usrInit*( )** distributed with VxWorks, the pool is set to start immediately following the end of the booted system, and to contain all the rest of available memory.

The extent of available memory is determined by ***sysMemTop*( )**, which is a system-dependent routine that determines the size of available memory. If your system has other noncontiguous memory areas, you can make them available in the general memory pool by later calling ***memAddToPool*( )** in the ***usrRoot*( )** task.

The Initial Task: *usrRoot*( )

When the multitasking kernel starts executing, all VxWorks multitasking facilities are available. Control is transferred to the ***usrRoot*( )** task and the initialization of the system can be completed. For example, ***usrRoot*( )** performs the following:

– initialization of the system clock
– initialization of the I/O system and drivers
– creation of the console devices
– setting of standard in and standard out
– installation of exception handling and logging
– initialization of the pipe driver
– initialization of standard I/O
– creation of file system devices and installation of disk drivers
– initialization of floating-point support
– initialization of performance monitoring facilities
– initialization of the network
– initialization of optional facilities
– initialization of WindView (see the *WindView User's Guide*)
– initialization of target agent
– execution of a user-supplied startup script

To review the complete initialization sequence within ***usrRoot*( )**, see *installDir***/target/config/all/ usrConfig.c**.

Modify these initializations to suit your configuration. The meaning of each step and the significance of the various parameters are explained in the following sections.

Initialization of the System Clock

The first action in the ***usrRoot*( )** task is to initialize the VxWorks clock. The system clock interrupt vector is connected to the routine ***usrClock*( )** (described in *The System Clock Routine: usrClock( )*, p.322) by calling ***sysClkConnect*( )**. Then, the system clock rate (usually 60Hz) is set by ***sysClkRateSet*( )**. Most boards allow clock rates as low as 30Hz (some even as low as 1Hz), and as high as several thousand Hz. High clock rates (>1000Hz) are not desirable, because they can cause system *thrashing*.[1]

The timer drivers supplied by WRS include a call to ***sysHwInit2*( )** as part of the ***sysClkConnect*( )** routine. Wind River BSPs use ***sysHwInit2*( )** to perform further

1. *Thrashing* occurs when clock interrupts are so frequent that the processor spends too much time servicing the interrupts, and no application code can run.

board initialization that is not completed in ***sysHwInit*( )**. For example, an ***intConnect*( )** of ISRs can take place here, because memory can be allocated now that the system is multitasking.

Initialization of the I/O System

If **INCLUDE_IO_SYSTEM** is defined in **configAll.h**, the VxWorks I/O system is initialized by calling the routine ***iosInit*( )**. The arguments specify the maximum number of drivers that can be subsequently installed, the maximum number of files that can be open in the system simultaneously, and the desired name of the "null" device that is included in the VxWorks I/O system. This null device is a "bit-bucket" on output and always returns end-of-file for input.

The inclusion or exclusion of **INCLUDE_IO_SYSTEM** also affects whether the console devices are created, and whether standard in, standard out, and standard error are set; see the next two sections for more information.

Creation of the Console Devices

If the driver for the on-board serial ports is included (**INCLUDE_TTY_DEV**), it is installed in the I/O system by calling the driver's initialization routine, typically ***ttyDrv*( )**. The actual devices are then created and named by calling the driver's device-creation routine, typically ***ttyDevCreate*( )**. The arguments to this routine includes the device name, a serial I/O channel descriptor (from the BSP), and input and output buffer sizes.

The macro **NUM_TTY** specifies the number of *tty* ports (default is 2), **CONSOLE_TTY** specifies which port is the console (default is 0), and **CONSOLE_BAUD_RATE** specifies the bps rate (default is 9600). These macros are specified in **configAll.h**, but can be overridden in **config.h** for boards with a nonstandard number of ports.

PCs can use an alternative console with keyboard input and VGA output; see your PC workstation documentation for details.

Setting of Standard In, Standard Out, and Standard Error

The system-wide standard in, standard out, and standard error assignments are established by opening the console device and calling ***ioGlobalStdSet*( )**. These assignments are used throughout VxWorks as the default devices for communicating with the application developer. To make the console device an interactive terminal, call ***ioctl*( )** to set the device options to **OPT_TERMINAL**.

Installation of Exception Handling and Logging

Initialization of the VxWorks exception handling facilities (supplied by the module **excLib**) and logging facilities (supplied by **logLib**) takes place early in the execution of the root task. This facilitates detection of program errors in the root task itself or in the initialization of the various facilities.

The exception handling facilities are initialized by calling ***excInit*( )** when **INCLUDE_EXC_HANDLING** and **INCLUDE_EXC_TASK** are defined. The ***excInit*( )** routine spawns the exception support task, ***excTask*( )**. Following this initialization, program errors causing hardware exceptions are safely trapped and reported, and hardware interrupts to uninitialized vectors are reported and dismissed. The VxWorks signal facility, used for task-specific exception handling, is initialized by calling ***sigInit*( )** when **INCLUDE_SIGNALS** is defined.

The logging facilities are initialized by calling ***logInit*( )** when **INCLUDE_LOGGING** is defined. The arguments specify the file descriptor of the device to which logging messages are to be written, and the number of log message buffers to allocate. The logging initialization also includes spawning the logging task, ***logTask*( )**.

Initialization of the Pipe Driver

If named pipes are desired, define **INCLUDE_PIPE** in **configAll.h** so that ***pipeDrv*( )** is called automatically to initialize the pipe driver. Tasks can then use pipes to communicate with each other through the standard I/O interface. Pipes must be created with ***pipeDevCreate*( )**.

Initialization of Standard I/O

VxWorks includes an optional *standard I/O* package when **INCLUDE_STDIO** is defined.

Creation of File System Devices and Initialization of Device Drivers

Many VxWorks configurations include at least one disk device or RAM disk with a dosFs, rt11Fs, or rawFs file system. First, a disk driver is installed by calling the driver's initialization routine. Next, the driver's device-creation routine defines a device. This call returns a pointer to a **BLK_DEV** structure that describes the device.

The new device can then be initialized and named by calling the file system's device-initialization routine—***dosFsDevInit*( )**, ***rt11FsDevInit*( )**, or ***rawFsDevInit*( )**—when the respective constants **INCLUDE_DOSFS**, **INCLUDE_RT11FS**, and **INCLUDE_RAWFS** are defined. (Before a device can be initialized, the file system module must already be initialized with ***dosFsInit*( )**,

***rt11FsInit*( )**, or ***rawFsInit*( )**.) The arguments to the file system device-initialization routines depend on the particular file system, but typically include the device name, a pointer to the **BLK_DEV** structure created by the driver's device-creation routine, and possibly some file-system-specific configuration parameters.

Initialization of Floating-Point Support

Support for floating-point *I/O* is initialized by calling the routine ***floatInit*( )** when **INCLUDE_FLOATING_POINT** is defined in **configAll.h**. Support for floating-point *coprocessors* is initialized by calling ***mathHardInit*( )** when **INCLUDE_HW_FP** is defined. Support for software floating-point *emulation* is initialized by calling ***mathSoftInit*( )** when **INCLUDE_SW_FP** is defined. See the appropriate architecture appendix for details on your processor's floating-point support.

Inclusion of Performance Monitoring Tools

VxWorks has two built-in performance monitoring tools. A task activity summary is provided by **spyLib**, and a subroutine execution timer is provided by **timexLib**. These facilities are included by defining the macros **INCLUDE_SPY** and **INCLUDE_TIMEX**, respectively, in **configAll.h**.

Initialization of the Network

Before the network can be used, it must be initialized with the routine ***usrNetInit*( )**, which is called by ***usrRoot*( )** when the constant **INCLUDE_NET_INIT** is defined in one of the configuration header files. (The source for ***usrNetInit*( )** is in *installDir***/target/src/config/usrNetwork.c**.) The routine ***usrNetInit*( )** takes a configuration string as an argument. This configuration string is usually the "boot line" that is specified to the VxWorks boot ROMs to boot the system (see *Tornado Getting Started*). Based on this string, ***usrNetInit*( )** performs the following:

- Initializes network subsystem by calling the routine ***netLibInit*( )**.
- Attaches and configures appropriate network drivers.
- Adds gateway routes.
- Initializes the remote file access driver **netDrv**, and adds a remote file access device.
- Initializes the remote login facilities.
- Optionally initializes the Remote Procedure Calls (RPC) facility.
- Optionally initializes the Network File System (NFS) facility.

As noted previously, the inclusion of some of these network facilities is controlled by definitions in **configAll.h**; see Table 8-6 for a list of these constants. The network initialization steps are described in the *VxWorks Network Programmer's Guide*.

Initialization of Optional Products and Other Facilities

Shared memory objects are provided with the optional product VxMP. Before shared memory objects can be used, they must be initialized with the routine ***usrSmObjInit*( )** (in *installDir***/target/src/config/usrSmObj.c**), which is called from ***usrRoot*( )** if **INCLUDE_SM_OBJ** is defined.

⚠ **CAUTION:** The shared memory objects library requires information from fields in the VxWorks boot line. The functions are contained in the **usrNetwork.c** file. If no network services are included, **usrNetwork.c** is not included and the shared memory initialization fails. The project facility calculates all dependencies but if you are using manual configuration, either add **INCLUDE_NETWORK** to **configAll.h** or extract the bootline cracking routines from **usrNetwork.c** and include them elsewhere.

Basic MMU support is provided if **INCLUDE_MMU_BASIC** is defined. Text protection, vector table protection, and a virtual memory interface are provided with the optional product VxVMI, if **INCLUDE_MMU_FULL** is defined. The MMU is initialized by the routine ***usrMmuInit*( )**, located in *installDir***/target/src/config/usrMmuInit.c**. If the macros **INCLUDE_PROTECT_TEXT** and **INCLUDE_PROTECT_VEC_TABLE** are also defined, text protection and vector table protection are initialized.

The GNU C++ compiler is shipped with Tornado. To initialize C++ support for the GNU compiler, define either **INCLUDE_CPLUS** or **INCLUDE_CPLUS_MIN**. To include one or more of the Wind Foundation Class libraries, define the appropriate **INCLUDE_CPLUS_***library* macros (listed in Table 8-6).[2]

Initialization of WindView

Kernel instrumentation is provided with the optional product WindView. It is initialized in ***usrRoot*( )** when **INCLUDE_WINDVIEW** is defined in **configAll.h**. Other WindView configuration constants control particular initialization steps; see the *WindView User's Guide: Configuring WindView.*

2. For information on using the GNU C++ compiler and the optional Wind Foundation Classes, see *5. C++ Development* and *8.4.2 Compiling Application Modules*, p.329.

Initialization of the Target Agent

If **INCLUDE_WDB** is defined, ***wdbConfig*( )** in *installDir*/**target/src/config/usrWdb.c** is called. This routine initializes the agent's communication interface, then starts the agent. For information on configuring the agent and the agent's initialization sequence, see *Tornado Getting Started*.

Execution of a Startup Script

The ***usrRoot*( )** routine executes a user-supplied startup script if the target-resident shell is configured into VxWorks, **INCLUDE_STARTUP_SCRIPT** is defined, and the script's file name is specified at boot time with the startup script parameter (see *Tornado Getting Started*). If the parameter is missing, no startup script is executed.

The System Clock Routine: usrClock( )

Finally, the system clock ISR ***usrClock*( )** is attached to the system clock timer interrupt by the ***usrRoot*( )** task described *The Initial Task: usrRoot( )*, p.317. The ***usrClock*( )** routine calls the kernel clock tick routine ***tickAnnounce*( )**, which performs OS bookkeeping. You can add application-specific processing to this routine.

Initialization Summary

Table 8-1 shows a summary of the entire VxWorks initialization sequence for typical configurations. For a similar summary applicable to ROM-based VxWorks systems, see *Overall Initialization for ROM-Based VxWorks*, p.350.

Table 8-1 **VxWorks Run-time System Initialization Sequence**

Routine	Activity	File
***sysInit*( )**	(a) lock out interrupts	**sysALib.s**
	(b) invalidate caches, if any	
	(c) initialize system interrupt tables with default stubs (i960 only)	
	(d) initialize system fault tables with default stubs (i960 only)	

Table 8-1 **VxWorks Run-time System Initialization Sequence** *(Continued)*

Routine	Activity	File
	(e) initialize processor registers to known default values	
	(f) disable tracing	
	(g) clear all pending interrupts	
	(h) invoke ***usrInit*( )** specifying boot type	
***usrInit*( )**	(a) zero *bss* (uninitialized data)	**usrConfig.c**
	(b) save **bootType** in **sysStartType**	
	(c) invoke ***excVecInit*( )** to initialize all system and default interrupt vectors	
	(d) invoke ***sysHwInit*( )**	
	(e) invoke ***usrKernelInit*( )**	
	(f) invoke ***kernelInit*( )**	
***usrKernelInit*( )**	The following routines are invoked if their configuration constants are defined.	**usrKernel.c**
	(a) ***classLibInit*( )**	
	(b) ***taskLibInit*( )**	
	(c) ***taskHookInit*( )**	
	(d) ***semBLibInit*( )**	
	(e) ***semMLibInit*( )**	
	(f) ***semCLibInit*( )**	
	(g) ***semOLibInit*( )**	
	(h) ***wdLibInit*( )**	
	(i) ***msgQLibInit*( )**	
	(j) ***qInit*( )** for all system queues	
	(k) ***workQInit*( )**	
***kernelInit*( )**	Initialize and start the kernel.	**kernelLib.c**

Table 8-1 **VxWorks Run-time System Initialization Sequence** *(Continued)*

Routine	Activity	File
	(a) invoke ***intLockLevelSet*( )** (b) create root stack and TCB from top of memory pool (c) invoke ***taskInit*( )** for ***usrRoot*( )** (d) invoke ***taskActivate*( )** for ***usrRoot*( )** (e) ***usrRoot*( )**	
***usrRoot*( )**	Initialize I/O system, install drivers, and create devices as specified in **configAll.h** and **config.h**. (a) ***sysClkConnect*( )** (b) ***sysClkRateSet*( )** (c) ***iosInit*( )** (d) if (**INCLUDE_TTY_DEV** and **NUM_TTY**) ***ttyDrv*( )**, then establish console port, **STD_IN**, **STD_OUT**, **STD_ERR** (e) initialize exception handling with ***excInit*( )**, ***logInit*( )**, ***sigInit*( )** (f) initialize the pipe driver with ***pipeDrv*( )** (g) ***stdioInit*( )** (h) ***mathSoftInit*( )** or ***mathHardInit*( )** (i) ***wdbConfig*( )**: configure and initialize target agent (j) run startup script if target-resident shell is configured	**usrConfig.c**

8.4 Building, Loading, and Unloading Application Modules

In the Tornado development environment, application modules for the target system are created and maintained on a separate development host. First, the source code, generally in C or C++, is edited and compiled to produce a relocatable object module. Application modules use VxWorks facilities by virtue of including header files that define operating-system interfaces and data structures. The resulting object modules can then be loaded and dynamically linked into a running VxWorks system over the network.

The following sections describe in detail the procedures for carrying out cross-development manually (without using the project facility).

8.4.1 Using VxWorks Header Files

Many application modules make use of VxWorks operating system facilities or utility libraries. This usually requires that the source module refer to VxWorks *header files*. The following sections discuss the use of VxWorks header files.

VxWorks header files supply ANSI C function prototype declarations for all global VxWorks routines. The ANSI C prototypes are conditionally compiled; to use them, the preprocessor constant **__STDC__** must be defined. ANSI C compilers define this constant by default. VxWorks provides all header files specified by the ANSI X3.159-1989 standard.

VxWorks system header files are in the directory *installDir*/**target/h** and its subdirectories.

NOTE: The notation **$(WIND_BASE)** is used in makefiles to refer to the Tornado installation directory. This chapter uses that notation because makefiles are the most convenient way to run the Tornado compilation tools. If you run the compiler from the Windows command prompt, write **%WIND_BASE%** instead.

VxWorks Header File: vxWorks.h

The header file **vxWorks.h** contains many basic definitions and types that are used extensively by other VxWorks modules. Many other VxWorks header files require these definitions. Thus, this file must be included first by every application module that uses VxWorks facilities. Include **vxWorks.h** with the following line:

```
#include "vxWorks.h"
```

Other VxWorks Header Files

Application modules can include other VxWorks header files as needed to access VxWorks facilities. For example, an application module that uses the VxWorks linked-list subroutine library must include the **lstLib.h** file with the following line:

```
#include "lstLib.h"
```

The manual entry for each library lists all header files necessary to use that library.

ANSI Header Files

All ANSI-specified header files are included in VxWorks. (UNIX)

This implies that many familiar UNIX header files are available under VxWorks as well. There are two file names that differ from the usual UNIX names: **a_out.h** (which corresponds to the UNIX **a.out.h**) and **stdlib.h** (which corresponds to the UNIX **malloc.h**)

The -I Compiler Flag

By default, the compiler searches for header files first in the directory of the source module and then in directories that apply only to the development host. With the GNU compiler, you can avoid these host-system include directories with the compilation flag **-nostdinc**. To access the VxWorks header files, the compiler must also be directed to search **$(WIND_BASE)/target/h**. Thus, the following option flag is standard for VxWorks compilation:

```
-I $(WIND_BASE)/target/h
```

Some header files are located in subdirectories. To refer to header files in these subdirectories, be sure to specify the subdirectory name in the include statement, so that the files can be located with a single **-I** specifier. For example:

```
#include "vxWorks.h"
#include "sys/stat.h"
```

VxWorks Nested Header Files

Some VxWorks facilities make use of other, lower-level VxWorks facilities. For example, the *tty* management facility uses the ring buffer subroutine library. The *tty* header file **tyLib.h** uses definitions that are supplied by the ring buffer header file **rngLib.h**.

It would be inconvenient to require you to be aware of such include-file interdependencies and ordering. Instead, all VxWorks header files explicitly include all prerequisite header files. Thus, **tyLib.h** itself contains an include of **rngLib.h**. (The exception to this is the basic VxWorks header file **vxWorks.h**, which all other header files assume is already included.)

This, in turn, might lead to a problem: a header file could get included more than once, if one were included by several other header files, or if it were also included directly by the application module. Normally, including a header file more than once generates fatal compilation errors, because the C preprocessor regards duplicate definitions as potential sources of conflict. To avoid this problem, all VxWorks header files contain conditional compilation statements and definitions that ensure that their text is included only once, no matter how many times they are specified by include statements. Thus, an application module can include just those header files it needs directly, without regard for interdependencies or ordering, and no conflicts arise.

Internal Header Files

Table 8-2 lists the subdirectories of *installDir***/target/h** used by VxWorks for internal header files. These header files are, for the most part, not intended for applications. The following subdirectories are exceptions, and are sometimes required by application programs:

- *installDir***/target/h/net**, which is used by network drivers for specific network controllers.
- *installDir***/target/h/rpc**, which is used by applications using the remote procedure call library.
- *installDir***/target/h/sys**, which is used by applications using standard POSIX functions.

Table 8-2 **Include Subdirectories**

Subdirectory	Use
*installDir***/target/h/arch**	Architecture-specific header files.
*installDir***/target/h/arpa**	Fundamental Internet header file.
*installDir***/target/h/make**	Generic makefile information.

Table 8-2 **Include Subdirectories**

Subdirectory	Use
installDir/**target/h/drv**	Device-driver header files.
installDir/**target/h/net**	Network header files.
installDir/**target/h/netinet**	Internet protocol header files.
installDir/**target/h/private**	VxWorks private header files.
installDir/**target/h/rpc**	Remote Procedure Call (RPC) header files.
installDir/**target/h/rw**	Header files for Tools.h++ from Rogue Wave (Optional).
installDir/**target/h/sys**	System header files specified by POSIX.
installDir/**target/h/types**	Data types used by the system.
installDir/**target/h/wdb**	Target-agent declarations.

VxWorks Private Header Files

VxWorks modules are designed so that you never need to know or reference the modules' internal data structures. In general, all legitimate access to a facility is provided by a module's subroutine interfaces. The internal details should be thought of as "hidden" from application developers. This means that the internal implementations can change without affecting your use of the corresponding facilities.

Internal details in VxWorks are hidden using two conventions. Some header files mark hidden code using the following comments:

```
/* HIDDEN */
...
/* END HIDDEN */
```

Internal details are also hidden with *private* header files: files that are stored in the directory *installDir*/**target/h/private**. The naming conventions for these files parallel those in *installDir*/**target/h** with the library name followed by **P.h**. For example, the private header file for **semLib** is *installDir*/**target/h/private/semLibP.h**.

⚠ **CAUTION:** Never make references to any of the hidden definitions, or base any assumptions on those definitions. The only supported uses of a module's facilities are through the public definitions in the header file, and through the module's subroutine interfaces. Although this rule is not currently enforced in any way, it is in your interest to observe it. Your adherence ensures that your application code is not affected by internal changes in the implementation of a VxWorks module.

8.4.2 Compiling Application Modules

Tornado includes a full-featured C and C++ compiler and associated tools, collectively called the *GNU ToolKit*. Extensive documentation for this set of tools is printed in a separate manual: the *GNU ToolKit User's Guide*. This section provides some general orientation about the source of these tools, and describes how the tools are integrated into the Tornado development environment.

The GNU Tools

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It is important to be aware that the terms under which the GNU tools are distributed do not apply to the software you create with them. In fact, the General Public License makes no requirements of you as a software developer at all, as long as you do not modify or redistribute the tools themselves. On the other hand, it gives you the right to do both of these things, provided you comply with its terms and conditions. It also permits you to make unrestricted copies for your own use.

The Wind River GNU distribution consists of the GNU ToolKit, which contains GNU tools modified and configured for use with your VxWorks target architecture. The source code for these tools is included.

Cross-Development Commands

The GNU cross-development tools in Tornado have names that clearly indicate the target architecture. This allows you to install and use tools for more than one architecture, and to avoid confusion with corresponding host native tools. A suffix identifying the target architecture is appended to each tool name. For example, the cross-compiler for the 68K processor family is called **cc68k**, and the assembler **as68k**. The suffixes used are shown in Table 8-3. Note that the text in the *GNU ToolKit User's Guide* refers to these tools by their generic names (without a suffix).

Table 8-3 **Suffixes for Cross-Development Tools**

Architecture	Command Suffix
MC680*x*0	**68k**
SPARC/SPARClite	**sparc**
i960	*
x86	**386**
MIPS	**mips**
PowerPC	**ppc**
ARM	**arm**
Simulators	**simso**, **hppa**, **simnt**

* See *C. Intel i960.*

Defining the CPU Type

Tornado can support multiple target architectures in a single development tree. To accommodate this, several VxWorks header files contain conditional compilation directives based on the definition of the variable **CPU**. When using these header files, the variable **CPU** must be defined in one of the following places:

– the source modules
– the header files
– the compilation command line

To define **CPU** in the source modules or header files, add the following line:

```
#define CPU cputype
```

To define **CPU** on the compilation command line, add the following flag:

```
-DCPU=cputype
```

The constants shown in Table 8-4 are supported values for *cputype*.

Table 8-4 **Values for** *cputype*

Architecture	Value
MC680*x*0	**MC68000**, **MC68010**, **MC68020**[*], **MC68040**, **MC68LC040**[†], **MC68060**, **CPU32**
SPARC, SPARClite	**SPARC**[‡]
i960	**I960CA**, **I960KB**, **I960KA**, **I960JX**
i386,i486, Pentium, PentiumPro	**I80386**, **I80486**, **PENTIUM**[**]
MIPS	**R3000**, **R4000**, **R4650**
PowerPC	**PPC403**, **PPC603**, **PPC604**, **PPC860**
ARM	**ARM7TDMI**, **ARM7TDMI_T**, **ARMSA110**, **ARM710A**, **ARM810**
Simulators	**SIMSPARCSOLARIS**, **SIMHPPA**, **SIMNT**

* **MC68020** is the appropriate value for both the MC68020 and the MC68030 CPUs.
† **MC68LC040** is the appropriate value for both the MC68LC040 and the MC68EC040.
‡ **SPARC** is the appropriate value for both SPARC and SPARClite CPUs.
****PENTIUM** is the appropriate value for both Pentium and PentiumPro CPUs.

With makefiles, the **CPU** definition can be added to the definition of the flags passed to the compiler (usually **CFLAGS**).

In the source code, the file **vxWorks.h** must be included before any other files with dependencies on the **CPU** flag.

As well as specifying the **CPU** value, you must usually run the compiler with one or more option flags to generate object code optimally for the particular architecture variant. These option flags usually begin with **-m**; see *Compiling C Modules*, p.332.

Compiling C Modules

The following is an example command to compile an application module for a VxWorks MC68020 system:

```
% cc68k -fno-builtin -I %WIND_BASE%\target\h -nostdinc -O \
-c -DCPU=MC68020 applic.c
```

This compiles the module **applic.c** into an object file **applic.o**. Table 8-5 shows a similar example compiler invocation for each CPU architecture family.

Table 8-5 **Compiler Invocation by Architecture Family**

Architecture	Example Invocation
MC680*x*0	**cc68k -fno-builtin -I $(WIND_BASE)/target/h -nostdinc -O -c\ -m68040 -DCPU=MC68040 applic.c**
SPARC	**ccsparc -fno-builtin -I $(WIND_BASE)/target/h -nostdinc -O2 -c \ -DCPU=SPARC applic.c**
SPARClite	**ccsparc -fno-builtin -I $(WIND_BASE)/target/h -nostdinc -O2 -c \ -msparclite -DCPU=SPARC applic.c**
i960	See your i960 toolkit documentation and *C. Intel i960*.
i386/i486	**cc386 -fno-builtin -I $(WIND_BASE)/target/h -nostdinc -O -c \ -fno-defer-pop -mno-486 -DCPU=I80386 applic.c**
MIPS	**ccmips -fno-builtin -I $(WIND_BASE)/target/h -nostdinc -O2 -c \ -mcpu=r4000 -mips3 -G 0 -DCPU=R4000 applic.c**
PowerPC	**ccppc -O2 -mcpu=603 -I$WIND_BASE/target/h -fno-builtin \ -fno-for-scope -nostdinc -DCPU=PPC603 -D_GNU_TOOL -c applic.c**
ARM	**ccarm -DCPU=ARM7TDMI -mcpu=arm7tdmi -mno-sched-prolog \ -fno-builtin -O2 -nostdinc -I $WIND_BASE/target/h -c applic.c**
Simulator	**ccsimso -DCPU=SIMSPARCSOLARIS -ansi -nostdinc -g \ -fno-builtin -fvolatile -DRW_MULTI_THREAD -D_REENTRANT \ -O2 -I. -I /wind/target/h -c applic.c**

The following list gives summary descriptions of the compiler flags in Table 8-5. For more information, see the *GNU ToolKit User's Guide*, or the architecture appendices.

-c Compile only; do not link for execution under the host. The output is an unlinked object module with the suffix ".o", in this case **applic.o**.

-DCPU=*arch*
Define the CPU type.

-DVX_IGNORE_GNU_LIBS
Define the constant used by the i960 configuration to suppress the use of the GNU libraries (**cc960** only).

-D_GNU_TOOL
Required; defines the compilation toolkit used to compile VxWorks or applications (**ccppc** only).

-fno-builtin
Use library calls even for common library subroutines.

-fno-defer-pop
Always pop the arguments to each function call as soon as that function returns.

-fno-for-scope
Required; allows the scope of variables declared within a for loop to be outside of the for loop.

-G 0 Do not use the MIPS global pointer (**ccmips** only).

-I $(WIND_BASE)/target/h
Include VxWorks header files (see *8.4.1 Using VxWorks Header Files*, p.325).

-m68040
Generate code for a specific variant of the MC680*x*0 family.

-mcpu=
Generate MIPS R4200 or R4600 specific code (**ccmips** only).

-mips3
Issue instructions from level 3 of the MIPS instruction set (**ccmips** only).

-mno-486
Generate code optimized for an i386 rather than for an i486 (**cc386** only).

-msparclite
Generate SPARClite-specific code (**ccsparc** only).

-nostdinc
Do not search host-system header files; search only the directories specified with the **-I** flag and the current directory for header files.

-O Perform standard optimizations.

-O2 Use level 2 optimization.

Compiling C++ Modules

Tornado supports the GNU compiler, a standard part of the cross-compilation tools distributed for Tornado, compiles source programs in either C or C++. To use this compiler for C++, invoke **cc***arch* on any source file with a C++ suffix (such as **.cpp**). For complete information on using C++, including a detailed discussion of compiling C++ modules, see *5. C++ Development*.

Compiling C++ applications in the VxWorks environment involves the following steps:

1. C++ source code is compiled into object code for a specific target architecture, just as for C applications.
2. The compiled object module is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks run-time support can use to call the objects' constructors and destructors. The details are described in *5.2.5 Munching C++ Application Modules*, p.232.

8.4.3 Static Linking (Optional)

After you compile an application module, you can load it directly into the target with the Tornado dynamic loader (through the shell or through the debugger).

In general, application modules do not need to be linked with the linker from the GNU ToolKit, **ld***arch*. However, using **ld***arch* may be required when several application modules cross-reference each other. The following example is a command to link several application modules, using the GNU linker for the MC680*x*0 family of processors.

```
C:\devt> ld68k -o applic.o -r applic1.o applic2.o applic3.o
```

This creates the object module **applic.o** from the object modules **applic1.o**, **applic2.o**, and **applic3.o**. The **-r** option is required, because the object-module output must be left in relocatable form so that it can be downloaded and linked to the target VxWorks image.

Any VxWorks facilities called by the application modules are reported by **ld***arch* as unresolved externals. These are resolved by the Tornado loader when the module is loaded into VxWorks memory.

WARNING: Do not link each application module with the VxWorks libraries. Doing this defeats the load-time linking feature of Tornado, and wastes space by writing multiple copies of VxWorks system modules on the target.

8.4.4 Downloading an Application Module

After application object modules are compiled (and possibly linked by the host **ld***arch* command), they can be dynamically loaded into a running VxWorks system by invoking the Tornado module loader. You can do this either from the Tornado shell using the built-in command ***ld*( )**, or from the debugger using the Debug menu or the **load** command.

The following is a typical load command from the Tornado shell:

```
-> ld <applic.o
```

This relocates the code from the host file **applic.o**, linking to previously loaded modules, and loads the object module into the target's memory. Once an application module is loaded into target memory, any subroutine in the module can be invoked directly from the shell, spawned as a task, connected to an interrupt, and so on.

The shell ***ld*( )** command, by default, adds only global symbols to the symbol table. During debugging, you may want local symbols as well. To get all symbols loaded (including local symbols), you can use the GDB command **load** from the debugger. Because this command is meant for debugging, it always loads all symbols. Alternately, you can load all symbols by calling the shell command ***ld*( )** with a full argument list instead of the shell-redirection syntax shown above. When you use an argument list, you can get all symbols loaded by specifying a 1 as the first argument, as in the following example:

```
-> ld 1,0,"applic.o"
```

In the foregoing examples, the object module **applic.o** comes from the shell's current working directory. Normally, you can use either relative path names or absolute path names to identify object modules to ***ld*( )**. If you use a relative path name, the shell converts it to an absolute path (using its current working directory) before passing the download request to the target server. In order to avoid trouble when the shell where you call ***ld*( )** is not running on the same host as its target server, Tornado supplies the **LD_SEND_MODULES** facility; see the *Tornado User's Guide: Shell*. If you are using a remote target server and ***ld*( )** fails with a "no such file" message, be sure that **LD_SEND_MODULES** is set to "on."

⚠ **CAUTION:** (Windows) If you call ***ld*( )** with an explicit argument list, any backslash characters in the module-name argument must be doubled. If you supply the module name with the redirection symbol, as in the earlier example in this section, no double backslashes are needed. See the *Tornado User's Guide: Shell* for more discussion of this issue.

For more information about loader arguments, see the discussion of ***ld*( )** (in the reference entry for **windsh**).

For information about the target-resident version of the loader (which also requires the target-resident symbol table), see the VxWorks reference entry for **loadLib**.

8.4.5 Module IDs and Group Numbers

When a module is loaded, it is assigned a module ID and a group number. Both the module ID and the group number are used to reference the module. The module ID is returned by ***ld*( )** as well as by the target-resident loader routines. When symbols are added to the symbol table, the associated module is identified by the group number (a small integer). (Due to limitations on the size of the symbol table, the module ID is inappropriate for this purpose.) All symbols with the same group number are from the same module. When a module is unloaded, the group number is used to identify and remove all the module's symbols from the symbol table.

8.4.6 Unloading Modules

Whenever you load a particular object module more than once, using the target server (from either the shell or the debugger), the older version is unloaded automatically. You can also unload a module explicitly: both the Tornado shell and the target-resident VxWorks libraries include an unloader. To remove a module from the shell, use the shell routine ***unld*( )**; see the reference entry for **windsh**.

For information about the target-resident version of the unloader (which also requires the target-resident symbol table and loader), see the VxWorks reference entry for **unldLib**.

After a module has been unloaded, any calls to routines in that module fail with unpredictable results. Take care to avoid unloading any modules that are required by other modules. One solution is to link interdependent files using the static linker **ld***arch* as described in *8.4.3 Static Linking (Optional)*, p.334, so that they can only be loaded and unloaded as a unit.

8.5 Configuring VxWorks

The configuration of VxWorks is determined by the configuration header files *installDir***/target/config/all/configAll.h** and *installDir***/target/config/***bspname***/config.h**. These files are used by the **usrConfig.c**, **bootConfig.c**, and **bootInit.c** modules as they run the initialization routines distributed in the directory *installDir***/target/src/config** to configure VxWorks.

The VxWorks distribution includes the configuration files for the default development configuration. You can create your own versions of these files to better suit your particular configurations; this is described in the following subsections. In addition, if you need multiple configurations, environment variables are provided so you can move easily between them.

NOTE: To rebuild VxWorks for your own configuration, follow the procedures described in the *Tornado User's Guide: Projects* (recommended) or see *8.7 Building a VxWorks System Image*, p.351.

Including optional components in your VxWorks image can significantly increase the image size. If you receive a warning from **vxsize** when building VxWorks, or if the size of your image becomes greater than that supported by the current setting of **RAM_HIGH_ADRS**, be sure to see *8.6.1 Scaling Down VxWorks*, p.344 and *8.9 Creating Bootable Applications*, p.364 for information on how to resolve the problem.

8.5.1 The Environment Variables

In a development environment, you may have several different configurations you wish to test, or you may wish to specify different target code in different situations. In order to build VxWorks to these different specifications, you need to modify your environment.

In general, your Tornado environment consists of three parts: the host code (Tornado), the target code, and the configuration files discussed in this section. If you use the default environment, your UNIX environment variables are defined as follows:

Host code:	**$WIND_BASE/host/***hosttype***/bin**
Target code:	**TGT_DIR** = **$WIND_BASE/target**
Configuration code:	**CONFIG_ALL** = $**TGT_DIR/config/all**

On Windows hosts, the IDE automatically locates Tornado code in the following locations:

Host code:	*installDir***/host/***hosttype***/bin**
Target code:	*installDir***/target**
Configuration code:	*installDir***/target/config/all**

To use different versions of **usrConfig.c**, **bootConfig.c**, and **bootInit.c**, store them in a different directory and change the value of **CONFIG_ALL**. To use different target code, point to the alternate directory by changing the value of **TGT_DIR**.

You can change the value of **CONFIG_ALL** by changing it either in your makefile or on the command line. The value of **TGT_DIR** must be changed on the command line.

NOTE: Changing **TGT_DIR** will change the default value of **CONFIG_ALL**. If this is not what you want, reset **CONFIG_ALL** as well.

To change **CONFIG_ALL** in your makefile, add the following command:

```
CONFIG_ALL = $WIND_BASE/target/config/newDir
```

To change **CONFIG_ALL** on the command line, do the following:

```
% make ... CONFIG_ALL = $WIND_BASE/target/config/newDir
```

To change **TGT_DIR** on the command line, do the following:

```
% make ... TGT_DIR = $ALT_DIR/target
```

8.5.2 The Configuration Header Files

You can control VxWorks's configuration by including or excluding definitions in the global configuration header file **configAll.h** and in the target-specific configuration header file **config.h**. This section describes these files.

The Global Configuration Header File: configAll.h

The **configAll.h** header file, in the directory *installDir***/target/config/all**, contains default definitions that apply to all targets, unless redefined in the target-specific header file **config.h**. The following options and parameters are defined in **configAll.h**:

– kernel configuration parameters
– I/O system parameters
– NFS parameters
– selection of optional software modules
– selection of optional device controllers
– cache modes
– maximum number of the different shared memory objects
– device controller I/O addresses, interrupt vectors, and interrupt levels
– miscellaneous addresses and constants

The BSP-specific Configuration Header File: config.h

There is also a BSP-specific header file, **config.h**, in the directory *installDir***/target/config/***bspname*. This file contains definitions that apply only to the specific target, and can also redefine default definitions in **configAll.h** that are inappropriate for the particular target. For example, if a target cannot access a device controller at the default I/O address defined in **configAll.h** because of addressing limitations, the address can be redefined in **config.h**.

The **config.h** header file includes definitions for the following parameters:

– default boot parameter string for boot ROMs
– interrupt vectors for system clock and parity errors
– device controller I/O addresses, interrupt vectors, and interrupt levels
– shared memory network parameters
– miscellaneous memory addresses and constants

⚠ **CAUTION:** If any options from **configAll.h** need to be changed for this one BSP, then any previous definition of that option should be undefined and redefined as necessary in **config.h**. Unless options are to apply to all BSPs at your site, do not change them in *installDir***/target/config/all/configAll.h**.

Selection of Optional Features

VxWorks ships with optional features and device drivers that can be included or omitted from the target system. These are controlled by macros in the project facility or the configuration header files that cause conditional compilation in the *installDir*/**target/config/all/usrConfig.c** module.

The distributed versions of the configuration header files **configAll.h** and **config.h** include all the available software options and several network device drivers. If you are not using the project facility (see *Tornado User's Guide: Projects*), you define a macro by moving it from the EXCLUDED FACILITIES section of the header file to the INCLUDED SOFTWARE FACILITIES section.[3] For example, to include the ANSI C **assert** library, make sure the macro **INCLUDE_ANSI_ASSERT** is defined; to include the Network File System (NFS) facility, make sure **INCLUDE_NFS** is defined. Modification or exclusion of particular facilities is discussed in detail in *8.6 Alternative VxWorks Configurations*, p.344.

Macros shown in Table 8-6 that end in *XXX* are not valid macros but represent families of options where the *XXX* is replaced by a suffix declaring a specific routine. For example, **INCLUDE_CPLUS**_*XXX* refers to a family of macros that includes **INCLUDE_CPLUS_MIN** and **INCLUDE_CPLUS_STL**.

Table 8-6 **Key VxWorks Options**

Macro	*	Option
INCLUDE_ANSI_*XXX*	*	Various ANSI C library options
INCLUDE_BOOTLINE_INIT		Parse boot device configuration information
INCLUDE_BOOTP	*	BOOTP support
INCLUDE_CACHE_SUPPORT	*	Cache support
INCLUDE_CPLUS	*	Bundled C++ support
INCLUDE_CPLUS_*XXX*		Various C++ support options

3. For a partial listing of the configuration macros, see Table 8-6. To see all the available macros with their descriptions, see *installDir*/**target/config/all/configAll.h** (for macros applicable to all bsps) and *installDir*/**target/config/***bspname*/**config.h** (for macros applicable to a specific BSP).

Table 8-6 **Key VxWorks Options** *(Continued)*

Macro	*	Option
INCLUDE_DOSFS		DOS-compatible file system
INCLUDE_FLOATING_POINT	*	Floating-point I/O
INCLUDE_FORMATTED_IO	*	Formatted I/O
INCLUDE_FTP_SERVER		FTP server support
INCLUDE_IO_SYSTEM	*	I/O system package
INCLUDE_LOADER		Target-resident object module loader package
INCLUDE_LOGGING	*	Logging facility
INCLUDE_MEM_MGR_BASIC	*	Core partition memory manager
INCLUDE_MEM_MGR_FULL	*	Full-featured memory manager
INCLUDE_MIB2_*XXX*		Various MIB-2 options
INCLUDE_MMU_BASIC	*	Bundled MMU support
INCLUDE_MMU_FULL		Unbundled MMU support (requires VxVMI)
INCLUDE_MSG_Q	*	Message queue support
INCLUDE_NETWORK	*	Network subsystem code
INCLUDE_NFS		Network File System (NFS)
INCLUDE_NFS_SERVER		NFS server
INCLUDE_PIPES	*	Pipe driver
INCLUDE_POSIX_*XXX*		Various POSIX options
INCLUDE_PROTECT_TEXT		Text segment write protection (requires VxVMI)
INCLUDE_PROTECT_VEC_TABLE		Vector table write protection (requires VxVMI)
INCLUDE_PROXY_CLIENT	*	Proxy ARP client support
INCLUDE_PROXY_SERVER		Proxy ARP server support

Table 8-6 **Key VxWorks Options** *(Continued)*

Macro	*	Option
INCLUDE_RAWFS		Raw file system
INCLUDE_RLOGIN		Remote login with **rlogin**
INCLUDE_SCSI		SCSI support
INCLUDE_SCSI2		SCSI-2 extensions
INCLUDE_SECURITY		Remote login security package
INCLUDE_SELECT		Remote login security package
INCLUDE_SEM_BINARY	*	Binary semaphore support
INCLUDE_SEM_COUNTING	*	Counting semaphore support
INCLUDE_SEM_MUTEX	*	Mutual exclusion semaphore support
INCLUDE_SHELL		C-expression interpreter (target shell)
INCLUDE_*XXX***_SHOW**		Various system object show facilities
INCLUDE_SIGNALS	*	Software signal facilities
INCLUDE_SM_OBJ		Shared memory object support (requires VxMP)
INCLUDE_SNMPD		SNMP agent
INCLUDE_SPY		Task activity monitor
INCLUDE_STDIO	*	Standard buffered I/O package
INCLUDE_SW_FP		Software Floating point emulation package
INCLUDE_SYM_TBL		Target-resident symbol table support
INCLUDE_TASK_HOOKS	*	Kernel call-out support
INCLUDE_TASK_VARS	*	Task variable support
INCLUDE_TELNET		Remote login with **telnet**
INCLUDE_TFTP_CLIENT	*	TFTP client support
INCLUDE_TFTP_SERVER		TFTP server support

Table 8-6 **Key VxWorks Options** *(Continued)*

Macro	*	Option
INCLUDE_TIMEX	*	Function execution timer
INCLUDE_TRIGGERING		Function execution timer
INCLUDE_UNLOADER		Target-resident object module unloader package
INCLUDE_WATCHDOGS	*	Watchdog support
INCLUDE_WDB	*	Target agent
INCLUDE_WDB_TSFS	*	Target server file system
INCLUDE_WINDVIEW		WindView command server; see the *WindView User's Guide* for details
INCLUDE_ZBUF_SOCK		Zbuf socket interface

* Items marked with an asterisk are included in the default configuration. Note that, since this list of options is not complete, not all macros included in the default configuration are listed here. Note also that their inclusion may be overridden in **config.h** for your BSP.

8.5.3 *The Configuration Module:* usrConfig.c

Use VxWorks configuration header files to configure your VxWorks system to meet your development requirements. Users should not resort to changing the WRS-supplied **usrConfig.c**, or any other module in the directory *installDir***/target/config/all**. If an extreme situation requires such a change, we recommend you copy all the files in *installDir***/target/config/all** to another directory, and add a **CONFIG_ALL** macro to your makefile to point the make system to the location of the modified files. For example, add the following to your makefile after the first group of include statements:

```
# ../myAll contains a copy of all the ../all files
    CONFIG_ALL = ../myAll
```

8.6 Alternative VxWorks Configurations

The discussion of the **usrConfig** module in *8.5.3 The Configuration Module: usrConfig.c*, p.343 outlined the default configuration for a development environment. In this configuration, the VxWorks system image contains all of the VxWorks modules that are necessary to allow you to interact with the system through the Tornado host tools.

However, as you approach a final production version of your application, you may want to change the VxWorks configuration in one or more of the following ways:

- Change the configuration of the target agent.
- Decrease the size of VxWorks.
- Run VxWorks from ROM.

The following sections discuss the latter two alternatives to the typical development configuration. For a discussion on reconfiguring the target agent, see the *Tornado User's Guide: Projects*.

8.6.1 Scaling Down VxWorks

In a production configuration, it is often desirable to remove some of the VxWorks facilities to reduce the memory requirements of the system, to reduce boot time, or for security purposes.

Optional VxWorks facilities can be omitted by commenting out or using **#undef** to undefine their corresponding control constants in the header files **configAll.h** or **config.h**. For example, logging facilities can be omitted by undefining **INCLUDE_LOGGING**, and signalling facilities can be omitted by undefining **INCLUDE_SIGNALS**.

VxWorks is structured to make it easy to exclude facilities you do not need. However, not every BSP will be structured in this way. If you wish to minimize your application, be sure to examine your BSP code and eliminate references to facilities you do not need to include. Otherwise, they will be included even though you undefined them in your VxWorks configuration files.

Excluding Kernel Facilities

The definition of the following constants in **configAll.h** is optional, because referencing any of the corresponding kernel facilities from the application automatically includes the kernel service:

- **INCLUDE_SEM_BINARY**
- **INCLUDE_SEM_MUTEX**
- **INCLUDE_SEM_COUNTING**
- **INCLUDE_MSG_Q**
- **INCLUDE_WATCHDOGS**

These configuration constants appear in the default VxWorks configuration to ensure that all kernel facilities are configured into the system, even if not referenced by the application. However, if your goal is to achieve the smallest possible system, exclude these constants; this ensures that the kernel does not include facilities you are not actually using.

There are two other configuration constants that control optional kernel facilities: **INCLUDE_TASK_HOOKS** and **INCLUDE_CONSTANT_RDY_Q**. Define these constants in **configAll.h** if the application requires either kernel callouts (use of task hook routines) or a constant-insertion-time, priority-based ready queue. A ready queue with constant insert time allows the kernel to operate context switches with a fixed overhead regardless of the number of tasks in the system. Otherwise, the worst-case performance degrades linearly with the number of ready tasks in the system. Note that the constant-insert-time ready queue uses 2KB for the data structure; some systems do not have sufficient memory for this. In those cases, the definition of **INCLUDE_CONSTANT_RDY_Q** may be omitted, thus enabling use of a smaller (but less deterministic) ready queue mechanism.

Excluding Network Facilities

In some applications it may be appropriate to eliminate the VxWorks network facilities. For example, in the ROM-based systems or standalone configurations described in *8.9 Creating Bootable Applications*, p.364, there may be no need for network facilities.

To exclude the network facilities, be sure the following constants are not defined:

- **INCLUDE_NETWORK**
- **INCLUDE_NET_INIT**
- **INCLUDE_NET_SYM_TBL**
- **INCLUDE_NFS**
- **INCLUDE_RPC**

To exclude the Remote Procedure Call library (RPC), undefine **INCLUDE_RPC**.

Option Dependencies

Option dependencies are coded in the file *installDir***/target/src/config/usrDepend.c**, so that when a particular option is chosen, everything required is included. This assures you of a working system with minimum effort. Although you can exclude the features that you do not need by undefining them in **config.h** and **configAll.h**, you should be aware that in some cases they may not be excluded because of dependencies.

For example, you cannot use **telnet** without running the network. Therefore, if in your **configAll.h** file, the option **INCLUDE_TELNET** is selected but the option **INCLUDE_NET_INIT** is not, **usrDepend.c** defines **INCLUDE_NET_INIT** for you. Because the network initialization requires the network software, the **userDepend.c** file also defines **INCLUDE_NETWORK**.

Because most of the dependencies are taken care of in **usrDepend.c**, that file is currently included in **usrConfig.c**. This simplifies the build process and the selection of options. However, you can change or add dependencies if you choose.

8.6.2 Executing VxWorks from ROM

You can put VxWorks or a VxWorks-based application into ROM; this is discussed in *8.9.2 Creating a VxWorks System in ROM*, p.367. For an example of a ROM-based VxWorks application, see the VxWorks boot ROM program. The file *installDir***/target/config/all/bootConfig.c** is the configuration module for the boot ROM, replacing the file **usrConfig.c** provided for the default VxWorks development system.

In such ROM configurations, the *text* and *data* segments of the boot or VxWorks image are first copied into the system RAM, then the boot procedure or VxWorks executes in RAM. On some systems where memory is a scarce resource, it is possible to save space by copying only the data segment to RAM. The text segment remains in ROM and executes from that address space, and thus is termed *ROM resident*. The memory that was to be occupied by the text segment in RAM is now available for an application (up to 300KB for a standalone VxWorks system). Note that ROM-resident VxWorks is not supported on all boards; see your target's man page if you are not sure that your board supports this configuration.

The drawback of a ROM-resident text segment is the limited data widths and lower memory access time of the EPROM, which causes ROM-resident text to execute more slowly than if it was in RAM. This can sometimes be alleviated by using faster EPROM devices or by reconfiguring the standalone system to exclude unnecessary system features.

Aside from program text not being copied to RAM, the ROM-resident versions of the VxWorks boot ROMs and the standalone VxWorks system are identical to the conventional versions. A ROM-resident image is built with an uncompressed version of either the boot ROM or standalone VxWorks system image. VxWorks target makefiles include entries for building these images; see Table 8-7.

Table 8-7 **Makefile ROM-Resident Images**

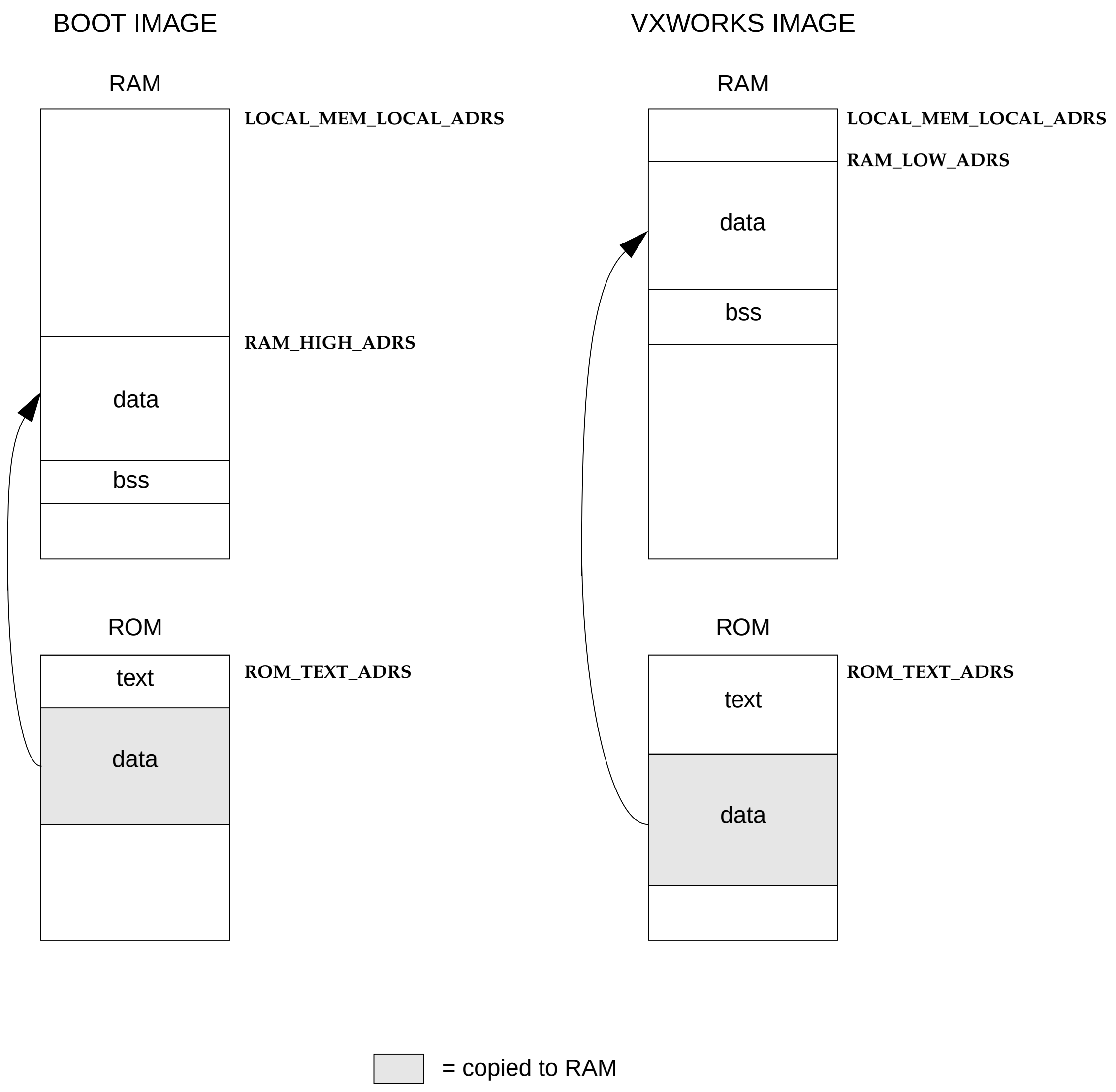
Architecture	Image FIle[*]	Description
MIPS and PowerPC	**bootrom_res_high**	ROM-resident boot ROM image. The data segment is copied from ROM to RAM at address **RAM_HIGH_ADRS**.
	vxWorks.res_rom_res_low	ROM-resident standalone system image without compression. The data segment is copied from ROM to RAM at address **RAM_LOW_ADRS**.
	vxWorks.res_rom_nosym_res_low	ROM-resident standalone system image without compression or symbol table. Data segment is copied from ROM to RAM at address **RAM_LOW_ADRS**.
All Other Targets	**bootrom_res**	ROM-resident boot ROM image.
	vxWorks.res_rom	ROM-resident standalone system image without compression.
	vxWorks.res_rom_nosym	ROM-resident system image without compression or symbol table. Ideal for the Tornado environment.

* All images have a corresponding file in Motorola S-record or Intel Hex format with the same file name plus the extension **.hex**.

Because of the size of the system image, 512KB of EPROM is recommended for the ROM-resident version of the standalone VxWorks system. More space is probably required if applications are linked with the standalone VxWorks system. For a ROM-resident version of the boot ROM, 256KB of EPROM is recommended. If you use ROMs of a size other than the default, modify the value of **ROM_SIZE** in the target makefile and **config.h**.

A new make target, **vxWorks.res_rom_nosym**, has been created to provide a ROM-resident image without the symbol table. This is intended to be a standard

Figure 8-1 **ROM-Resident Memory Layout**



ROM image for use with the Tornado environment where the symbol table resides on the host system. Being ROM-resident, the debug agent and VxWorks are ready almost immediately after power-up or restart.

The data segment of a ROM-resident standalone VxWorks system is loaded at **RAM_LOW_ADRS** (defined in the makefile) to minimize fragmentation. The data segment of ROM-resident boot ROMs is loaded at **RAM_HIGH_ADRS**, so that loading VxWorks does not overwrite the resident boot ROMs. For a CPU board with limited memory (under 1MB of RAM), make sure that **RAM_HIGH_ADRS** is less than **LOCAL_MEM_SIZE** by a margin sufficient to accommodate the data segment. Note that **RAM_HIGH_ADRS** is defined in both the makefile and **config.h**. These definitions *must* agree.

Figure 8-1 shows the memory layout for ROM-resident boot and VxWorks images. The lower portion of the diagram shows the layout for ROM; the upper portion shows the layout for RAM. **LOCAL_MEM_LOCAL_ADRS** is the starting address of RAM. For the boot image, the data segment gets copied into RAM above **RAM_HIGH_ADRS** (after space for *bss* is reserved). For the VxWorks image, the data segment gets copied into RAM above **RAM_LOW_ADRS** (after space for *bss* is reserved). Note that for both images the text segment remains in ROM.

8.6.3 Initialization Sequence for ROM-Based VxWorks

The early steps of system initialization are somewhat different for the ROM-based versions of VxWorks: on most target architectures, the two routines ***romInit*( )** and ***romStart*( )** execute instead of the usual VxWorks entry point, ***sysInit*( )**.

ROM Entry Point: *romInit*( )

At power-up the processor begins executing at ***romInit*( )** (defined in *installDir*/**target/config/***bspname*/**romInit.s**). The ***romInit*( )** routine disables interrupts, puts the boot type (cold/warm) on the stack, performs hardware-dependent initialization (such as clearing caches or enabling DRAM), and branches to ***romStart*( )**. The stack pointer is initialized to reside below the data section in the case of ROM-resident versions of VxWorks (in RAM versions, the stack pointer instead resides below the text section).

Copying the VxWorks Image: *romStart*( )

Next, the ***romStart*( )** routine (in *installDir*/**target/config/all/bootInit.c**) loads the VxWorks system image into RAM. If the ROM-resident version of VxWorks is selected, the data segment is copied from ROM to RAM and memory is cleared. If VxWorks is not ROM resident, all of the text and code segment is copied and decompressed from ROM to RAM, to the location defined by **RAM_HIGH_ADRS** in **Makefile**. If VxWorks is neither ROM resident nor compressed, the entire text and data segment is copied without decompression straight to RAM, to the location defined by **RAM_LOW_ADRS** in **Makefile**.

Overall Initialization for ROM-Based VxWorks

Beyond ***romStart*( )**, the initialization sequence for ROM-based VxWorks resembles the normal sequence, continuing with the ***usrInit*( )** call.

Table 8-8 summarizes the complete initialization sequence. For details on the steps after ***romInit*( )** and ***romStart*( )**, see *8.3 VxWorks Initialization Timeline*, p.313.

Table 8-8 **ROM-Based VxWorks Initialization Sequence**

Routine	Activity	File
1. ***romInit*( )**	(a) disable interrupts	**romInit.s**
	(b) save boot type (cold/warm)	
	(c) hardware-dependent initialization	
	(d) branch to ***romStart*( )**	
2. ***romStart*( )**	(a) copy data segment from ROM to RAM; clear memory	**bootInit.c**
	(b) copy code segment from ROM to RAM, decompressing if necessary	
	(c) invoke ***usrInit*( )** with boot type	
3. ***usrInit*( )**	Initial routine.	**usrConfig.c**
4. ***usrKernelInit*( )**	Routines invoked if the corresponding configuration constants are defined.	**usrKernel.c**
5. ***kernelInit*( )**	Initialize and start the kernel.	**kernelLib.c**
6. ***usrRoot*( )**	Initialize I/O system, install drivers, and create devices as configured in **configAll.h** and **config.h**.	**usrConfig.c**
Application routine	Application code.	Application source file

8.7 Building a VxWorks System Image

You can redefine the VxWorks configuration in two ways: interactively, as described in this manual in the *Tornado User's Guide: Projects*, or by editing VxWorks configuration files as described in *8.5 Configuring VxWorks*, p.337. In either case, after you alter the configuration, VxWorks must be rebuilt to incorporate the changes. This includes recompiling certain modules and re-linking the system image. This section explains the procedures for rebuilding the VxWorks system image using manual techniques.

8.7.1 Available VxWorks Images

There are three types of VxWorks images.

- Boot ROM images
- Downloaded VxWorks images
- ROMmed VxWorks images

Boot ROM images come in 3 flavors: compressed, uncompressed, and ROM-resident.

bootrom	normal compressed boot ROM
bootrom_uncmp	uncompressed boot ROM
bootrom_res	ROM-resident boot ROM

Downloaded VxWorks images come in two basic varieties, Tornado and standalone. (Here "Tornado" is a Vxworks image that uses the host-based tools and symbol table.)

vxWorks	basic Tornado	uses host shell and symbol table
vxWorks.st	standalone image	has target shell and symbol table

ROMmed VxWorks images:

vxWorks_rom	Tornado in ROM (uncompressed)
vxWorks.st_rom	**vxWorks.st** in ROM (compressed)
vxWorks.res_rom	**vxWorks.st** ROM-resident
vxWorks.res_rom_nosym	Tornado, ROM-resident

Note that there are variations in available targets for the x86 architecture. See *D. Intel x86* for details.

8.7.2 Rebuilding VxWorks with **make**

VxWorks uses the GNU **make** facility to recompile and relink modules. A file called **Makefile** in each VxWorks target directory contains the directives for rebuilding VxWorks for that target. See *GNU ToolKit User's Guide: GNU Make* for a detailed description of GNU **make** and of how to write makefiles.

Making on UNIX Hosts

With a UNIX host, you can use either the GNU version of **make** included with Tornado or the version included with your UNIX system. If you choose that version, see your host system's reference for **make** for information about the version of **make** supplied in that system.

To rebuild VxWorks on a UNIX host, first change to the VxWorks target directory for the desired target, and invoke **make** as follows:

```
% cd ${WIND_BASE}/target/config/bspname
% make
```

Making on Windows Hosts

If you choose to use manual techniques on Windows hosts, you must use the command line for building individual application modules. You can use either the command line or the project facility in Tornado 1.0.1 compatibility mode to rebuild BSPs. For information on how to implement Tornado 1.0.1 compatibility mode, see the *Tornado User's Guide: Customization*.

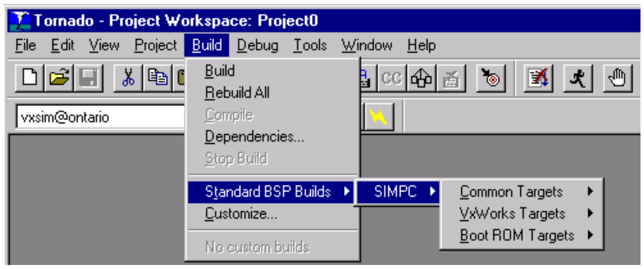
Rebuilding BSP Components

The Project menu includes entries for rebuilding every BSP installed on your system as a part of Tornado. These entries all have the form Make *bspname*. Figure 8-2 illustrates the Project menu in a Tornado system that has a family of i386/i486 BSPs installed.

When you select any Make *bspname* menu entry, the **make** targets available are grouped into the following categories (also illustrated in Figure 8-2):

Common Targets
: The BSP **make** targets needed most often. Two of them also appear in the next two categories: **vxWorks**, the VxWorks system image, and **bootrom.hex**, the simplest form of the boot-program object code.

Figure 8-2 **Rebuilding VxWorks from the Project Menu**



The standard make target **clean** (which erases all objects that can be built by the BSP makefile) is also in this category.

VxWorks Targets
: Alternate forms of the VxWorks run-time image, as described in *8.7 Building a VxWorks System Image*, p.351 and *8.9 Creating Bootable Applications*, p.364.

Boot ROM Targets
: Alternate forms of the VxWorks boot program, discussed in *8.6.2 Executing VxWorks from ROM*, p.346.

When you click any of the targets from the categories above, Tornado builds the corresponding object in the BSP directory. Output from the build goes to a Build Output window, which you can use as a diagnostic aid.

Rebuilding VxWorks

To rebuild VxWorks, click the vxWorks target name under the appropriate Make *bspname* entry for your target in the Project menu. For example, Figure 8-2 shows the vxWorks target selected for the EPC4 BSP.

You can also rebuild VxWorks from the Windows command prompt (or from a batch file). Change to the **config** directory for the desired target, and invoke **make** as follows:

```
C:\> cd tornado\target\config\bspname
C:\tornado\target\config\bspname> make
```

In either case, **make** compiles and links modules as necessary, based on the directives in the target directory's **Makefile**.

NOTE: For the sake of compactness, most examples of calling **make** in this chapter use the command line; in real practice, the Project menu is usually more convenient. This is true for Windows hosts even if you use the Tornado 1.0.1 methods described in this section.

To rebuild VxWorks when only header files change:

```
% make clean VxWorks
```

This regenerate all **.o** files required by VxWorks. Or:

```
% make clean
% make
```

The "make clean" removes all existing **.o** files, and then "make" recreates the new **.o** files required by VxWorks.

8.7.3 Including Customized VxWorks Code

The directory *installDir*/**target/target/src/usr** contains the source code for certain portions of VxWorks that you may wish to customize. For example, **usrLib.c** is a popular place to add target-resident routines that provide application-specific development aids. For a summary of other files in this directory, see the *Tornado User's Guide: Directories and Files*.

If you modify one of these files, an extra step is necessary before rebuilding your VxWorks image: you must replace the modified object code in the appropriate VxWorks archive. The **Makefile** in *installDir*/**target/target/src/usr** automates the details; however, because this directory is not specific to a single architecture, you must specify the value of the **CPU** variable on the **make** command line:

```
% make CPU=cputype
```

If you do this frequently on a Windows host, you can record the **CPU** definition in the Build Target field of a custom command in the Project menu; see *Tornado User's Guide: Customization*.

This step recompiles all modified files in the directory, and replaces the corresponding object code in the appropriate architecture-dependent directory. After that, the next time you rebuild VxWorks, the resulting system image includes your modified code.

The following example illustrates replacing **usrLib** with a modified version, rebuilding the archives, and then rebuilding the VxWorks system image. For the sake of conciseness, the **make** output is not shown. The example assumes the **epc4** (**I80386**) BSP; replace the BSP directory name and **CPU** value as appropriate for your environment. (On a Windows host, use **copy** instead of the UNIX **cp**.)

```
% cd ${WIND_BASE}/target/src/usr
% cp usrLib.c usrLib.c.orig
% cp develDir/usrLib.c usrLib.c
% make CPU=I80386
...

% cd ${WIND_BASE}/target/config/epc4
% make
...
```

8.7.4 Linking the System Modules

The commands to link a VxWorks system image are somewhat complicated. Fortunately, it is not necessary to understand those commands in detail because the **Makefile** in each VxWorks target directory includes the necessary commands. However, for completeness, this section gives an explanation of the flags and parameters used to link VxWorks.

VxWorks operating system modules are distributed in the form of an archive library for each target architecture. The library is *installDir***/target/lib/lib***cpu***gnuvx.a**.

These modules are combined with the configuration module **usrConfig.o** by the **ld***arch* command on the host. (**usrConfig.c** is described in *8.5.3 The Configuration Module: usrConfig.c*, p.343.) The following is an example command for linking a VxWorks system using the GNU linker for the MC680*x*0:

```
ld68k -o vxWorks -X -N -Ttext 1000 -e _sysInit sysALib.o sysLib.o \
usrConfig.o version.o /tornado/target/lib/libcpugnuvx.a
```

The meanings of the flags in this command are as follows:

-o vxWorks
name the output object module **vxWorks**.

-X eliminate some compiler-generated symbols from the symbol table.

-N do not configure the output object module for a virtual-memory system.

-Ttext 1000
specify the relocation address as a hexadecimal constant; in this example, 1000 hexadecimal. This is the address where the system must be loaded in

the target, and is also the address where execution starts. Some target systems have limitations on where this relocation address can be.

-e _sysInit
define the entry point to **vxWorks**. ***sysInit*( )** is the first routine in **sysALib.o**, which is the first module loaded by **ld***arch*.

sysALib.o and **sysLib.o**
modules that contain CPU-dependent initialization and support routines. The module **sysALib.o** must be the first module specified in the **ld***arch* command.

usrConfig.o
the configuration module (described in detail in *8.5.3 The Configuration Module: usrConfig.c*, p.343). If you have several different system configurations, you may maintain several different configuration modules, either in *installDir***/target** or in your own directory.

version.o
a module that defines the creation date and version number of this **vxWorks** object module. It is created by compiling the output of **makeVersion**, an auxiliary tool in the *installDir***/host/***host-os***/bin** directory.

*installDir***/target/lib/lib***cpu***gnuvx.a**
the archive library that contains all the VxWorks modules.

Additional object modules:
You can link additional object modules (with **.o** suffix) into the run-time VxWorks system by naming them on the **ld***arch* command line. An easy way to do this is to use the variable **MACH_EXTRA** in the BSP makefiles. Define this variable and list the object modules to be linked with VxWorks. Note that during development, application object modules are generally not linked with the system (unless they are needed by the **usrConfig** module), because it is more convenient to load them incrementally from the host, after booting VxWorks. See *8.9 Creating Bootable Applications*, p.364 for more detail on linking application modules in a bootable system.

i960 systems require additional Intel libraries, which are listed in the makefiles for i960 BSPs.

8.7.5 Creating the System Symbol Table Module

The Tornado target server uses the VxWorks symbol table on the host system, both for dynamic linking and for symbolic debugging. The symbol table file is created by the supplied tool **xsym**. Processing an object module with **xsym** creates a new object module that contains all the symbols of the original file, but with no code or data. The line in **Makefile** that creates this file executes the command as follows:

```
xsym < vxWorks > vxWorks.sym
```

The file **vxWorks.sym** is the symbol table that the target server loads when it begins executing.

8.8 Makefiles for BSPs and Applications

Makefiles for VxWorks applications are easy to create by exploiting the makefiles and **make** include files shipped with VxWorks BSPs. This section discusses how the VxWorks BSP makefiles are structured. An example of how to utilize this structure for application makefiles is in *8.8.2 Using Makefile Include Files for Application Modules*, p.363.

In Tornado, a set of supporting files in *installDir*/**target/h/make** makes it possible for each BSP or application **Makefile** to be terse, specifying only the essential parameters that are unique to the object being built.

Example 8-1 shows the makefile from the *installDir*/**target/config/mv147** directory; the makefile for any other BSP is similar. Two variables are defined at the start of the makefile: **CPU**, to specify the target architecture, and **TOOL** to identify what compilation tools to use. Based on the values of these variables and on the environment variables defined as part of your Tornado configuration, the makefile selects the appropriate set of definitions from *installDir*/**target/h/make**. After the standard definitions, several variables define properties specific to this BSP. Finally, the standard rules for building a BSP on your host are included.

Example 8-1 **Makefile for MVME147**

```
# Makefile - makefile for target/config/mv147
#
# Copyright 1984-1995 Wind River Systems, Inc.
#
# DESCRIPTION
# This file contains rules for building VxWorks for the
# Motorola MVME147.
#*/

CPU             = MC68020
```

```
TOOL             = gnu

include $(WIND_BASE)/target/h/make/defs.bsp
include $(WIND_BASE)/target/h/make/make.$(CPU)$(TOOL)
include $(WIND_BASE)/target/h/make/defs.$(WIND_HOST_TYPE)

## Only redefine make definitions below this point, or your definitions
## will be overwritten by the makefile stubs above.


TARGET_DIR       = mv147
VENDOR           = Motorola
BOARD            = MVME147, MVME147S-1

#
# The constants ROM_TEXT_ADRS, ROM_SIZE, and RAM_HIGH_ADRS are
# defined in config.h as well as in this Makefile.
# Both definitions of these constants must be identical.
#

ROM_TEXT_ADRS    = ff800008 # ROM entry address
ROM_SIZE         = 00020000 # number of bytes of ROM space

RAM_LOW_ADRS     = 00001000 # RAM text/data address
RAM_HIGH_ADRS    = 00090000 # RAM text/data address

HEX_FLAGS        = -v -p $(ROM_TEXT_ADRS) -a 8

MACH_EXTRA       =

## Only redefine make definitions above this point, or the expansion of
## makefile target dependencies may be incorrect.

include $(WIND_BASE)/target/h/make/rules.bsp
include $(WIND_BASE)/target/h/make/rules.$(WIND_HOST_TYPE)
```

There are two kinds of include files in *installDir***/target/h/make** (as reflected by the two blocks of **include** statements in Example 8-1): variable definitions, and rule definitions. Just as for **#include** statements in the C preprocessor, **include** statements in makefiles accept the slash (**/**) character between directory segments of a file name. This feature of GNU **make** helps to write portable makefiles.

The following **make** include files define variables. These files are useful for application-module makefiles, as well as for BSP makefiles.

defs.bsp
Standard variable definitions for a VxWorks run-time system.

make.$(CPU)$(TOOL)
Files named using this pattern (such as **make.MC68060gnu**) provide definitions for a particular target architecture and a particular set of

compilation tools, such as architecture-specific tool names and option flags.

defs.$(WIND_HOST_TYPE)
Files named using this pattern (such as **make.x86-win32**) provide definitions that depend on the host system: names of tools that are independent of the target architecture, and pathnames for the Tornado installation on your host.

The following include files define **make** targets, and the rules to build them. These files are usually not required for building application modules in separate directories, because most of the rules they define are specific to the VxWorks run-time system and boot programs.

rules.bsp
Rules defining all the standard targets for building a VxWorks run-time system (described in *8.7 Building a VxWorks System Image*, p.351 and *8.9 Creating Bootable Applications*, p.364). The rules for building object code from C, C++, or assembly language are also spelled out here.

rules.$(WIND_HOST_TYPE)
Files named using this pattern (such as **make.x86-win32**) specify targets that depend only on the host system (dependency lists).

8.8.1 Make Variables

The variables defined in the **make** include files provide convenient defaults for most situations, and allow individual makefiles to specify only the definitions that are unique to each. This section describes the **make** variables most often used to specify properties of BSPs or applications. The following lists are not intended to be comprehensive; see the **make** include files for the complete set.

NOTE: Certain **make** variables are intended specifically for customization; see *Variables for Customizing the Run-Time*, p.362. Do not override other variables in BSP makefiles. They are described in the following sections for expository purposes.

Variables for Compilation Options

The variables grouped in this section are useful for either BSP makefiles or application-module makefiles. They specify aspects of how to invoke the compiler.

CFLAGS
The complete set of option flags for any invocation of the C compiler. This variable gathers the options specified in **CC_COMPILER**, **CC_WARNINGS**, **CC_OPTIM**, **CC_INCLUDE**, **CC_DEFINES**, and **ADDED_CFLAGS**. To add your own option flags, define them as **ADDED_CFLAGS**.

C++FLAGS
The complete set of option flags for any invocation of the C++ compiler. This variable gathers together the options specified in **C++_COMPILER**, **C++_WARNINGS**, **CC_OPTIM**, **CC_INCLUDE**, **CC_DEFINES**, and **ADDED_C++FLAGS**. To add your own option flags, use **ADDED_C++FLAGS**.

CC_COMPILER
Option flags specific to compiling the C language. Default: **-ansi -nostdinc**.

C++_COMPILER
Option flags specific to compiling the C++ language. Default: **-ansi -nostdinc**.

CC_WARNINGS
Option flags to select the level of warning messages from the compiler, when compiling C programs. Two predefined sets of warnings are available: **CC_WARNINGS_ALL** (the compiler's most comprehensive collection of warnings) and **CC_WARNINGS_NONE** (no warning flags). Default: **CC_WARNINGS_ALL**.

C++_WARNINGS
Option flags to select the level of warning messages from the compiler, when compiling C++ programs. The same two sets of flags are available as for C programs. Default: **CC_WARNINGS_NONE**.

CC_OPTIM
Optimization flags. Three sets of flags are predefined for each architecture: **CC_OPTIM_DRIVER** (optimization level appropriate to a device driver), **CC_OPTIM_TARGET** (optimization level for BSPs), and **CC_OPTIM_NORMAL** (optimization level for application modules). Default: **CC_OPTIM_TARGET**.

CC_INCLUDE
Standard set of header-file directories. To add application-specific header-file paths, specify them in **EXTRA_INCLUDE**.

CC_DEFINES
Definitions of preprocessor constants. This variable is predefined to propagate the makefile variable **CPU** to the preprocessor, to include any constants required for particular target architectures, and to include the value of the makefile variable **EXTRA_DEFINE**. To add application-specific constants, specify them in **EXTRA_DEFINE**.

Variables for BSP Parameters

The variables included in this section specify properties of a particular BSP, and are thus recorded in each BSP makefile. They are not normally used in application-module makefiles.

TARGET_DIR
Name of the BSP (used for dependency lists and name of documentation reference entry). The value matches the *bspname* directory name.

ROM_TEXT_ADRS
Address of the ROM entry point. Also defined in **config.h**; the two definitions must match.

ROM_SIZE
Number of bytes available in the ROM. Also defined in **config.h**; the two definitions must match.

RAM_HIGH_ADRS
RAM address where the boot ROM data segment is loaded. Must be a high enough value to ensure loading VxWorks does not overwrite part of the ROM program. Also defined in **config.h**; the two definitions must match. See *8.9 Creating Bootable Applications*, p.364 for more discussion.

RAM_LOW_ADRS
Beginning address to use for the VxWorks run-time in RAM.

HEX_FLAGS
Option flags for the program (such as **hex**, **coffHex**, or **elfHex**) that converts a boot program into S-records or the equivalent.

LDFLAGS
Linker options for the static link of VxWorks and boot ROMs.

ROM_LDFLAGS
Additional static-link option flags specific to boot ROM images.

Variables for Customizing the Run-Time

The variables listed in this section make it easy to control what facilities are statically linked into your run-time system. You can specify values for these variables either from the **make** command line, or from your own makefiles (when you take advantage of the predefined VxWorks make include files).

CONFIG_ALL
Location of a directory containing the architecture-independent BSP configuration files. Set this variable if you maintain several versions of these files for different purposes. Default: *installDir***/target/config/all**.

LIB_EXTRA
Linker options to include additional archive libraries (you must specify the complete option, including the **-L** for each library). These libraries appear in the link command before the standard VxWorks libraries.

MACH_EXTRA
Names of application modules to include in the static link to produce a VxWorks run-time. See *8.9 Creating Bootable Applications*, p.364.

ADDED_MODULES
Do not define a value for this variable in makefiles. This variable is reserved for adding modules to a static link from the **make** command line. Its value is used in the same way as **MACH_EXTRA**, to include additional modules in the link. Reserving a separate variable for use from the command line avoids the danger of overriding any object modules that are already listed in **MACH_EXTRA**.

EXTRA_INCLUDE
Preprocessor options to define any additional header-file directories required for your application (you must specify the complete option, including the **-I**).

EXTRA_DEFINE
Definitions for application-specific preprocessor constants (you must specify the complete option, including the **-D**).

ADDED_CFLAGS
Application-specific compiler options for C programs.

ADDED_C++FLAGS
Application-specific compiler options for C++ programs.

8.8.2 Using Makefile Include Files for Application Modules

You can exploit the VxWorks makefile structure to put together your own application makefiles quickly and tersely. If you build your application directly in a BSP directory (or in a copy of one), you can use the **Makefile** in that BSP, by specifying variable definitions (*Variables for Customizing the Run-Time*, p.362) that include the components of your application.

You can also take advantage of the Tornado makefile structure if you develop application modules in separate directories. Example 8-2 illustrates the general scheme: include the makefile headers that specify variables, and list the object modules you want built as dependencies of a target. This simple scheme is usually sufficient, because the Tornado makefile variables are carefully designed to fit into the default rules that **make** knows about.[4]

NOTE: The target name **exe** is the Tornado convention for a default make target. You may either use that target name (as in Example 8-2), or define a different **default** rule in your makefiles. However, there must always be an **exe** target in makefiles based on the Tornado makefile headers (even if the associated rules do nothing).

Example 8-2 **Skeleton Makefile for Application Modules**

```
# Makefile - makefile for ...
#
# Copyright ...
#
# DESCRIPTION
# This file specifies how to build ...
#

## It is often convenient to override the following with "make CPU=..."
CPU              = cputype
TOOL             = gnu

include $(WIND_BASE)/target/h/make/defs.bsp
include $(WIND_BASE)/target/h/make/make.$(CPU)$(TOOL)
include $(WIND_BASE)/target/h/make/defs.$(WIND_HOST_TYPE)

## Only redefine make definitions below this point, or your definitions
## will be overwritten by the makefile stubs above.

exe : myApp.o
```

4. However, if you are working with C++, it may be also convenient to copy the **.cpp.out** rule from *installDir*/**target/h/make/rules.bsp** into your application's **Makefile**.

8.8.3 Makefile for SIO Drivers

The directory *installDir***/target/src/drv/sio/** contains source and templates for serial drivers that support both polled and asynchronous communications. The makefile for drivers in this directory is named **Makefile.sio**. Because this is not one of the names **make** can find automatically, you must specify the makefile with the **-f** option when you build a driver in this directory.

For example, to build the driver **cd2400Sio.c** and install it in the VxWorks archives, execute the following commands in this directory:

Windows

```
C:\tornado\target\src\drv\sio> make -f Makefile.sio CPU=cputype cd2400Sio.o
C:\tornado\target\src\drv\sio> make -f Makefile.sio CPU=cputype default
```

UNIX

```
% make -f Makefile.sio CPU=cputype cd2400Sio.o default
```

8.9 Creating Bootable Applications

As you approach a final version of your application, you will probably want to add modules to the bootable system image, and include startup of your application with the system initialization routines. In this way, you can create a *bootable application*, which is completely initialized and functional after booting, without requiring any interaction with the host-resident development tools.

Linking the application with VxWorks is really a two-step process. You must add an entry point to the application in **usrConfig.c**, and you must modify the makefile to link the application statically with VxWorks.

To start your application during system initialization, add code to the ***usrRoot*( )** routine in **usrConfig.c**. You can call application initialization routines, create additional I/O devices, spawn application tasks, and so on, just as you do from the Tornado shell during development. An example is provided in **usrConfig.c**. This file includes and initializes a simple demo if the preprocessor constant **INCLUDE_DEMO** is defined in one of the configuration files. In that situation, ***usrRoot*( )** spawns ***usrDemo*( )** as a task as the last step in booting the system. You can simply insert the appropriate initialization of your application after the conditional code to start the demo. For example:

```
/* spawn demo if selected */
#if defined(INCLUDE_DEMO)
    taskSpawn ("demo", 20, 0, 2000, (FUNCPTR)usrDemo, 0,0,0,0,0,0,0,0,0,0);
#endif
    taskSpawn ("myMod", 100, 0, 20000, (FUNCPTR)myModEntryPt,
    0,0,0,0,0,0,0,0,0,0);
```

To include your application modules in the bootable system image, add the names of the application object modules (with the **.o** suffix) to **MACH_EXTRA** in **Makefile**. For example, to link the module **myMod.o**, add a line like the following:

```
    MACH_EXTRA = myMod.o
    ...
```

Building the system image with the application linked in is the final part of this step. In the target directory, execute the following command:

```
    % make vxWorks
```

Application size is usually an important consideration in building bootable applications. Generally, VxWorks boot ROM code is copied to a start address in RAM above the constant **RAM_HIGH_ADRS**, and the ROM in turn copies the downloaded system image starting at **RAM_LOW_ADRS**. The values of these constants are architecture dependent, but in any case the system image must not exceed the space between the two. Otherwise the system image overwrites the boot ROM code while downloading, thus killing the booting process.

To help avoid this, the last command executed when you make a new VxWorks image is **vxsize**, which shows the size of the new executable image and how much space (if any) is left in the area below the space used for ROM code:

```
    vxsize 386 -v 00100000  00020000  vxWorks
    vxWorks: 612328(t) + 69456(d) + 34736(b) = 716520 (235720 bytes left)
```

If your new image is too large, **vxsize** issues a warning. In this case, you can reprogram the boot ROMs to copy the ROM code to a sufficiently high memory address by increasing the value of **RAM_HIGH_ADRS** in **config.h** and in your BSP's **Makefile** (both values must agree). Then rebuild the boot ROMs by executing the following command:

```
    % make bootrom.hex
```

The binary image size of typical boot ROM code is 128KB or less. This small size is achieved through compression; see *Boot ROM Compression*, p.368. The compressed boot image begins execution with a single uncompressed routine, which uncompresses the remaining boot code to RAM. To avoid uncompressing and thus initialize the system a bit faster, you can build a larger, uncompressed boot ROM image by specifying the **make** target **bootrom_uncmp.hex**.

8.9.1 Creating a Standalone VxWorks System with a Built-in Symbol Table

It is sometimes necessary to create a VxWorks system that includes a copy of its own symbol table. However, it is confusing to work with the host-resident Tornado tools when there is a target-resident symbol table, because the host-resident tools use a separate symbol table on the host. Thus, it is advisable to include the target-resident versions of the development tools (especially the shell) in this configuration, until you are ready to build a finished application that requires no interaction with the target.

The procedure for building such a system is somewhat different from the procedure described above. No change is necessary to **usrConfig.c**. A different **make** target, **vxWorks.st**, specifies the standalone form of VxWorks:

```
% make vxWorks.st
```

The rules for building **vxWorks.st** create a module **usrConfig_st.o**, which is the **usrConfig.c** module compiled with the **STANDALONE** flag defined. The **STANDALONE** flag causes the **usrConfig.c** module to be compiled with the built-in system symbol table, the target-resident shell, and associated interactive routines.

The **STANDALONE** flag also suppresses the initialization of the network. If you want to include network initialization, define **STANDALONE_NET** in either of the header files *installDir*/**target/config/***bspname*/**config.h** or *installDir*/**target/config/all/configAll.h**.[5]

VxWorks is linked as described previously, except that the first pass through the loader does not specify the final load address; thus the output from this stage is still relocatable. The **makeSymTbl** tool is invoked on the loader output; it constructs a data structure containing all the symbols in VxWorks. This structure is then compiled and linked with VxWorks itself to produce the final bootable VxWorks object module.

5. **vxWorks.st** suppresses network initialization, but it includes the network. The **STANDALONE** option defines **INCLUDE_STANDALONE_SYM_TBL** and **INCLUDE_NETWORK**, and undefines **INCLUDE_NET_SYM_TBL** and **INCLUDE_NET_INIT**. The alternative option **STANDALONE_NET** includes **INCLUDE_NET_INIT**.

As before, to include your own application in the system image, add the object modules to the definition of **MACH_EXTRA** and follow the procedures discussed in the previous section.

Because **vxWorks.st** has a built-in symbol table, there are some minor differences in how it treats VxWorks symbols, by contrast with the symbol table used through the target server during development. First, VxWorks symbol table entries cannot be deleted from the **vxWorks.st** symbol table. Second, no local (**static**) VxWorks symbols are present in **vxWorks.st**.

8.9.2 Creating a VxWorks System in ROM

General Procedures

To put VxWorks or a VxWorks-based application into ROM, you must enter the object files on the loader command line in an order that lists the module **romInit.o** before **sysALib.o**. Also specify the entry point option **-e _romInit**. The ***romInit*( )** routine initializes the stack pointer to point directly below the text segment. It then calls ***bootInit*( )**, which clears memory and copies the **vxWorks** text and data segments to the proper location in RAM. Control is then passed to ***usrInit*( )**.

A good example of a ROM-based VxWorks application is the VxWorks boot ROM program itself. The file *installDir***/target/config/all/bootConfig.c** is the configuration module for the boot ROM, replacing the file **usrConfig.c** provided for the default VxWorks development system. The makefiles in the target-specific directories contain directives for building the boot ROMs, including conversion to a file format suitable for downloading to a PROM programmer. Thus, you can generate the ROM image with the following **make** command:

```
% make bootrom.hex
```

Tornado makefiles also define a ROMable VxWorks runtime system suitable for use with Tornado tools, as the target **vxWorks.res_rom_nosym**. To generate this image in a form suitable for writing ROMs, run the following command:

```
% make vxWorks.res_rom_nosym.hex
```

VxWorks target makefiles also include the entry **vxWorks.st_rom** for creating a ROMable version of the standalone system described in the previous section. **vxWorks.st_rom** differs from **vxWorks.st** in two respects: (1) **romInit** code is loaded as discussed above, and (2) the portion of the system image that is not essential for booting is compressed by approximately 40 percent using the VxWorks **compress** tool (see *Boot ROM Compression*, p.368).

To build the form of this target that is suitable for writing into a ROM (most often, this form uses the Motorola S-record format), enter:

```
% make vxWorks.st_rom.hex
```

When adding application modules to a ROMable system, size is again an important consideration. Keep in mind that by using the **compress** tool, a configuration that normally requires a 256-KB ROM may well fit into a 128-KB ROM. Be sure that **ROM_SIZE** (in both **config.h** and **Makefile**) reflects the capacity of the ROMs used.

Boot ROM Compression

VxWorks boot ROMs are compressed to about 40 percent of their actual size using a binary compression algorithm, which is supplied as the tool **compress**. When control is passed to the ROMs on system reset or reboot, a small (8 KB) uncompression routine, which is *not* itself compressed, is executed. It then uncompresses the remainder of the ROM into RAM and jumps to the start of the uncompressed image in RAM. There is a short delay during the uncompression before the VxWorks prompt appears. The uncompression time depends on CPU speed and code size; it takes about 4 seconds on an MC68030 at 25 MHz.

This mechanism is also available to compress a ROMable VxWorks application. The entry for **vxWorks.st_rom** in the architecture-independent portion of the makefile, *installDir***/target/h/make/rules.bsp**, demonstrates how this can be accomplished. For more information, see also the reference manual entries for **bootInit** and **compress**.

9
Target Shell

9.1 Introduction

In the Tornado development system, a full suite of development tools resides and executes on the host machine, thus conserving target memory and resources; see the *Tornado User's Guide* for details. However, a target-resident symbol table and module loader/unloader can be configured into the VxWorks system if necessary, for example, to create a dynamically configured run-time system. In this case, use the target-resident shell for development.

⚠ **CAUTION:** If you choose to use the target-resident tools, you must use the target shell. The host tools cannot access the target-resident symbol table; thus symbols defined on the target are not visible to the host.

This chapter briefly describes these target-resident facilities.

9.2 Target-Resident Shell

For the most part, the target-resident shell works the same as the Tornado shell; for details, see the *Tornado User's Guide: Shell*. However, there are some differences, which are described in this section.

9.2.1 Creating the Target Shell

To create the target shell, you must configure it into the VxWorks configuration by selecting **INCLUDE_SHELL** for inclusion in the project facility VxWorks view (for details, see *Tornado User's Guide: Projects*). When you do so, ***usrRoot*( )** (in **usrConfig.c**) spawns the target shell task by calling ***shellInit*( )**. The first argument to ***shellInit*( )** specifies the target shell's stack size, which must be large enough to accommodate any routines you call from the target shell. The second argument is a boolean that specifies whether the target shell's input is from an interactive source (TRUE), or a non-interactive source (FALSE) such as a script file. If the source is interactive, then the shell prompts for commands but does not echo them to standard out; the reverse is true if the source is non-interactive.

The shell task (**tShell**) is created with the **VX_UNBREAKABLE** option; therefore, breakpoints cannot be set in this task, because a breakpoint in the shell would make it impossible for the user to interact with the system. Any routine or task that is invoked from the target shell, rather than spawned, runs in the **tShell** context.

Only one target shell can run on a VxWorks system at a time; the target shell parser is not reentrant, because it is implemented using the UNIX tool **yacc**.

When the shell is started, the banner displayed in Figure 9-1 appears.For more information, see the reference entry for **shellLib**.

Figure 9-1 **Typical Target Shell Sign-on Banner**

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]]]]]]]]]]]]]]]]]]]]]]]]]       Copyright Wind River Systems, Inc., 1984-1998

                 CPU: Motorola MVME2600 - MPC 603p.  Processor #0.
                Memory Size: 0x400000.  BSP version 1.2/0.
               WDB: Ready.

->
```

9.2.2 Using the Target Shell

The target shell works almost exactly like the Tornado shell; see the *Tornado User's Guide: Shell* and the **usrLib** reference entry for details. You can also type the following command to display help:

```
    -> help
```

The following target shell command lists all the available help routines:

```
    -> lkup "Help"
```

The target shell has its own set of terminal-control characters, unlike the Tornado shell, which inherits its setting from the host window from which it was invoked. Table 9-1 lists the target shell's terminal-control characters. The first four of these are defaults that can be mapped to different keys using routines in **tyLib** (see also *Tty Special Characters*, p. 120).

Table 9-1 **Target Shell Terminal Control Characters**

Command	Description
CTRL+H	Delete a character (backspace).
CTRL+U	Delete an entire line.
CTRL+C	Abort and restart the shell.
CTRL+X	Reboot (trap to the ROM monitor).
CTRL+S	Temporarily suspend output.
CTRL+Q	Resume output.
ESC	Toggle between input mode and edit mode.

The shell line-editing commands are the same as they are for the Tornado shell. For a summary of the commands, see the *Tornado User's Guide: Shell*.

9.2.3 Debugging with the Target Shell

The target shell includes the same debugging utilities as the Tornado shell, if **INCLUDE_DEBUG** is selected for inclusion in the project facility VxWorks view. For details, see the *Tornado User's Guide: Shell* and the reference entry for **dbgLib**.

9.2.4 Aborting the Target Shell

Occasionally it is desirable to abort the shell's evaluation of a statement. For example, an invoked routine may loop excessively, suspend, or wait on a semaphore. This may happen as the result of errors in arguments specified in the invocation, errors in the implementation of the routine itself, or simply oversight as to the consequences of calling the routine at all.

In such cases it is usually possible to abort and restart the target shell task. This is done by pressing the special target-shell abort character on the keyboard, **CTRL+C** by default. This causes the target shell task to restart execution at its original entry point. Note that the abort key can be changed to a character other than **CTRL+C** by calling ***tyAbortSet*( )**.

When restarted, the target shell automatically reassigns the system standard input and output streams to the original assignments they had when the target shell was first spawned. Thus any target shell redirections are canceled, and any executing shell scripts are aborted.

The abort facility works only if the following are true:

- ***dbgInit*( )** has been called (see *9.2.3 Debugging with the Target Shell*, p.371).
- ***excTask*( )** is running (see *Installation of Exception Handling and Logging*, p.319).
- The driver for the particular keyboard device supports it (all VxWorks-supplied drivers do).
- The device's abort option is enabled. This is done with an ***ioctl*( )** call, usually in the root task in **usrConfig.c**. For information on enabling the target shell abort character, see *Tty Options*, p.119.

Also, you may occasionally enter an expression that causes the target shell to incur a fatal error such as a bus/address error or a privilege violation. Such errors normally result in the suspension of the offending task, which allows further debugging.

However, when such an error is incurred by the target shell task, VxWorks automatically restarts the target shell, because further debugging is impossible without it. Note that for this reason, as well as to allow the use of breakpoints and single-stepping, it is often useful when debugging to spawn a routine as a task instead of just calling it directly from the target shell.

When the target shell is aborted for any reason, either because of a fatal error or because it is aborted from the terminal, a task trace is displayed automatically. This trace shows where the target shell was executing when it died.

Note that an offending routine can leave portions of the system in a state that may not be cleared when the target shell is aborted. For instance, the target shell might have taken a semaphore, which cannot be given automatically as part of the abort.

9.2.5 Remote Login to the Target Shell

Remote Login From Host: **telnet** *and* **rlogin**

When VxWorks is first booted, the target shell's terminal is normally the system console. You can use **telnet** to access the target shell from a host over the network if you select **INCLUDE_TELNET** for inclusion in the project facility VxWorks view (see *Tornado User's Guide: Projects*). Defining **INCLUDE_TELNET** creates the **tTelnetd** task. To access the target shell over the network, enter the following command from the host (*targetname* is the name of the target VxWorks system):

```
% telnet "targetname"
```

UNIX host systems also use **rlogin** to provide access to the target shell from the host. Select **INCLUDE_RLOGIN** for inclusion in the project facility VxWorks view to create the **tRlogind** task. However, note that VxWorks does not support **telnet** or **rlogin** access from the VxWorks system to the host.

A message is printed on the system console indicating that the target shell is being accessed via **telnet** or **rlogin**, and that it is no longer available from its console.

If the target shell is being accessed remotely, typing at the system console has no effect. The target shell is a single-user system—it allows access either from the system console or from a single remote login session, but not both simultaneously. To prevent someone from remotely logging in while you are at the console, use the routine ***shellLock*( )** as follows:

```
-> shellLock 1
```

To make the target shell available again to remote login, enter the following:

```
-> shellLock 0
```

To end a remote-login target shell session, call ***logout*( )** from the target shell. To end an **rlogin** session, type **TILDE** and **DOT** as the only characters on a line:

```
-> ~.
```

Remote Login Security

You can be prompted to enter a login user name and password when accessing VxWorks remotely:

```
VxWorks login: user_name

Password: password
```

The remote-login security feature is enabled by selecting **INCLUDE_SECURITY** for inclusion in the project facility VxWorks view. The default login user name and password provided with the supplied system image is *target* and *password*. You can change the user name and password with the ***loginUserAdd*( )** routine, as follows:

```
-> loginUserAdd "fred", "encrypted_password"
```

To obtain *encrypted_password*, use the tool **vxencrypt** on the host system. This tool prompts you to enter your password, and then displays the encrypted version.

To define a group of login names, include a list of ***loginUserAdd*( )** commands in a startup script and run the script after the system has been booted. Or include the list of ***loginUserAdd*( )** commands to the file **usrConfig.c**, then rebuild VxWorks.

NOTE: The values for the user name and password apply only to remote login into the VxWorks system. They do not affect network access from VxWorks to a remote system; See *VxWorks Network Programmer's Guide: rlogin and telnet, Host Access Applications*.

The remote-login security feature can be disabled at boot time by specifying the flag bit 0x20 (**SYSFLAG_NO_SECURITY**) in the *flags* parameter on the boot line (see *Tornado Getting Started*). This feature can also be disabled by deselecting **INCLUDE_SECURITY** in the project facility VxWorks view.

9.2.6 Summary of Target and Host Shell Differences

For details on the Tornado shell, see the *Tornado User's Guide: Shell*. The following is a summary of the differences between it and the target shell:

- Both shells contain a C interpreter, which allows C-shell and **vi** editing facilities. However, the Tornado shell also provides a Tcl interpreter.
- You can have multiple Tornado shells active for any given target; only one target shell can be active for a target at any one time.
- The Tornado shell allows virtual I/O; the target shell does not.

- The target shell does not have a GNU C++ demangler; it is necessary to use the target tools when C++ demangling is required.
- The Tornado shell is always ready to execute. The target shell, as well as its associated target-resident symbol table and module loader/unloader, must be configured into the VxWorks image by including the appropriate components in the project facility VxWorks view (discussed throughout this chapter).
- Because the target shell is often started from the system console, the standard input and output are directed to the same window. For the Tornado shell, these standard I/O streams are not necessarily directed to the same window as the Tornado shell. For details, see the *Tornado User's Guide: Shell*.
- The Tornado shell can perform many control and information functions entirely on the host without consuming target resources.
- The Tornado shell uses host resources for most functions so that it remains segregated from the target. This means that the Tornado shell can operate on the target from the outside. The target shell, on the other hand, must act on itself. This means that there are limitations to what the target shell can do (for example, while debugging it cannot set breakpoints on itself or on routines it calls). Also, conflicts in priority may occur while using the target shell.
- When the target shell encounters a string literal ("...") in an expression, it allocates space for the string including the null-byte string terminator. The value of the literal is the address of the string in the newly allocated storage. For example, the following expression allocates 12 bytes from the target memory pool, enters the string in those 12 bytes (including the null terminator), and assigns the address of the string to **x**:

  ```
  -> x = "hello there"
  ```

  The following expression can be used to return those 12 bytes to the target memory pool (see the **memLib** reference entry for information on memory management):

  ```
  -> free (x)
  ```

  Furthermore, even when a string literal is not assigned to a symbol, memory is still permanently allocated for it. For example, the following expression uses 12 bytes of memory that are never freed:

  ```
  -> printf ("hello there")
  ```

  This is because if strings were only temporarily allocated, and a string literal were passed to a routine being spawned as a task, then by the time the task executed and attempted to access the string, the target shell would have already released (and possibly even reused) the temporary storage where the string was held.

After extended development sessions with the target shell, the cumulative memory used for strings may be noticeable. If this becomes a problem, you must reboot your target. Because the Tornado shell has access to a host-controlled target memory pool, this memory leak never occurs.

9.3 Other Target-Resident Facilities

9.3.1 Target Symbol Table, Module Loader, and Module Unloader

To make full use of the target shell's features, you should also define the target symbol table, as well as the target module loader and unloader. Select the following components (identified by their associated macros) in the VxWorks view (see *Tornado User's Guide: Projects* for configuration information):

- **INCLUDE_SYM_TBL** for target symbol table support, plus one of the following:
  - **INCLUDE_NET_SYM_TBL** to load the symbol table from the network (**vxWorks.sym**; you will also need to separately load **vxWorks**)
  - **INCLUDE_STANDALONE_SYM_TBL** to build a VxWorks image that includes the target symbol table (**vxWorks.st**)
- **INCLUDE_LOADER**
- **INCLUDE_UNLOADER**

If the target symbol table is included, ***usrRoot*( )** runs ***hashLibInit*( )** and ***symLibInit*( )** to initialize the corresponding libraries. The target symbol table is created by calling ***symTblCreate*( )**. For convenience during debugging (see *9.2.3 Debugging with the Target Shell*, p.371), it is most useful to have access to all symbols in the system. On the other hand, a production version of a system can be built that does not require the target symbol table, if (for example) memory resources are constrained.

The ***symTblCreate*( )** call creates an empty target symbol table. VxWorks system facilities are not accessible through the target shell until the symbol definitions for the booted VxWorks system are entered into the target symbol table. This is done by reading the target symbol table from a file called **vxWorks.sym** in the same directory from which **vxWorks** was loaded (*installDir***/target/config/***bspname*). This file contains an object module that consists only of a target symbol table section containing the symbol definitions for all the variables and routines in the booted system module. It has zero-length (empty) code, data, and relocation sections. Nonetheless, it is a legitimate object module in the standard object module format.

The symbols in **vxWorks.sym** are entered in the target symbol table by calling ***loadSymTbl*( )** (whose source is in *installDir***/target/src/config/usrLoadSym.c**). This routine uses the target-resident module loader to load symbols from **vxWorks.sym** into the target symbol table.

For the most part, the target-resident facilities work the same as their Tornado host counterparts; see *8.9.1 Creating a Standalone VxWorks System with a Built-in Symbol Table*, p.366, *8.4.4 Downloading an Application Module*, p.335, and *8.4.6 Unloading Modules*, p.336. However, as stated earlier, the target-resident facilities can be useful if you are building dynamically configured applications. For example, with the target-resident loader, you can load from a target disk as well as over the network, with these caveats: If you use the target-resident loader to load a module over the network (as opposed to loading from a target-system disk), the amount of memory required to load an object module depends on what kind of access is available to the remote file system over the network. Loading a file that is mounted over the default network driver requires enough memory to hold two copies of the file simultaneously. First, the entire file is copied to a buffer in local memory when opened; second, the file resides in memory when it is linked to VxWorks. On the other hand, loading an object module from a host file system mounted through NFS only requires enough memory for one copy of the file (plus a small amount of overhead). In any case, however, using the target-resident loader takes away additional memory from your application—most significantly for the target-resident symbol table required by the target-resident loader.

For information on the target-resident module loader, unloader, and symbol table, see the **loadLib**, **unldLib**, and **symLib** reference entries.

9.3.2 Show Routines

VxWorks includes system information routines which print pertinent system status on the specified object or service; however, they show only a snapshot of the system service at the time of the call and may not reflect the current state of the system. To use these routines, you must define the associated configuration macro (see the *Tornado User's Guide: Projects*). When you invoke them, their output is sent to the standard output device. Table 9-2 lists common system show routines.

Table 9-2 **Show Routines**

Call	Description	Configuration Macro
***envShow*( )**	Display the environment for a given task on *stdout*	**INCLUDE_TASK_SHOW**
***memPartShow*( )**	Show the partition blocks and statistics	**INCLUDE_MEM_SHOW**
***memShow*( )**	System memory show routine	**INCLUDE_MEM_SHOW**
***moduleShow*( )**	Show statistics for all loaded modules	Included automatically with **INCLUDE_MODULE_MANAGER**
***msgQShow*( )**	Message queue show utility (both POSIX and *wind*)	**INCLUDE_POSIX_MQ_SHOW** **INCLUDE_MSG_Q_SHOW**
***semShow*( )**	Semaphore show utility (both POSIX and *wind*)	**INCLUDE_SEM_SHOW**, **INCLUDE_POSIX_SEM_SHOW**
***show*( )**	Generic object show utility	
***stdioShow*( )**	Standard I/O file pointer show utility	**INCLUDE_STDIO_SHOW**
***taskSwitchHookShow*( )**	Show the list of task switch routines	**INCLUDE_TASK_HOOKS_SHOW**
***taskCreateHookShow*( )**	Show the list of task create routines	**INCLUDE_TASK_HOOKS_SHOW**
***taskDeleteHookShow*( )**	Show the list of task delete routines	**INCLUDE_TASK_HOOKS_SHOW**
***taskShow*( )**	Display the contents of a task control block	**INCLUDE_TASK_SHOW**
***wdShow*( )**	Watchdog show utility	**INCLUDE_WATCHDOGS_SHOW**

An alternative method of viewing system information is the Tornado browser, which can be configured to update system information periodically. For information on this tool, see the *Tornado User's Guide: Browser.*

VxWorks also includes several network information routines. These routines are initialized by defining **INCLUDE_NET_SHOW** in your VxWorks configuration; see *8. Configuration and Build*. Table 9-3 lists commonly called network show routines.

Table 9-3 **Network Show Routines**

Call	Description
***ifShow*( )**	Display the attached network interfaces.
***inetstatShow*( )**	Display all active connections for Internet protocol sockets.
***ipstatShow*( )**	Display IP statistics.
***netPoolShow*( )**	Show pool statistics.
***netStackDataPoolShow*( )**	Show network stack data pool statistics.
***netStackSysPoolShow*( )**	Show network stack system pool statistics.
***mbufShow*( )**	Report mbuf statistics.
***netShowInit*( )**	Initialize network show routines.
***arpShow*( )**	Display entries in the system ARP table.
***arptabShow*( )**	Display the known ARP entries.
***routestatShow*( )**	Display routing statistics.
***routeShow*( )**	Display host and network routing tables.
***hostShow*( )**	Display the host table.
***mRouteShow*( )**	Print the entries of the routing table.

Appendices

A
Motorola MC680*x*0

A.1 Introduction

This appendix provides information specific to VxWorks development on Motorola MC680*x*0 targets. It includes the following topics:

- Building Applications: how to compile modules for your target architecture.
- Interface Changes: information on changes or additions to particular VxWorks features to support the MC680*x*0 processors.
- Architecture Considerations: special features and limitations of the MC680*x*0 processors, including a figure showing the VxWorks memory layout for these processors.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

A.2 Building Applications

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for MC680*x*0 targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate architecture-specific features enabled. Define this variable to one of the following values, to match the processor you are using:

– **MC68000**
– **MC68010**
– **MC68020** (used also for MC68030 processors)
– **MC68040**
– **MC68LC040** (used also for MC68EC040 processors)
– **MC68060**
– **CPU32**

For example, to define **CPU** for a MC68040 on the compiler command line, specify the following command-line option when you invoke the compiler:

```
-DCPU=MC68040
```

To provide the same information in a header or source file instead, include the following line in the file:

```
#define CPU MC68040
```

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. Tornado is configured to use these tools by default. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables.

Compiling C or C++ Modules

The following is an example of a compiler command line for MC680*x*0 cross-development. The file to be compiled in this example has a base name of **applic**.

```
% cc68k -DCPU=MC68040 -I $WIND_BASE/target/h -fno-builtin \
-O -nostdinc -c applic.language_id
```

The options shown in the example have the following meanings:[1]

-DCPU=MC68040
Required; defines the CPU type. If you are using another MC680*x*0 processor, specify the appropriate value (see *Defining the CPU Type*, p.384).

-I $WIND_BASE/target/h
Required; includes VxWorks header files. (Additional **-I** flags may be included to specify other header files.)

-fno-builtin
Required; uses library calls even for common library subroutines.

-O Optional; performs standard optimization.

-nostdinc
Required; searches only the directory specified with the **-I** flag (see above) and the current directory for header files. Does not search host-system include files.

-c Required; specifies that the module is to be compiled only, and not linked for execution under the host.

applic.*language_id*
Required; the file(s) to compile. For C compilation, specify a suffix of **.c**. For C++ compilation, specify a suffix of **.cpp**. The output is an unlinked object module in **a.out** format with the suffix **.o**; for the example, the output is **applic.o**.

During C++ compilation, the compiled object module (*applic***.o**) is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks run-time support can use to call the objects' constructors and destructors. See the *VxWorks Programmer's Guide: C++ Development* for details.

⚠ **CAUTION:** Do not use **-msoft-float** on the MC68040 or MC68060. However, do use this flag for floating-point support on the MC68LC040. See *Floating-Point Support*, p.393.

1. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; a list of these options is included in the *Guide*. Other options are not supported, although they are available with the tools as shipped.

A.3 Interface Variations

This section describes particular routines and tools that are specific to 68K targets in any of the following ways:

- available only on certain 68K targets
- parameters specific to 68K targets
- special restrictions or characteristics on 68K targets

For complete documentation, see the reference entries for the libraries, subroutines, and tools discussed below.

CPU-Specific Interfaces

Because of specific characteristics of the MC68040 or MC68060, certain VxWorks features are not useful on these targets. Conversely, other VxWorks features are particular to one or both of these processors, to exploit specific characteristics.

Note that discussion of the MC68040 also applies to the MC68LC040 unless otherwise noted. The MC68LC040 is a derivative of the MC68040 and differs only in that it has no floating-point unit.

Table A-1 lists such CPU-specific VxWorks interfaces. Section *A.4 Architecture Considerations*, p.387 discusses these interfaces in the context of CPU architecture. For more complete documentation on these routines, see the associated reference entries.

Table A-1 **VxWorks Interface Variations for MC68040/MC68060**

Routine or Macro Name	CPU	Change	Detailed Discussion
***checkStack*( )**	060	Interrupt stack display meaningless	*MC68060: No Interrupt Stack*, p.389
***vxSSEnable*( )** ***vxSSDisable*( )**	060	Only for this architecture	*MC68060 Superscalar Pipeline*, p.389
***cacheLock*( )** ***cacheUnlock*( )**	040	Always return **ERROR**	*MC68040 Caches*, p.390
***cacheStoreBufEnable*( )** ***cacheStoreBufDisable*( )**	060	Only for this architecture	*MC68060 Caches*, p.391
USER_B_CACHE_ENABLE	060	Architecture-specific configuration	*MC68060 Caches*, p.391

Table A-1 **VxWorks Interface Variations for MC68040/MC68060** *(Continued)*

Routine or Macro Name	CPU	Change	Detailed Discussion
BRANCH_CACHE	060	Architecture-specific cache	*MC68060 Caches*, p.391
VM_STATE…	both	Architecture-specific MMU states	*Memory Management Unit*, p.392

a.out-Specific Tools

The following tools are specific to the **a.out** format. For more information, see the reference entries for each tool.

hex
converts an **a.out**-format object file into Motorola hex records. The syntax is:

`hex [-a` *adrs*] **`[-l] [-v] [-p`** *PC*] **`[-s`** *SP*] *file*

aoutToBin
extracts text and data segments from an **a.out** file and writes it to standard output as a simple binary image. The syntax is:

`aoutToBin <` *inFile* **`>`** *outfile*

xsym
extracts the symbol table from an **a.out** file. The syntax is:

`xsym <` *objMod* **`>`** *symTbl*

A.4 Architecture Considerations

This section describes the following characteristics of the MC680*x*0 processors (particularly the MC68040 and MC68060) that you should keep in mind as you write a VxWorks application:

- MC68060 unimplemented integer instructions
- Double-word integers
- Interrupt stack
- MC68060 superscalar pipeline
- Caches
- Memory Management Unit

- Floating-point support
- Memory layout

Note that discussion of the MC68040 also applies to the MC68LC040 unless otherwise noted. The MC68LC040 is a derivative of the MC68040 and differs only in that it has no floating-point unit.

For comprehensive documentation of Motorola architectures, see the appropriate Motorola microprocessor user's manual.

The names of macros specific to these architectures, and specialized terms in the remainder of this section, match the terms used by the Motorola manuals.

MC68060 Unimplemented Integer Instructions

Neither the 64-bit divide and multiply instructions, nor the **movep**, **cmp2**, **chk2**, **cas**, and **cas2** instructions are implemented on the MC68060 processor. To eliminate these restrictions, VxWorks integrates the software emulation provided in the Motorola MC68060 software package, version B1. This package contains an exception handler that allows full emulation of the instructions listed above. VxWorks connects this exception handler to the unimplemented-integer-instruction exception (vector 61).

The Motorola exception handler allows the host operating system to add or to substitute its own routines. VxWorks does not add or substitute any routines; the instruction emulation is the full Motorola implementation.

Double-word Integers: **long long**

The double-word integer **long long** is not supported, except as an artifact of your particular architecture and compiler. For more information about handling unsupported features, please see the *Customer Support User's Guide*.

Interrupt Stack

VxWorks uses a separate interrupt stack whenever the underlying architecture supports it. All MC680*x*0 processors, except the MC68060, have an interrupt stack.

The MC680x0 Interrupt Stack

For all MC680*x*0 processors that have an interrupt stack, VxWorks uses the separate interrupt stack instead of the current task stack when the processor takes an interrupt.

The interrupt stack size is defined by the **ISR_STACK_SIZE** parameter in the project facility under **INCLUDE_KERNEL**. The default size of the interrupt stack is 1000 bytes.

MC68060: No Interrupt Stack

When the MC68060 processor takes an interrupt, VxWorks uses the current supervisor stack. To avoid stack overflow, spawn every task with a stack big enough to hold both the task stack and the interrupt stack.

The routine ***checkStack*( )**, which is built into the Tornado shell, displays the stack state for each task and also for the interrupt stack. Because this routine is the same for all processors that VxWorks supports, ***checkStack*( )** displays a line for the interrupt stack state. For the MC68060, the values appearing on this line are meaningless.

MC68060 Superscalar Pipeline

The MC68060 implements a superscalar pipeline that allows multiple instructions to be executed in a single machine cycle. This feature can be enabled or disabled by setting or clearing the ESS (Enable SuperScalar) bit of the Processor Configuration Register (PCR). For this architecture, VxWorks provides two routines to enable and disable the superscalar pipeline, declared as follows:

```
void vxSSEnable (void)
void vxSSDisable (void)
```

In the default configuration, VxWorks enables the superscalar pipeline.

Caches

The MC68000 and MC68010 processors do not have caches. The MC68020 has only a 256-byte instruction cache; see the general cache information presented in *Cache Coherency*, p. 155.

The MC68040 has 4KB instruction and data caches, and the MC68060 has 8KB instruction and data caches. The following subsections augment the information in *Cache Coherency*, p. 155.

MC68040 Caches

The MC68040 processor contains an instruction cache and a data cache. By default, VxWorks uses both caches; that is, both are enabled. To disable the instruction cache, highlight the **USER_I_CACHE_ENABLE** macro in the Params tab under **INCLUDE_CACHE_ENABLE** and remove the **TRUE**; to disable the data cache, highlight the **USER_D_CACHE_ENABLE** macro and remove the **TRUE**.

These caches can be set to the following modes:

– cacheable writethrough (the default for both caches)
– cacheable copyback
– cache-inhibited serialized
– cache-inhibited not-serialized

Choose the mode by setting the **USER_I_CACHE_MODE** parameter or the **USER_D_CACHE_MODE** parameter in the Params tab under **INCLUDE_CACHE_MODE**. The list of possible values for these macros is defined in *installDir***/target/h/cacheLib.h**.

For most boards, the cache capabilities must be used with the MMU to resolve cache coherency problems. In that situation, the page descriptor for each page selects the cache mode. This page descriptor is configured by filling the **sysPhysMemDesc[]** data structure defined in the BSP *installDir***/target/config/***bspname***/sysLib.c** file. (For more information about cache coherency, see the **cacheLib** reference entry. See also *7. Virtual Memory Interface* for information on VxWorks MMU support. For MMU information specific to the MC680*x0* family, see *Memory Management Unit*, p. 392.)

The MC68040 caches do not support cache locking and unlocking. Thus the ***cacheLock*( )** and ***cacheUnlock*( )** routines have no effect on this target, and always return **ERROR**.

The ***cacheClear*( )** and ***cacheInvalidate*( )** routines are very similar. Their effect depends on the cache:

- With the data cache, ***cacheClear*( )** first pushes dirty data[2] to memory (if the cache line contains any) and then invalidates the cache line, while ***cacheInvalidate*( )** just invalidates the line (in which case any dirty data contained in this line is lost).

2. *Dirty data* refers to data saved in the cache, not in memory (copyback mode only).

- For the instruction cache, both routines have the same result: they invalidate the cache lines.

MC68060 Caches

VxWorks for the MC68060 processor provides all the cache features of the MC68040, and some additional features.

Instruction and Data Cache

Motorola has introduced a change of terminology with the MC68060: the mode called "cache-inhibited serialized mode" on the MC68040 is called "cache-inhibited precise mode" on the MC68060, and the MC68040's "cache-inhibited not-serialized mode" is replaced by "cache-inhibited imprecise mode" on the MC68060.

To make your code consistent with this change, you can use the macros[3] **CACHE_INH_PRECISE** and **CACHE_INH_IMPRECISE** with VxWorks cache routines when writing specifically for the MC68060, instead of using the MC68040-oriented macro names **CACHE_INH_SERIAL** and **CACHE_INH_NONSERIAL**. (The corresponding macros in each pair have the same definition, however, to make MC68040 object code compatible with the MC68060.)

A four-entry first-in-first-out (FIFO) buffer is implemented on the MC68060. This buffer, used by the cacheable writethrough and cache inhibited imprecise mode, is enabled by default. Two VxWorks routines are available to enable or disable this store buffer. Their names and prototypes are declared as follows:

```
void cacheStoreBufEnable (void)
void cacheStoreBufDisable (void)
```

On the MC68060, the instruction cache and data cache can be locked by software. Thus, on this architecture (unlike for the MC68040), the ***cacheLock*( )** and ***cacheUnlock*( )** routines are effective.

VxWorks does not support the MC68060 option to use only half of the instruction cache or data cache.

Branch Cache

In addition to the instruction cache and the data cache, the MC68060 contains a branch cache that VxWorks supports as an additional cache. Use the name **BRANCH_CACHE** to refer to this cache with the VxWorks cache routines.

3. Defined in **h/arch/mc68k/cacheMc68kLib.h**.

Most routines available for both instruction and data caches are also available for the branch cache. However, the branch cache cannot be locked; thus, the ***cacheLock*( )** and ***cacheUnlock*( )** routines have no effect and always return **ERROR**.

The branch cache uses only one operating mode and does not require a macro to specify the current mode. In the default configuration, VxWorks enables the branch cache. This option can be removed by highlighting the **USER_B_CACHE_ENABLE** macro in the Params tab under **INCLUDE_CACHE_ENABLE** and remove the **TRUE**.

The branch cache can be invalidated only in its entirety. Trying to invalidate one branch cache line, or, as for the instruction cache, clearing the branch cache, invalidates the whole cache.

The branch cache is automatically cleared by the hardware as part of any instruction-cache invalidate.

Memory Management Unit

VxWorks provides two levels of virtual memory support: the basic level bundled with VxWorks, and the full level, unbundled, that requires the optional product VxVMI. These two levels are supported by the MC68040 and MC68060 processors; however, the MC68000, MC68010, and MC68020 processors do not have MMUs.

For detailed information on VxWorks's MMU support, see *7. Virtual Memory Interface*. The following subsections augment the information in that chapter.

MC68040 Memory Management Unit

On the MC68040, you can set a specific configuration for each memory page. The entire physical memory is described by the data structure **sysPhysMemDesc[]** defined in the BSP file **sysLib.c**. This data structure is made up of state flags for each page or group of pages. All the state flags defined in Table 7-2 of *7. Virtual Memory Interface* are available for MC68040 virtual memory pages.

⚠ **CAUTION:** The **VM_STATE_CACHEABLE** flag listed in Table 7-2 of *7. Virtual Memory Interface* sets the cache to copyback mode for each page or group of pages.

In addition, two other state flags are supported:

– **VM_STATE_CACHEABLE_WRITETHROUGH**
– **VM_STATE_CACHEABLE_NOT_NON_SERIAL**

The first flag sets the page descriptor cache mode field in cacheable writethrough mode, and the second sets it in cache-inhibited non-serialized mode.

For more information on memory page states, state flags, and state masks, see *Page States*, p.294.

MC68060 Memory Management Unit

The MMU on the MC68060 is very similar to the MC68040 MMU, and MC68060 virtual memory management provides the same capabilities as the MC68040 virtual memory; see *MC68040 Memory Management Unit*, p.392 for details.

You can use the page state constant **VM_STATE_CACHEABLE_NOT_IMPRECISE** instead of **VM_STATE_CACHEABLE_NOT_NON_SERIAL**, to match changes in Motorola terminology (see *MC68060 Caches*, p.391). Use this constant (as its name suggests) to set the page descriptor cache mode field to "cache-inhibited imprecise mode." To set the page cache mode to "cache-inhibited precise mode," use **VM_STATE_CACHEABLE_NOT**.

The MC68060 does not use the data cache when searching MMU address tables, because the MC68060 tablewalker unit has a direct interface to the bus controller. Therefore, virtual address translation tables are always placed in writethrough space. (Although VxWorks maps virtual addresses to the identical physical addresses, the MMU address translation tables also record the page protection provided through VxVMI.)

Floating-Point Support

The MC68020 uses an MC68881/MC68882 floating-point coprocessor for hardware floating-point support. The MC68040 and MC68060 CPUs (but not the MC68LC040) include internal floating-point units that provide a significant subset of the MC68881/MC68882 instruction set, in addition to the same control, status, and data register programming model. Basic floating-point arithmetic and manipulation functions are provided, but higher-level transcendental functions (for example, trigonometric, logarithmic, rounding) are not. Floating-point support for the MC68LC040 is provided in software only.

Different subsets of the floating-point math routines in **mathALib** are supported for each processor of the MC680*x*0 family. Table A-2 shows the supported double-precision routines.

There is no hardware support for single-precision floating-point. On the MC68000, MC68010, MC68020, MC68LC040, and CPU32, software support is available for the following single-precision routines:

***acosf*( )**	***asinf*( )**	***atanf*( )**	***atan2f*( )**	***cbrtf*( )**
***ceilf*( )**	***cosf*( )**	***expf*( )**	***fabsf*( )**	***floorf*( )**
***infinityf*( )**	***logf*( )**	***log10f*( )**	***log2f*( )**	***powf*( )**
***sinf*( )**	***sincosf*( )**	***sqrtf*( )**	***tanf*( )**	

On the MC68040 or MC68060, there are no supported single-precision floating-point routines.

Table A-2 **Double-Precision Floating-Point Routines Supported for MC680x0 Family**

	MC68000/ MC68010	MC68020/ CPU32	MC68040	MC68LC040	MC68060
***acos*( )**	S	HS	E	S	E
***asin*( )**	S	HS	E	S	E
***atan*( )**	S	HS	E	S	E
***atan2*( )**	S	HS	E	S	E
***cbrt*( )**	S	S		S	
***ceil*( )**	S	HS	E	S	H
***cos*( )**	S	HS	E	S	E
***cosh*( )**	S	HS	E	S	E
***exp*( )**	S	HS	E	S	E
***fabs*( )**	S	HS	E	S	H
***floor*( )**	S	HS	E	S	H
***fmod*( )**		H	E		E
***infinity*( )**	S	HS	E	S	H
***irint*( )**		H	E		H
***iround*( )**		H	E		H
***log*( )**	S	HS	E	S	E
***log10*( )**	S	HS	E	S	E
***log2*( )**	S	HS	E	S	E
***pow*( )**	S	HS	E	S	E
***round*( )**		H	E		H
***sin*( )**	S	HS	E	S	E
***sincos*( )**	S	HS	E	S	E
***sinh*( )**	S	HS	E	S	E

Table A-2 **Double-Precision Floating-Point Routines Supported for MC680x0 Family**

	MC68000/ MC68010	MC68020/ CPU32	MC68040	MC68LC040	MC68060
***sqrt*( )**	S	HS	E	S	H
***tan*( )**	S	HS	E	S	E
***tanh*( )**	S	HS	E	S	E
***trunc*( )**		H	E		H

S = software floating-point support
H = hardware floating-point support
E = emulated hardware floating-point support

Floating-Point Support for MC680x0 CPUs Using MC68881/MC68882

VxWorks provides both hardware and software floating-point, in support of those target configurations that include a floating-point coprocessor as well as those that do not. Use the compiler option **-msoft-float** to generate object code that uses software floating-point, and the compiler option **-m68881** for hardware floating-point.

Floating-Point Support for the MC68040 and MC68060

For the MC68040 and the MC68060 (but not the MC68LC040), VxWorks includes support for MC68881/MC68882 floating-point instructions that are not directly supported by the CPU. This emulation is provided by the Floating-Point Software Package (FPSP) from Motorola, which is integrated into VxWorks.

The FPSP is called by special exception handlers that are invoked when one of the unsupported instructions executes. This allows MC68881/MC68882 instructions to be interpreted, although the exception overhead can be significant. Exception handlers are also provided for other floating-point exceptions (for example, floating-point division by zero, over- and underflow).

The initialization routine ***mathHardInit*( )** installs these exception handlers; this routine is called from **usrConfig.c** when you configure VxWorks for hardware floating-point by selecting **INCLUDE_HW_FP** for inclusion in the project facility VxWorks view. (It is defined by default.)

To avoid the overhead associated with unimplemented-instruction exceptions, the floating-point libraries in VxWorks call specific routines in the FPSP directly. As a result, application code written in C that uses transcendental functions (for example, the ***sin*( )** or ***log*( )** routines) does not suffer from the exception-handling overhead. No special changes to application source code are necessary. (However, support is provided only for double-precision floating-point operations.)

If you are using the GNU ToolKit C compiler (**cc68k**) distributed by Wind River Systems, compile your code *without* the flag **-msoft-float**.

- **MC68040 Floating-Point Software Package**

  On the MC68040, VxWorks uses version 2.2 of the MC68040 Floating-Point Software Package (FPSP) from Motorola. This library makes full use of the floating-point support provided by the MC68040 hardware, as opposed to pure software emulation. The size of this FPSP is approximately 64KB.

- **MC68060 Floating-Point Software Package**

  As with the MC68040, the MC68060 floating-point unit implements only a subset of the MC68881/MC68882 instruction set. The two subsets are not identical (see *§6.5.1 Unimplemented Floating-Point Instructions* in the *MC68060 Microprocessors User's Manual*); hence the MC68060 has its own FPSP. VxWorks uses version B1 of the MC68060 Floating-Point Software Package from Motorola. The size of this FPSP is approximately 84KB.

Floating-Point Support for the MC68LC040

While the MC68LC040 is a derivative of the MC68040 (implementing the same integer unit and memory management unit), it has no floating-point unit. Applications for the MC68LC040 must use software floating-point emulation. Use the compiler option **-msoft-float** to generate object code that uses software floating-point. Be sure to specify a **CPU** value of **MC68LC040** when building VxWorks (see *Defining the CPU Type*, p.384).

Memory Layout

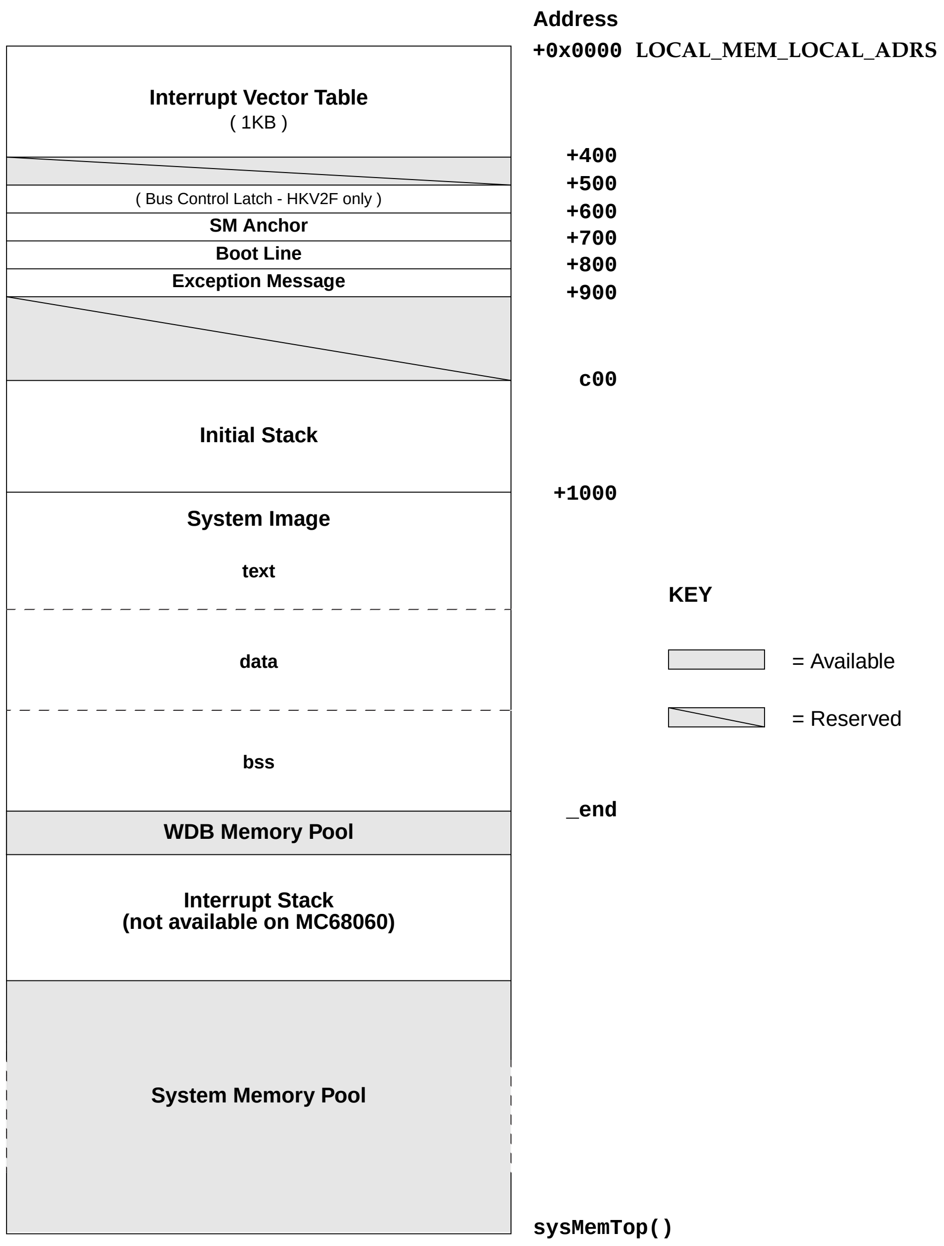
The VxWorks memory layout is the same for all MC680*x*0 processors, except that the MC68060 has no interrupt stack. Figure A-1 shows memory layout, labeled as follows:

Interrupt Vector Table	Table of exception/interrupt vectors.
SM Anchor	Anchor for the shared memory network (if there is shared memory on the board).
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of the fatal exception message.
Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.

System Image	VxWorks itself (three sections: text, data, bss). The entry point for VxWorks is at the start of this region.
WDB Memory Pool	Size depends on the macro **WDB_POOL_SIZE** which defaults to one-sixteenth of the system memory pool. This space is used by the target server to support host-based tools. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
Interrupt Stack	Stack for interrupt handlers (where present). Size is defined by **ISR_STACK_SIZE** under **INCLUDE_KERNEL**. Location depends on system image size.
System Memory Pool	Size depends on size of the system image and (on the all but MC68060) the interrupt stack. The ***sysMemTop*( )** routine returns the end of the free memory pool.

All addresses shown in Figure A-1 are relative to the start of memory for a particular target board. The start of memory (corresponding to 0x0 in the memory-layout diagram) is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

Figure A-1 **VxWorks System Memory Layout (MC680x0)**



B
Sun SPARC, SPARClite

B.1 Introduction

This appendix provides information specific to VxWorks development on Sun SPARC and SPARClite targets. It includes the following topics:

- Building Applications: how to compile modules for your target architecture.
- Interface Changes: information on changes or additions to particular VxWorks features to support the Sun processors.
- Architecture Considerations: special features and limitations of the Sun processors, including information specific to the SPARClite and a figure showing the VxWorks memory layout for these processors.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

B.2 Building Applications

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for SPARC and SPARClite targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate architecture-specific features enabled. Define this variable to **SPARC** for both the SPARC and SPARClite processors.

For example, to define **CPU** for a SPARC on the compiler command line, specify the following command-line option when you invoke the compiler:

```
-DCPU=SPARC
```

To provide the same information in a header or source file instead, include the following line in the file:

```
#define CPU SPARC
```

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. Tornado is configured to use these tools by default. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables.

Compiling C or C++ Modules

The following is an example of a compiler command line for SPARClite cross-development. The file to be compiled in this example has a base name of **applic**.

```
% ccsparc -DCPU=SPARC -I $WIND_BASE/target/h -O2 -nostdinc \
-fno-builtin -msparclite -msoft-float -c applic.language_id
```

The options shown in the example have the following meanings:[1]

-DCPU=SPARC
Required; defines the CPU type. Use **SPARClite** for SPARClite processors.

-I $WIND_BASE/target/h
Required; includes VxWorks header files. (Additional **-I** flags may be included to specify other header files.)

1. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; a list of these options is included in the *Guide*. Other options are not supported, although they are available with the tools as shipped.

-O2 Optional; performs level 2 optimization.

-nostdinc
Required; searches only the directory(ies) specified with the **-I** flag (see above) and the current directory for header files. Does not search host-system include files.

-fno-builtin
Required; uses library calls even for common library subroutines.

-msparclite
Required for SPARClite; generates SPARClite-specific code.

-msoft-float
Optional; generates software floating point library calls, rather than hardware floating point instructions. For more information, see *USS Floating-Point Emulation Library*, p.413,

-c Required; specifies that the module is to be compiled only, and not linked for execution under the host.

applic.*language_id*
Required; the file(s) to compile. For C compilation, specify a suffix of **.c**. For C++ compilation, specify a suffix of **.cpp**. The output is an unlinked object module in **a.out** format with the suffix **.o**; for the example, the output is **applic.o**.

During C++ compilation, the compiled object module (*applic***.o**) is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks can use to call the objects' constructors and destructors. See the *VxWorks Programmer's Guide: C++ Development* for details

B.3 Interface Variations

This section describes particular routines that are specific to SPARC targets in one of the following ways:

- available only for SPARC or SPARClite targets
- parameters specific to SPARC or SPARClite targets

- special restrictions or characteristics on SPARC or SPARClite targets

For complete documentation on these routines, see the reference entries.

NOTE: Unless otherwise noted, the information in this section applies to both the SPARC and SPARClite. For SPARClite-specific information, see *SPARClite Overview*, p. 412.

bALib

The following buffer-manipulation routines provided by **bALib** exploit the SPARC LDD and STD instructions.

***bzeroDoubles*( )**
Zeroes out a buffer, 256 bytes at a time.

***bfillDoubles*( )**
Fills a buffer with a specified eight-byte pattern.

***bcopyDoubles*( )**
Copies one buffer to another, eight bytes at a time.

cacheMb930Lib

The library **cacheMb930Lib** contains routines that allow you to initialize, lock, and clear the Fujitsu MB86930 (SPARClite) cache. For more information, see the manual pages and *Instruction and Data Cache Locking*, p. 412.

cacheMicroSparcLib

The library **cacheMicroSparcLib** contains routines that allow you to initialize, flush, and clear the MicroSparc I and II caches. For more information, see the manual pages.

dbgLib

If you are using the target shell, note the following architecture-specific information on routines in the **dbgLib**:

- **Optional Parameter for *c*( ) and *s*( )**

The SPARC versions of ***c*( )** (continue) and ***s*( )** (single-step) can take a second address parameter, *addr1*. With this parameter, you can set **nPC** as well as the **PC**.

Note that if *addr* is NULL, *addr1* is ignored.

- **Restrictions on *cret*( )**

In VxWorks for SPARC, ***cret*( )** cannot determine the correct return address. Because the actual return address is determined by code within the routine, only the calling address is known. With C code in general, the calling instruction is a **CALL** and routines return with the following:

```
ret
restore
```

This is the assumption made by ***cret*( )** when it places a breakpoint at the return address of the current subroutine and continues execution. Note that returns other than **%i7 + 8** result in ***cret*( )** setting an incorrect breakpoint value and continuing.

- **Restrictions on *so*( )**

The ***so*( )** routine single-steps a task stopped at a breakpoint, but steps over a subroutine. However, in the SPARC version, if the next instruction is a **CALL** or **JMPL x, %o7**, the routine breaks at the second instruction following the subroutine (that is, the first instruction following the delay slot's instruction). In general, the delay slot loads parameters for the subroutine. This loading can have unintended consequences if the delay slot is also a transfer of control.

- **Trace Routine, *tt*( )**

In general, a task trace works for all non-leaf C-language routines and any assembly language routines that contain the standard prologue and epilogue:

```
save    %sp, -STACK_FRAME_SIZE, %sp
...
ret
restore
```

Although the ***tt*( )** routine works correctly in general, note the following caveats:

– Routines written in assembly or other languages, strange entries in routines, or tasks with corrupted stacks, can result in confusing trace information.

– All parameters are assumed to be 32-bit quantities.

– The cross-compiler does not handle structures passed as parameters correctly.

– The current trace-back tag generated by C compilers is limited to 16 parameters; thus, ***tt*( )** does not report the value of parameters above 16. However, this does not mean that your application cannot use routines with more than 16 parameters.

– If the routine changes the values of its local registers between the time it is called and the time it calls the next level down (or, at the lowest level, the time the task is suspended), ***tt*( )** reports the changed values. It has no way to locate the original values.

– If the routine changes the values of registers **i0** through **i5** between the time it is called and the time it calls the next level down (or, at the lowest level, the time the task is suspended), ***tt*( )** reports the changed values. It has no way to locate the original values.

– If you attempt a ***tt*( )** of a routine between the time the routine is called and the time its initial *save* is finished, you can expect strange results.

dbgArchLib

If you are using the target shell, the following architecture-specific show routines are available if **INCLUDE_DEBUG** is defined:

psrShow( )
: Displays the symbolic meaning of a specified PSR value on the standard output device.

fsrShow( )
: Displays the symbolic meaning of a specified FSR value on the standard output device.

fppArchLib

The SPARC version of **fppArchLib** saves and restores a math coprocessor context appropriate to the SPARC floating-point architecture standard.

intArchLib

***intLevelSet*( )** parameters
: The SPARC version of ***intLevelSet*( )** takes an argument from 0 to 15.

***intLock*( )** returns
: The SPARC version of ***intLock*( )** returns an interrupt level.

ioMmuMicroSparcLib

The library **ioMmuMicroSparcLib** contains routines that allow you to initialize and map memory in the microSPARC I/O MMU. For more information, see the manual pages.

mathALib

Because the overall SPARC architecture includes hardware floating-point support, while the SPARClite variant does not, VxWorks includes **mathALib** hardware floating-point support for SPARC and software floating-point support for SPARClite.

▪ SPARC

On SPARC targets, the following **mathALib** routines are available. Note that these are all double-precision routines; no single-precision routines are supported for SPARC:

acos( )	***asin( )***	***atan( )***	***atan2( )***	***cbrt( )***	***ceil( )***	***cos( )***
cosh( )	***exp( )***	***fabs( )***	***floor( )***	***fmod( )***	***irint( )***	***iround( )***
log( )	***log10( )***	***pow( )***	***round( )***	***sin( )***	***sinh( )***	***sqrt( )***
tan( )	***tanh( )***	***trunc( )***				

▪ SPARClite

On SPARClite targets, the following **mathALib** routines are supported (for information about how to use this support, see *USS Floating-Point Emulation Library*, p. 413):

– Double-precision routines:

acos( )	***asin( )***	***atan( )***	***atan2( )***	***ceil( )***	***cos( )***	***cosh( )***
exp( )	***fabs( )***	***floor( )***	***fmod( )***	***frexp( )***	***ldexp( )***	***log( )***
log10( )	***pow( )***	***sin( )***	***sinh( )***	***sqrt( )***	***tan( )***	***tanh( )***

– Single-precision routines:

acosf( )	***asinf( )***	***atanf( )***	***atan2f( )***	***ceilf( )***	***cosf( )***	***coshf( )***
expf( )	***fabsf( )***	***floorf( )***	***fmodf( )***	***logf( )***	***log10f( )***	***modf( )***
powf( )	***sinf( )***	***sinhf( )***	***sqrtf( )***	***tanf( )***	***tanhf( )***	

vxALib

The test-and-set primitive ***vxTas( )*** provides a C-callable interface to the SPARC **ldstub** instruction.

vxLib

The routine ***vxMemProbeAsi( )*** probes addresses in SPARC ASI space.

a.out-Specific Tools for SPARC and SPARClite

The following tools are specific to the **a.out** format. For more information, see the reference entries for each tool.

hex
: converts an **a.out**-format object file into Motorola hex records. The syntax is:

```
hex [-a adrs] [-l] [-v] [-p PC] [-s SP] file
```

aoutToBin
: extracts text and data segments from an **a.out** file and writes it to standard output as a simple binary image. The syntax is:

```
aoutToBin < inFile > outfile
```

xsym
: extracts the symbol table from an **a.out** file. The syntax is:

```
xsym < objMod > symTbl
```

B.4 Architecture Considerations

This section describes the following characteristics of the SPARC and SPARClite architectures that you should keep in mind as you write a VxWorks application:

- Reserved registers
- Processor mode
- Vector table initialization
- Double-word Integers
- Interrupt handling
- Floating-point support
- Stack pointer usage
- SPARClite overview
- Memory layout

Reserved Registers

Following the SPARC specification (*Appendix D, Software Considerations*, in *The SPARC Architecture Manual, Version 8* from Sun Microsystems), registers **g5**, **g6**, and **g7** are reserved for VxWorks kernel use. Avoid using these registers in your applications.

Processor Mode

VxWorks for SPARC and SPARClite always runs in Supervisor mode.

Vector Table Initialization

After the VxWorks for SPARC or SPARClite has completed initialization, traps are enabled and the PIL (Processor Interrupt Level) is set to zero. All 15 interrupt levels are active with the coprocessor enables set according to hardware availability and application use.

The TBR (Trap Base Register) points to the active vector table at address 0x1000 in local memory.

Make sure that vectors are not reserved for the processor or the kernel before acquiring them for an application.

Double-word Integers: **long long**

The double-word integer **long long** is not supported, except as an artifact of your particular architecture and compiler. For more information about handling unsupported features, please see the *Customer Support User's Guide*.

Interrupt Handling

For VxWorks for SPARC and SPARClite, an interrupt stack allows all interrupt processing to be performed on a separate stack. The interrupt stack is implemented in software because the SPARC family does not support such a stack in hardware.

SPARC Interrupts

The SPARC microprocessor allows 15 levels of interrupts. The level is encoded by external hardware on the four interrupt signal lines. The integer unit (CPU) decodes this level and passes control directly to the entry in the vector table at an offset of 0x100 plus the interrupt level times 16 bytes. This corresponds to vectors 16 through 31 (addresses 0x100 to 0x1F0). Each 16-byte entry in the vector table contains up to four instructions. Typically, control passes to an interrupt service routine (ISR) with a call or branch instruction.

The SPARC uses auto-vectored interrupts. The chip does not perform any type of interrupt acknowledge (IACK) cycle. The address in the Trap Base Register (TBR) concatenated with the interrupt level vector displacement allows the SPARC to begin interrupt processing.

The alternative is vectored interrupts. The CPU responds to the interrupt with an IACK cycle so that an interrupt controller chip or individual device can return a value that clears and identifies the source of the interrupt. This is extremely useful for multiple sources of interrupts on a single-interrupt level.

The ability to perform an interrupt acknowledge cycle is a function of the microprocessor (not the software or board-level hardware). However, a target board can synthesize an IACK cycle by accessing an area created in its address space. This is often necessary to clear the interrupt pending bit in an interrupting device. An IACK cycle also differs from a normal read cycle in that the value returned is an interrupt vector. This vector is used to select an offset in the vector table that has the device's ISR connected to that table entry.

VxWorks allows an application to connect ISRs to vectors with the routine ***intConnect*( )**. A stub is built dynamically that calls an interrupt entry routine, calls the ISR, and then calls an exit routine. The SPARC, like other RISC processors, delegates to software the task of building an exception stack frame (ESF) to save volatile information. The kernel builds up two types of exception stack frames: one for interrupts and one for all other exceptions. The code execution sequence following an interrupt is as follows:

1. Vector table
2. Exception stack frame building
3. Overflow exception handling
4. Interrupt entry code
5. ISR
6. Interrupt exit code
7. Rescheduling, if the interrupt added work for the kernel (such as a ***semGive*( )**)

Vectored Interrupts

The SPARC kernel was designed to handle vectored interrupts as an option. Because this implementation varies with every target board, the kernel must work with the board support package (BSP). The implementation of vectored interrupts on a processor that does not support them must be done in software.

A table in the BSP allows an IACK for each of the 15 interrupt levels. A NULL (0) entry corresponds to no interrupt acknowledge. If an IACK is required, the table entry corresponds to a routine that performs the necessary operations. Because the SPARC vector table contains 256 entries, a byte-sized vector can select any exception handler.

Note that the microprocessor, the board, and the kernel reserve certain vector table entries. The kernel appends this vector to the TBR and continues execution with the selected ISR. All checking for the IACK condition and performing of the operation is done by the kernel and is transparent. The interrupt connection mechanism is the same, and checking for and clearing the pending interrupt is done before the ISR attached by ***intConnect*( )** is called.

The following shows the structure used on the SPARCengine 1E (also known as a Sun 1E) SPARC board in *installDir***/target/config/sun1e/sysLib.c**. It illustrates the use of vectored interrupts for VME, but does not require an IACK cycle for local (on-board) interrupts:

```
extern sysVmeAck();    /* IACK Leaf Functions, code in sysALib */

int (*sysIntAckTable [16])() =
    {
    NULL,              /* Reserved for Kernel                  */
    NULL,              /* Interrupt Level 1 - Software 1       */
    sysVmeAck,         /* Interrupt Level 2 - VME 1            */
    sysVmeAck,         /* Interrupt Level 3 - VME 2            */
    NULL,              /* Interrupt Level 4 - SCSI             */
    sysVmeAck,         /* Interrupt Level 5 - VME 3            */
    NULL,              /* Interrupt Level 6 - Ethernet         */
    NULL,              /* Interrupt Level 7 - P2 Bus           */
    sysVmeAck,         /* Interrupt Level 8 - VME 4            */
    sysVmeAck,         /* Interrupt Level 9 - VME 5            */
    NULL,              /* Interrupt Level 10 - Timer 0         */
    sysVmeAck,         /* Interrupt Level 11 - VME 6           */
    NULL,              /* Interrupt Level 12 - Serial Ports    */
    NULL,              /* Interrupt Level 13 - Mailbox         */
    NULL,              /* Interrupt Level 14 - Timer 1         */
    NULL               /* Interrupt Level 15 - NMI             */
    };
```

The performance penalty for this added feature is negligible. When vectored interrupts are used, this penalty increases, because an operation is being handled in software that the SPARC microprocessor was not designed to do. There are some restrictions on these vector routines because they are called in a critical section of code. Again, the Sun 1E SPARC board is used as an example. Note that you must use special "leaf" procedures.

The corresponding code for the function table is in *installDir***/target/config/sun1e/sysALib.s**:

```
/* IACK Function Call Template
/* Input:     %l5 - return address
/* Volatile:  %l4, %l6 (DO NOT USE OTHER REGISTERS !!!)
/* Return:    %l5 - vector table index */

    .global _sysVmeAck

_sysVmeAck:
    sethi    %hi(SUN_VME_ACK),%l6 /* VMEbus IACK - 0xFFD18001          */
    or       %l6,%lo(SUN_VME_ACK),%l6
    rd       %tbr,%l4             /* Extract interrupt level           */
    and      %l4,0x00F0,%l4
    add      %l4,0x0010,%l4       /* Sun 1E to VME level conversion    */
    srl      %l4,5,%l4            /* Add 1, divide by 2 (no remainder) */
    sll      %l4,1,%l4            /* Multiply VME level by 2           */
    ldub     [%l6 + %l4],%l4      /* VMEbus IACK and get vector        */
    jmpl     %l5,%g0              /* Return address - leaf routine     */
    mov      %l4,%l5              /* Interrupt vector to %l5           */
```

VMEbus Interrupt Handling

SPARC uses fifteen interrupt levels instead of the seven used by VMEbus. The mapping of the seven VMEbus interrupts to the fifteen SPARC levels is board dependent. VMEbus interrupts must be acknowledged.

Floating-Point Support

Floating-Point Contexts

A task can be spawned with floating-point support by setting the **VX_FP_TASK** option. This causes switch hooks to initialize, save, and restore a floating-point context. This option increases the task's context switch time and memory consumption, so only spawn tasks with **VX_FP_TASK** if they must perform floating-point operations.

The floating-point data registers are initialized to NaN (Not-a-Number), which is 0xFFFFFFFF. You can change the FSR's (Floating-point Status Register) value using the global variable **fppFsrDefault**.

Floating-Point Exceptions

The following are SPARC floating-point exceptions (most are deferred):

– FPU Disabled (or not present)
– Unfinished Operation
– Unimplemented Operation
– Sequence Error
– Invalid Operation
– Overflow
– Underflow
– Divide-by-Zero
– Inexact

▪ Exception Options

The application can configure the types of floating-point exceptions that VxWorks handles. The ideal solution is to not generate any floating-point exceptions in the application tasks. However, a more realistic scheme is to mask all exceptions globally (all tasks) in the TEM (Trap Enable Mask) field of the FSR (Floating-point Status Register). Alternatively, this can be done locally (on a per task basis) as tasks are spawned and the FSR is initialized. In addition to global and local masks, individual exceptions (invalid operation, overflow, underflow, divide-by-zero, inexact) can be masked in the TEM. The masked exception continues to accrue (for example, become more inexact, continue to overflow, and so on). The default for VxWorks is to mask only the inexact exception.

▪ Exception Handlers

All floating-point exceptions (if enabled) result in the suspension of the offending task and a message sent through the exception handling task, ***excTask( )***. The floating-point unit is flushed so that other tasks can still use the hardware and continue their numeric processing.

▪ Deferred Exceptions

Floating-point exceptions on the SPARC floating-point units are deferred. When they occur in the FPU, they do not immediately interrupt the CPU (integer unit). Instead they remain pended until they are pushed out of the queue by additional floating-point operations or an FSR access.

If one of the last floating-point operations causes an unmasked exception before a context switch, saving the task's context flushes out the exception while in the kernel. The exception handler checks for this special case and works its way back to the kernel so that it can continue the context switch. When the task that caused the exception is switched back in, it continues in the exception handler and suspends itself. The relationship between a deferred exception and a context switch cannot be controlled due to its asynchronous nature.

- **Floating-Point Exception Simulation**

SPARCmon is a product from Sun Microsystems that you can attach to the floating-point exception vectors to handle all exception cases for the SPARC. Any floating-point exceptions must be simulated by software and the queue flushed of all pending operations. This simulation fixes the error that caused the exception whenever possible, or takes some default action (for example, suspends the task).

Stack Pointer Usage

Because the stack pointer can advance without stack memory actually being written or read, it is possible for the stack high water marker to appear below the current stack pointer. In other words, current stack usage can be greater than the high stack usage. This is an artifact of the SPARC architecture's rolling register windows.

The stack pointer is used very little. The local and output registers in each register window perform the bulk of stack operations. The stack is used for long argument lists, or if a window overflow exception pushes registers onto the stack.

SPARClite Overview

All information pertaining to the SPARC applies to the SPARClite, with the addition of the architectural enhancements described in the following subsections.

Instruction and Data Cache Locking

The SPARClite allows the global and local locking of the instruction and data caches. The ability to lock instructions and/or data in the caches allows for higher performance and more deterministic systems. The locking must be done in such a way that overall system performance is improved, not degraded. For a better real-time system, call ***cacheMb930LockAuto*( )** to enable instruction and data cache locking. After the caches are locked, they cannot be unlocked or disabled.

To enhance performance, some of the VxWorks kernel data items are locked in the data cache. This uses approximately 128 bytes. The remainder of the data cache is available to the developer. Additional data can be locked in the cache using the BSP.

USS Floating-Point Emulation Library

The SPARClite does not have a floating-point coprocessor; thus, the USS floating-point emulation library is used. Using the **-msparclite** compile flag allows this library to be accessed by your code for floating-point calculations.

Memory Layout

The memory layout of both the SPARC and SPARClite processors is shown in Figure B-1. The memory layout of the microSPARC processor is in Figure B-2. These figures contain the following labels:

SM Anchor	Anchor for the shared memory network (if there is shared memory on the board).
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of the fatal exception message.
Interrupt Vector Table	Table of exception/interrupt vectors.
Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.
System Image	Entry point for VxWorks.
WDB Memory Pool	Size depends on the macro **WDB_POOL_SIZE** which defaults to one-sixteenth of the system memory pool. This space is used by the target server to support host-based tools. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
Interrupt Stack	Size is defined by **ISR_STACK_SIZE** under **INCLUDE_KERNEL**. Location depends on system image size.
System Memory Pool	Size depends on size of system image and interrupt stack. The end of the free memory pool for this board is returned by ***sysMemTop*( )**.

All addresses shown are relative to the start of memory for a particular target board. The start of memory (corresponding to 0x0 in the memory-layout diagram) is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

Figure B-1 **VxWorks System Memory Layout (SPARC/SPARClite)**

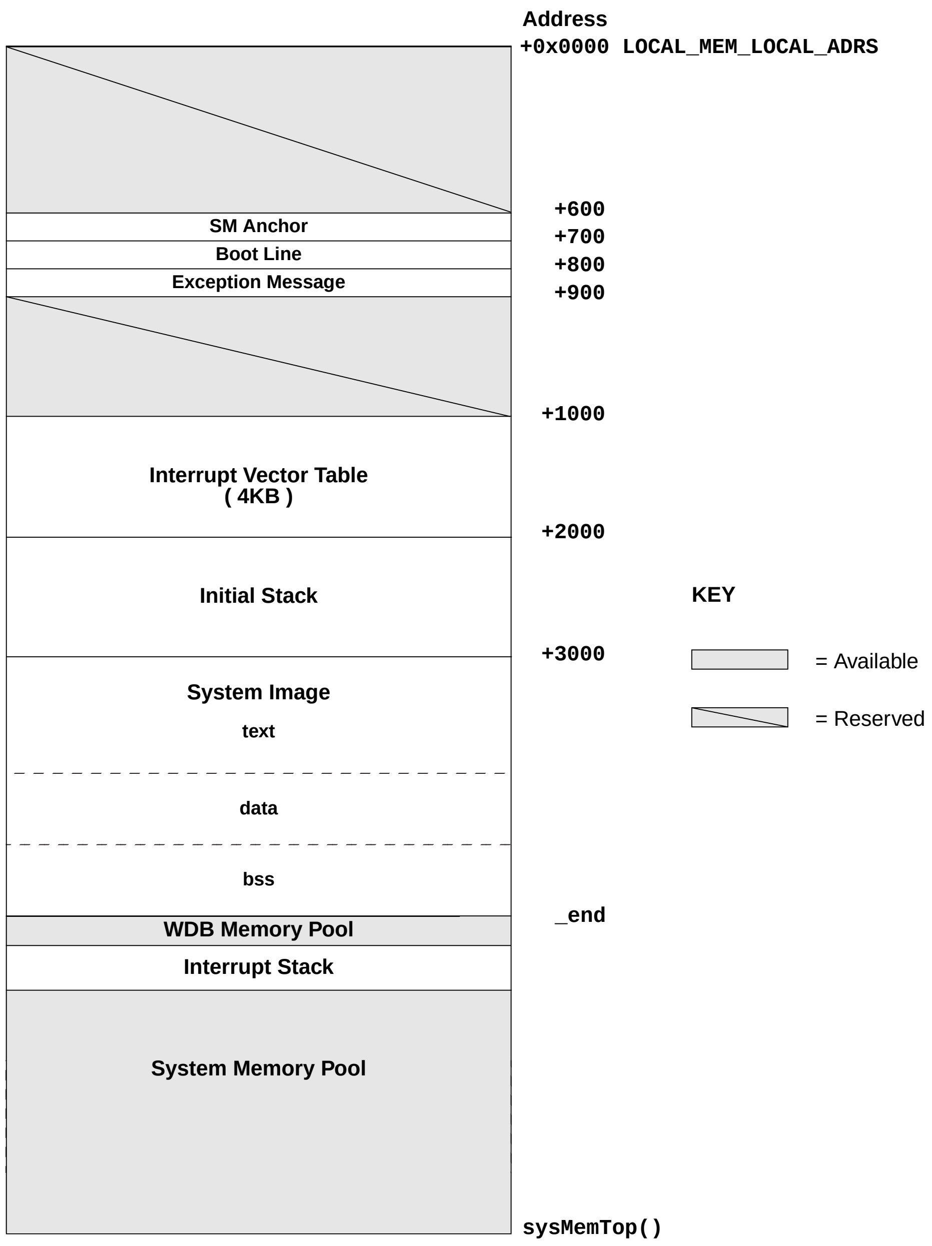
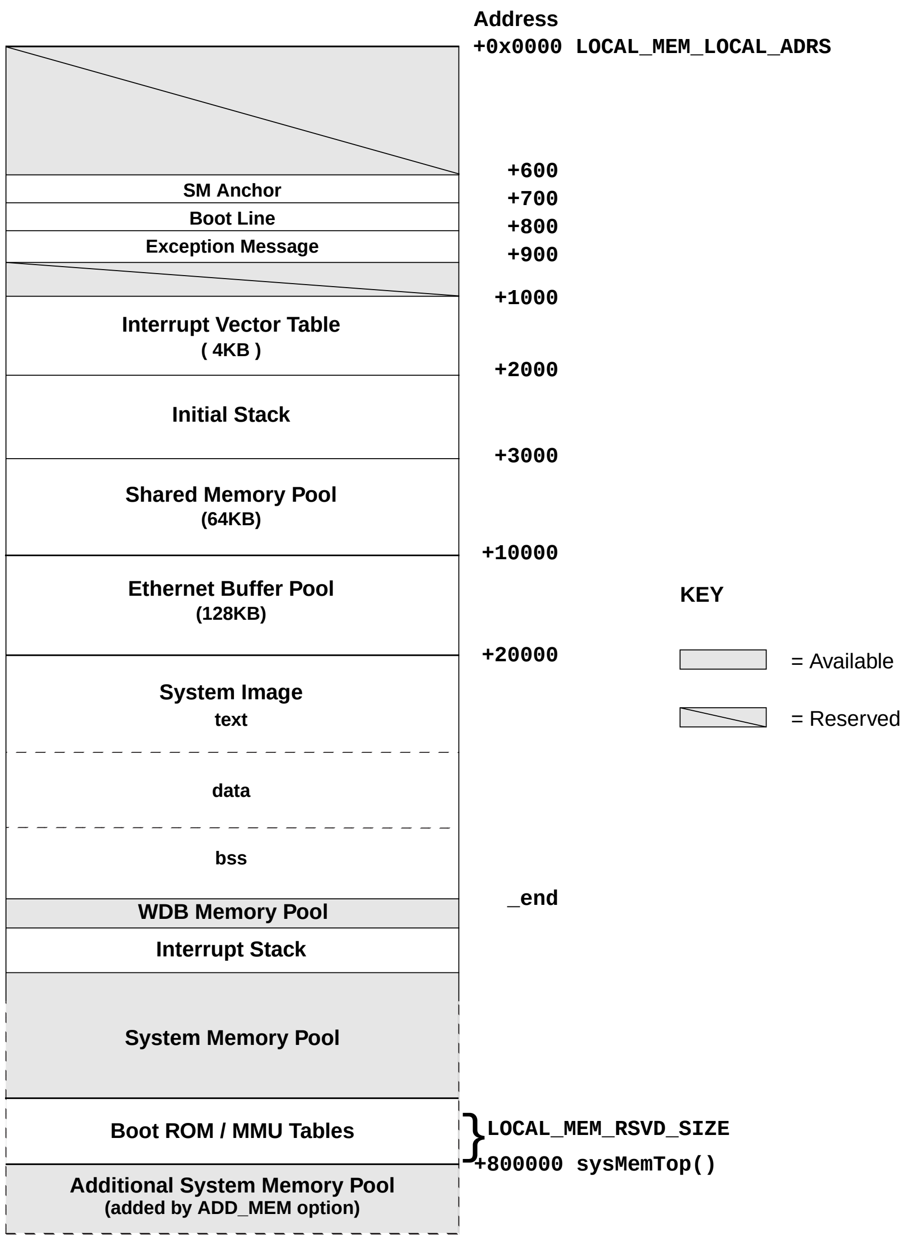


Figure B-2 **VxWorks System Memory Layout (microSPARC I & II)**



C
Intel i960

C.1 Introduction

This appendix provides information specific to VxWorks development on Intel i960CA, JX, KA, and KB targets. It includes the following topics:

- Building Applications: how to compile modules for your target architecture.
- Interface Changes: information on changes or additions to particular VxWorks features to support the i960 processors.
- Architecture Considerations: special features and limitations of the i960 processors.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

C.2 Building Applications

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for i960 targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate architecture-specific features enabled. Define this variable to one of the following values, to match the processor you are using:

– **I960CA**
– **I960JX**
– **I960KA**
– **I960KB**

For example, to define **CPU** for a i960CA on the compiler command line, specify the following command-line option when you invoke the compiler:

```
-DCPU=I960CA
```

To provide the same information in a header or source file instead, include the following line in the file:

```
#define CPU I960CA
```

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. Tornado is configured to use these tools by default. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables.

Compiling C or C++ Modules

The following is an example of a compiler command line for i960 cross-development. The file to be compiled in this example has a base name of **applic**.

```
% cc960 -fno-builtin -I $WIND_BASE/target/h -0 -c -mca\
-mstrict-align -fvolatile -nostdinc -DCPU=I960CA applic.c
```

The options shown in the example have the following meanings:[1]

1. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; a list of these options is included in the *Guide*. Other options are not supported, although they are available with the tools as shipped.

-fno-builtin
Required; uses library calls even for common library subroutines.

-I $WIND_BASE/target/h
Required; includes VxWorks header files. (Additional **-I** flags may be included to specify other header files.)

-O Optional; performs standard optimization.

-c Required; specifies that the module is to be compiled only, and not linked for execution under the host.

-mca
Required for i960CA and i960JX; specifies the instruction set. For the i960KA and KB, use **-mka** and **-mkb**, respectively.

-mstrict-align
Required; do not permit unaligned accesses.

-fvolatile
Required; consider all memory references through pointers to be volatile.

-nostdinc
Required; searches only the directory(ies) specified with the **-I** flag (see above) and the current directory for header files. Does not search host-system include files.

-DCPU=I960CA
Required; defines the CPU type. If you are using an i960 processor other than the CA, specify the appropriate value (see *Defining the CPU Type*, p.418).

applic.*language_id*
Required; the file(s) to compile. For C compilation, specify a suffix of **.c**. For C++ compilation, specify a suffix of **.cpp**. The output is an unlinked object module in **COFF** format with the suffix **.o**; for the example, the output is **applic.o**.

During C++ compilation, the compiled object module (**applic.o**) is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks run-time support can use to call the objects' constructors and destructors. For details, see the *VxWorks Programmer's Guide: C++ Development*.

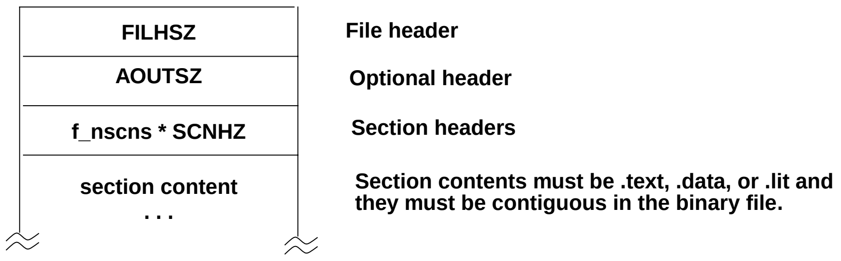
Boot Loader Changes

The target-resident loader for i960 targets loads **COFF** format VxWorks images which are composed of multiple text sections and multiple data sections. The ability to load **COFF** files with multiple text and data sections facilitates the use of linker scripts which scatter-load the VxWorks image at boot time. In addition, because the number of relocation entries for any particular **COFF** section may not exceed 65,535 entries, it may be necessary to split very large images into multiple sections.

It is assumed that users implementing linker scripts are comfortable with the GNU linker, the GNU linker command language, the particular OMF used by the GNU tools, and the target memory architecture. In addition to the aforementioned requisite background, the target-resident loader implementation places certain restrictions on how fully-linked **COFF** files (for example, a VxWorks image) are organized.

The target-resident loader assumes that a **COFF** format VxWorks image is ordered such that the **COFF** file header, optional header, and section headers are followed immediately by the section contents for text, data, or lit sections in the binary file. Moreover, it is assumed that the section contents are contiguous in the binary file. Figure C-1 shows typical headers in the binary file.

Figure C-1 **COFF File Headers**


FILHSZ
AOUTSZ
f_nscns * SCNHZ
section content
. . .
File header
Optional header
Section headers
Section contents must be .text, .data, or .lit and they must be contiguous in the binary file.

The fact that text, data, and lit sections must be contiguous with each other and follow the section headers in the binary file does not preclude using a linker script to locate multiple text and data sections at non-contiguous RAM addresses. For more information on the GNU linker and GNU linker command language, see the *GNU ToolKit User's Guide*.

The target-resident loader for i960 reports the sizes of individual text and data sections in addition to the bss section when VxWorks is booted. For example, if a multiple text section image is booted, output similar to the following might be seen:

```
Attaching network interface oli0... done.
Attaching network interface lo0... done.
Loading... 277764 + 82348 + 66664 + 7948 + 29692
Starting at 0x1000...

Attached TCP/IP interface to oli unit 0
Attaching network interface lo0... done.
NFS client support not included.

               VxWorks

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           CPU: Cyclone EP960Cx
       VxWorks: 5.4
   BSP version: 1.2/0
 Creation date: Feb 10 1999
           WDB: Ready.
```

This format is a slight cosmetic modification to the section size values which WRS boot loaders have traditionally reported as *size of text + size of data + size of bss*. Reporting the size of individual text and data sections rather than summing them up is intended to be an aid for developers working on VxWorks images which are organized by way of a linker script. This change is not likely to be noticed when the default VxWorks image types are used.

C.3 Interface Variations

This section describes particular routines that are specific to i960 targets in any of the following ways:

- available only on i960 targets
- parameters specific to i960 targets
- special restrictions or characteristics on i960 targets

For complete documentation on these routines, see the reference entries.

Initialization

There are several differences in what ***sysInit*( )** initializes and in the initialization sequence on i960 targets.

Differences in *sysInit*( ) Routine

For the i960, the ***sysInit*( )** routine initializes the system interrupt and fault tables with default stubs, in addition to its standard functions.

ROM-Based VxWorks with i960 Targets

As with other target architectures, the routines ***romInit*( )** and ***romStart*( )** execute first. Then initialization continues at the ***sysInit*( )** call, rather than with the ***usrInit*( )** call as for other ROM-based targets.

Data Breakpoint Routine bh( )

In addition to being able to break at an instruction with ***b*( )**, the i960CA permits breakpoints at a data address using ***bh*( )**. For more information, see the reference entry for ***bh*( )**. For example, the following command from the VxWorks shell causes a data breakpoint on any access to data address 0xFFFF:

```
-> bh 0xFFFF, 3
```

⚠ **CAUTION:** The ***bh*( )** routine does not work reliably on instruction fetches; use ***b*( )** to break on instructions.

The delete-breakpoint routines, ***bd*( )** and ***bdall*( )**, delete both instruction and data breakpoints. Only two data breakpoints can be present in the system at one time.

Parameter Change for intLevelSet( )

The i960 version of ***intLevelSet*( )** takes an argument from 0 to 31. Level 31 is equivalent to locking all interrupts.

Results Change for **memLib**

In VxWorks for the i960, the library **memLib** forces both partitions and blocks returned by ***malloc*( )** to be 16-byte aligned.

Math Routines

Mathematics routines using software floating-point emulation are part of the GNU/960 distribution from Cygnus, in the libraries **libm.a**, **libg.a**, and **libgcc.a**. The location of these libraries is described in *installDir*/**target/h/make/make.I960***xx***gnu** by the variable **LIBS** (where *xx* identifies libraries specific to the CA, JX, KA, or KB variant of the i960 architecture).

The following double-precision floating-point routines are included in the GNU/960 distribution from Cygnus:

***acos*( )**	***asin*( )**	***atan*( )**	***atan2*( )**	***ceil*( )**	***cos*( )**	***cosh*( )**
***exp*( )**	***fabs*( )**	***floor*( )**	***fmod*( )**	***log*( )**	***log10*( )**	***log2*( )**
***pow*( )**	***sin*( )**	***sinh*( )**	***sqrt*( )**	***tan*( )**	***tanh*( )**	

The following single-precision floating-point routines are also available:

***atanf*( )**	***atan2*( )**	***ceilf*( )**	***expf*( )**
***fabsf*( )**	***floorf*( )**	***logf*( )**	***log2f*( )**
***powf*( )**	***sinf*( )**	***sqrtf*( )**	***tanf*( )**

Adding in Unresolved Routines

Occasions can arise when an application requires **libm.a**, **libg.a**, and **libgcc.a** routines, although the application has *not* been prelinked with the VxWorks image. There are several alternatives for dealing with this situation:

- You can compile and link a set of dummy calls with VxWorks to ensure that the necessary routines are included in the VxWorks image.
- You can explicitly link the appropriate archive with your application module by using **ld960**.
- You can add any unresolved reference symbols to *installDir*/**target/src/config/mathInit.c** and rebuild VxWorks.

Floating-Point Task Option: VX_FP_TASK

The i960CA, JX, and KA processors contain no floating-point hardware; thus no floating-point context is used. Floating-point emulation is performed in software with the routines provided by the Cygnus libraries (see *Math Routines*, p.423); therefore, the task option **VX_FP_TASK** is not required.

The i960KB has on-board floating-point hardware. The task option **VX_FP_TASK** is required when spawning tasks on the i960KB processor.

COFF-Specific Tools For i960

The following tools are specific to the **COFF** format on i960 processors. For more information, see the reference entries for each tool.

coffHex960
converts an **COFF**-format object file into Motorola hex records. The syntax is:

> **`coffHex960 [-[TD]`***imifile*, *offset*] **`[-a`** *offset*] **`[-l]`** *file*

coffToBin
extracts text and data segments from a **COFF** file and writes it to standard output as a simple binary image. The syntax is:

> **`coffToBin <`** *inFile* **`>`** *outfile*

xsymc
extracts the symbol table from a **COFF** file. The syntax is:

> **`xsymc <`** *objMod* **`>`** *symTbl*

Limitation on d( ) in WindSh

On i960 targets not all memory is accessible from the host shell. For example, if there is no PCI bus on an ep960cx board, addresses 0x10000000 to 0x 9fffffff are not accessible. Although a ***d*( )** command from the target shell can access this region, the same command from the host can not. This is because the host shell ***d*( )** command verifies the memory using ***vxMemProbe*( )** before displaying it, while the target shell ***d*( )** command does not.

A further complication occurs with ev960 boards. ***vxMemProbe*( )** uses the bus error signal to detect whether a region of memory is accessible or not. If this signal is not present, as it is not on ev960 boards, ***vxMemProbe*( )** uses ***sysProbeMem*( )** to detect whether the requested address is valid or not. ***sysProbeMem*( )** determines whether an address is between **LOCAL_MEM_LOCAL_ADRS** and **sysPhysMemTop** or not. This means that if you want to access a new address on ev960 boards, for example because you added a new component, you must modify ***sysProbeMem*( )** so that it considers your new memory zone valid.

C.4 Architecture Considerations

This section describes the following characteristics of the i960 architecture that you should keep in mind as you write a VxWorks application:

- Byte order
- Double-word Integers
- VMEbus interrupt handling
- Memory layout

Byte Order

The i960 architecture uses little-endian byte order. For information about macros and routines to convert byte order (from big-endian to little-endian and vice versa), see *VxWorks Network Programmer's Guide: TCP/IP Under VxWorks*.

The VxWorks loader allows object module headers to be in either big-endian or little-endian byte order. Host utility programs can use the most convenient byte order to process i960 objects. Object file text and data segments must be little endian for i960 processors.

Double-word Integers: **long long**

The double-word integer **long long** is not supported, except as an artifact of your particular architecture and compiler. For more information about handling unsupported features, please see the *Customer Support User's Guide*.

VMEbus Interrupt Handling

The i960 uses 31 interrupt levels instead of the seven used by VMEbus. The mapping of the seven VMEbus interrupts to the 31 i960 levels is board dependent. VMEbus interrupts must be acknowledged with ***sysBusIntAck*( )**. VxWorks does not use the vector submitted by the interrupting device. For more information, see the file *installDir***/target/h/arch/i960/ivI960.h**.

Memory Layout

The figures on the following pages show the layout of a VxWorks system in memory for various target architectures. Areas contain the following labels:

Interrupt Vector Table	Table of exception/interrupt vectors.
SM Anchor	Anchor for the shared memory network (if there is shared memory on the board).
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of the fatal exception message.
Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.
System Image	Entry point for VxWorks.
WDB Memory Pool	Size depends on the macro **WDB_POOL_SIZE** which defaults to one-sixteenth of the system memory pool. This space is used by the target server to support host-based tools. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
Interrupt Stack	Location depends on system image size. Size is defined by **ISR_STACK_SIZE** under **INCLUDE_KERNEL**.
System Memory Pool	Size depends on size of system image and interrupt stack. The end of the free memory pool for this board is returned by ***sysMemTop*( )**.

Figure C-2 shows the memory layout for an i960CA target; Figure C-3 shows the memory layout for an i960JX target; Figure C-4 shows the memory layout for an i960KA or i960KB target.

All addresses shown in these figures are relative to the start of memory for a particular target board. The start of memory (corresponding to 0x0 in the memory-layout diagram) is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

Figure C-2 **VxWorks System Memory Layout (i960CA)**

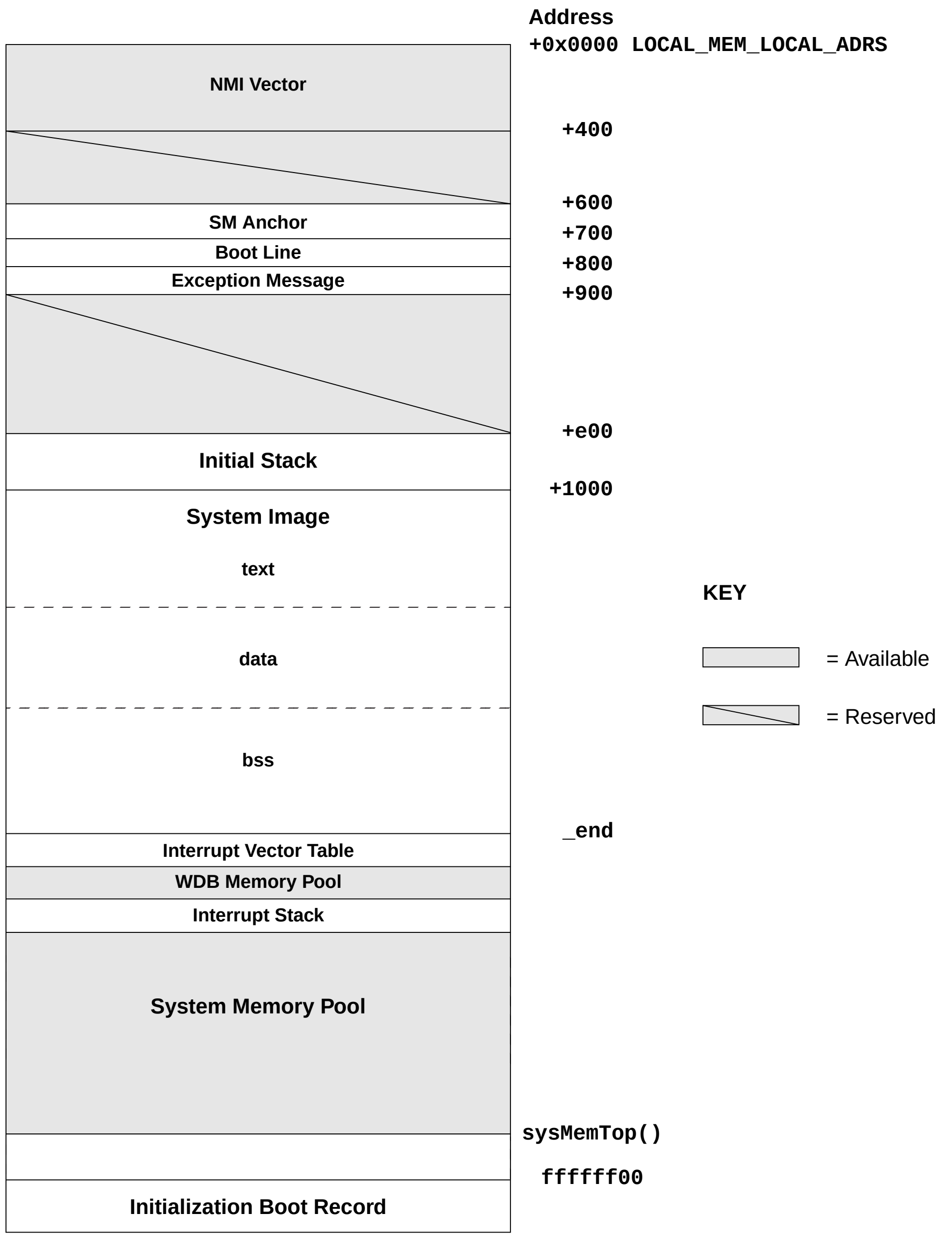


Figure C-3 **VxWorks System Memory Layout (i960JX)**

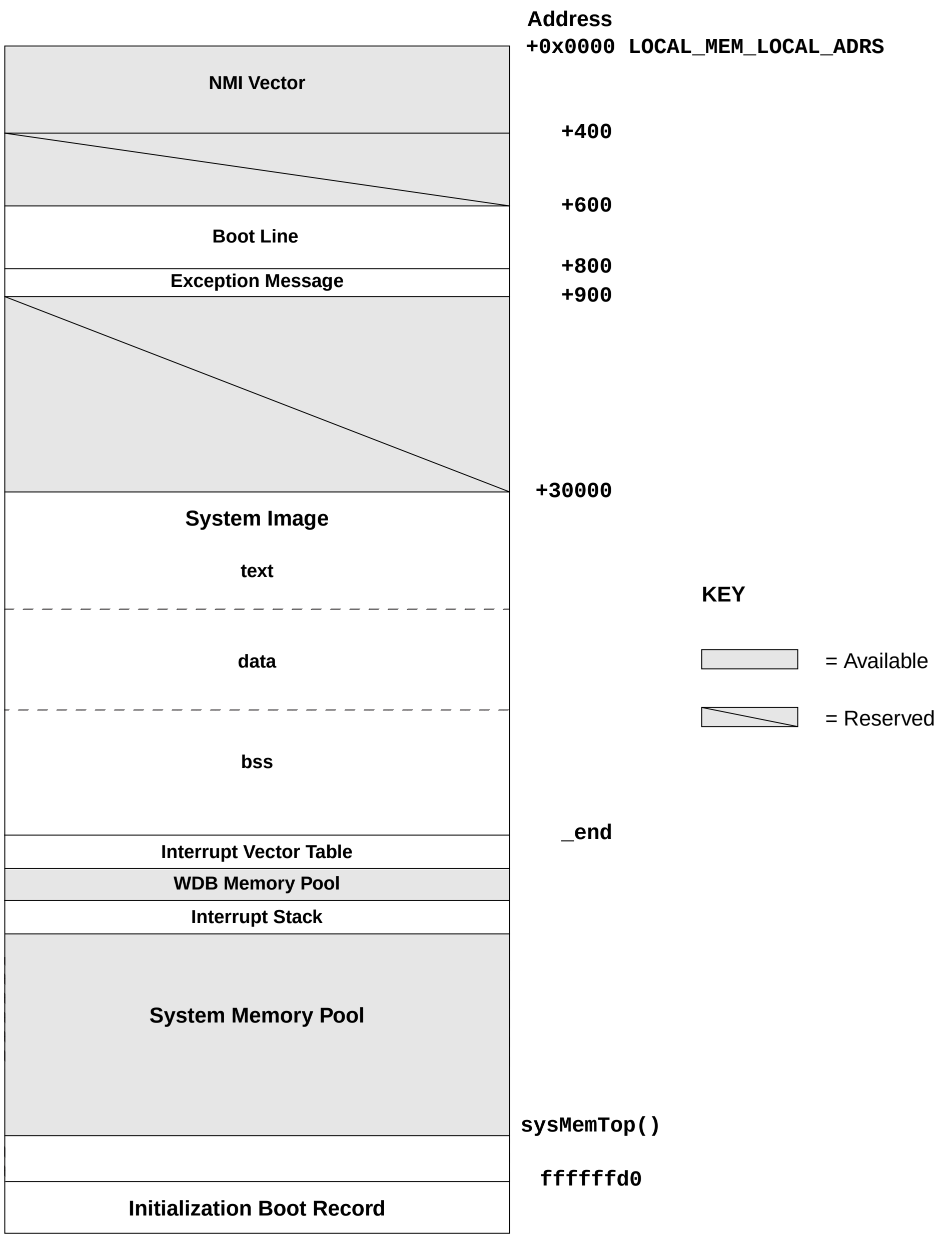
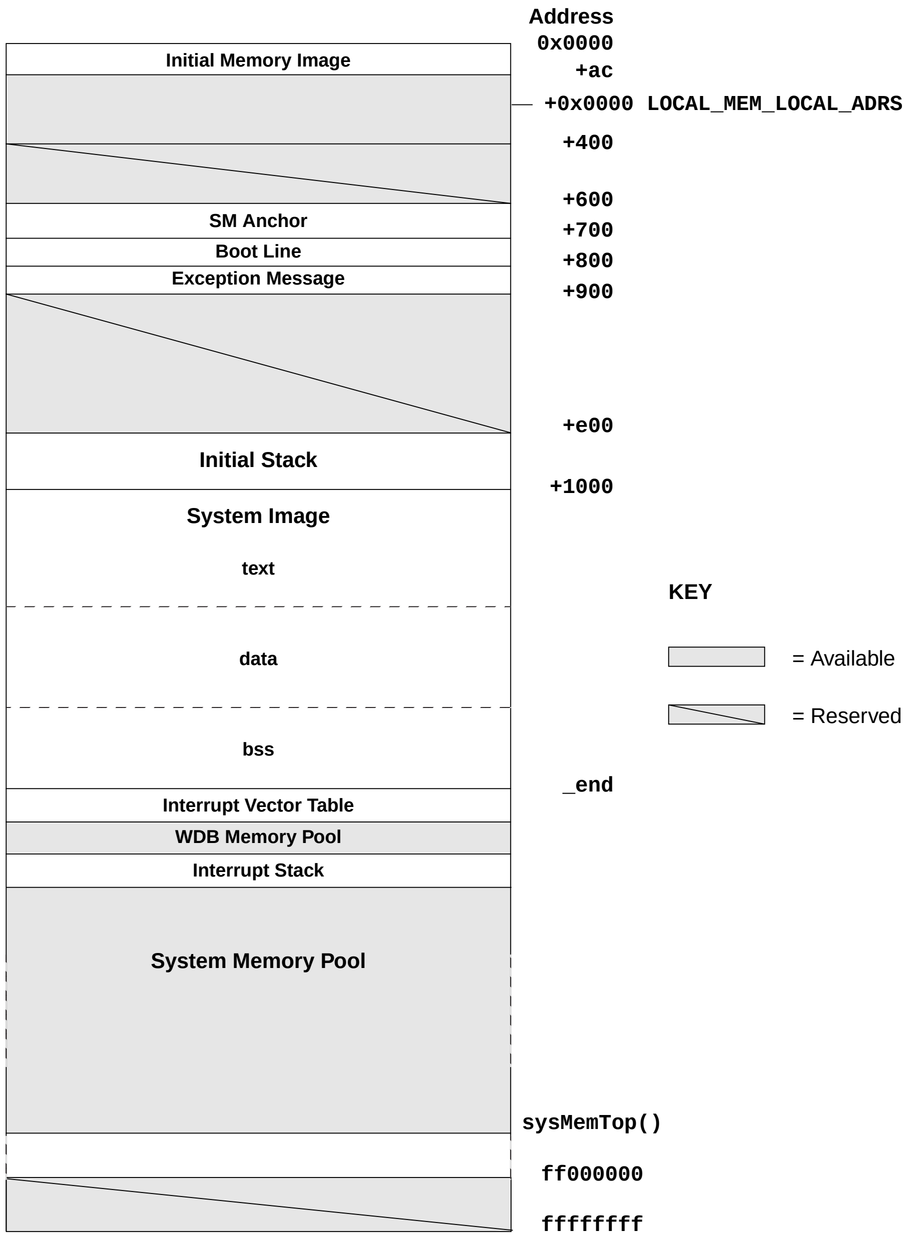


Figure C-4 **VxWorks System Memory Layout (i960KA and i960KB)**



D
Intel x86

D.1 Introduction

This appendix provides information specific to VxWorks development on Intel i386, i486, Pentium, and PentiumPro (x86) targets. It includes the following topics:

- Building Applications: how to compile modules for your target architecture.
- Interface Changes: information on changes or additions to particular VxWorks features to support the x86 processors.
- Architecture Considerations: special features and limitations of the x86 processors.
- Board Support Packages: information on specific BSPs and device drivers.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

D.2 Building Applications

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for x86 targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate architecture-specific features enabled. Define this variable to either **I80386**, **I80486**, or **PENTIUM** to match the processor you are using.

For example, to define **CPU** for an i386 on the compiler command line, specify the following command-line option when you invoke the compiler:

```
-DCPU=I80386
```

To provide the same information in a header or source file, include the following line in the file:

```
#define CPU I80386
```

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. Tornado is configured to use these tools by default. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables.

Compiling C and C++ Modules

The following is an example of a compiler command line for Intel x86 cross-development. The file to be compiled in this example has the base name of **applic**.

```
% cc386 -DCPU=I80386 -I $WIND_BASE/target/h -fno-builtin -0 \
-mno-486 -fno-defer-pop -nostdinc -c applic.lang_id
```

The options shown in the example have the following meanings:[1]

1. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; a list of these options is included in the *Guide*. Other options are not supported, although they are available with the tools as shipped.

cc386
Required; use **cc386** for all supported x86 processors.

-DCPU=I80386
Required; defines the CPU type for the i386. If you are using another CPU type, specify the appropriate value (see *Defining the CPU Type*, p.432).

-I $WIND_BASE/target/h
Required; includes VxWorks header files. (Additional **-I** flags may be included to specify other header files.)

-fno-builtin
Required; uses library calls even for common library routines.

-O
Optional; performs standard optimizations. Note that optimization is not supported for the Pentium.

-mno-486
Required for the i386; generates optimized code for the i386. For the i486, the compiler automatically generates optimized code; no additional flags are required.

-fno-defer-pop
Required; pops the arguments to each subroutine call as soon as that subroutine returns.

-nostdinc
Required; searches only the directory(ies) specified with the **-I** flag (see above) and the current directory for header files. Does not search host-system include files.

-fvolatile
Optional; considers all memory references through pointers to be volatile.

-c
Required; specifies that the module is to be compiled only, and not linked for execution under the host.

applic.*lang_id*
Required; the file(s) to compile. For C compilation, specify a suffix of **.c**. For C++ compilation, specify a suffix of **.cpp**. The output is an unlinked object module in **a.out** format with the suffix **.o**; for the example, the output is **applic.o**.

During C++ compilation, the compiled object module (**applic.o**) is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks run-time support can use to call the objects' constructors and destructors. For details, see the *VxWorks Programmer's Guide: C++ Development*.

D.3 Interface Variations

This section describes particular features and routines that are specific to x86 targets in any of the following ways:

- available only for x86 targets
- parameters specific to x86 targets
- special restrictions or characteristics on x86 targets

For complete documentation, see the reference entries.

Supported Routines in **mathALib**

For x86 targets, the following floating-point routines are supported. These routines are also available without a hardware floating-point processor by selecting **INCLUDE_SW_FP** for inclusion in the project facility VxWorks view. For more information about configuring the software floating-point emulation library, see *Software Floating-Point Emulation*, p. 448. See **mathALib** and the individual manual entries for descriptions of each routine.

***acos*( )**	***asin*( )**	***atan*( )**	***atan2*( )**	***ceil*( )**	***cos*( )**
***exp*( )**	***fabs*( )**	***floor*( )**	***fmod*( )**	***infinity*( )**	***irint*( )**
***iround*( )**	***log*( )**	***log10*( )**	***log2*( )**	***pow*( )**	***round*( )**
***sin*( )**	***sincos*( )**	***sqrt*( )**	***tan*( )**	***trunc*( )**	

Architecture-Specific Global Variables

The file **sysLib.c** contains the global variables shown in Table D-1.

Table D-1 **Architecture-Specific Global Variables**

Global Variable	Value	Description
sysVectorIRQ0	0x20 (default)	A mapping of the base vector for IRQ0.
sysIntIdtType	0x0000fe00 (default) = trap gate 0x0000ee00 = interrupt gate	Used when VxWorks initializes the interrupt vector table. The choice of trap gate vs. interrupt gate affects all interrupts (vectors 0x20 through 0xff).
sysGDT[]	0x3ff limit (default)	The Global Descriptor Table has five entries. The first is a null descriptor. The second and third are for task-level routines. The fourth is for interrupt-level routines. The fifth is reserved.
sysProcessor	0 = i386 1 = i486 2 = Pentium 4 = PentiumPro	The processor type (set by VxWorks).
sysCoprocessor	0 = no coprocessor 1 = 387 coprocessor 2 = 487 coprocessor	The type of floating-point coprocessor (set by VxWorks).

Architecture-Specific Routines

Register Routines

The following routines read x86 register values, and require one parameter, the task ID:

***eax*( )**	***ebx*( )**	***ecx*( )**	***edx*( )**	***edi*( )**
***esi*( )**	***ebp*( )**	***esp*( )**	***eflags*( )**	

Table D-2 shows additional architecture-specific routines. Other architecture-specific routines are described throughout this section.

Table D-2 **Architecture-Specific Routines**

Routine	Function Header	Description
pentiumBts( )	`STATUS pentiumBts (char * pFlag)`	Execute an atomic compare-and-exchange instruction to set a bit. (Pentium and PentiumPro.)
pentiumBtc( )	**STATUS pentiumBtc (pFlag) (char * pFlag)**	Execute an atomic compare-and-exchange instruction to clear a bit. (Pentium and PentiumPro.)
pentiumMcaShow	**void pentiumMcaShow (void)**	Show machine check global control registers and error reporting register banks.
pentiumMsrGet( )	**void pentiumMsrGet (int address, long long int * pData)**	Get the contents of the specified MSR. (PentiumPro)
pentiumMsrSet( )	**void pentiumMsrSet (int address, long long int * pData)**	Set the value of the specified MSR. (PentiumPro)
pentiumMtrrEnable( )	**void pentiumMtrrEnable (void)**	Enable MTRR. (PentiumPro)
pentiumMtrrDisable( )	**void pentiumMtrrDisable (void)**	Disable MTRR. (PentiumPro)
pentiumMtrrGet( )	**void pentiumMtrrGet (MTRR * pMtrr)**	Get MTRRs to the MTRR table specified by the pointer. (PentiumPro)
pentiumMtrrSet( )	**void pentiumMtrrSet (void) (MTRR * pMtrr)**	Set MTRRs from the MTRR table specified by the pointer. (PentiumPro)
pentiumPmcStart( )	STATUS **pentiumPmcStart (int pmcEvtSel0; int pmcEvtSel1;)**	Start PMC0 and PMC1. (PentiumPro)
pentiumPmcStop( )	**void pentiumPmcStop (void)**	Stop PMC0 and PMC1. (PentiumPro)
pentiumPmcStop1( )	**void pentiumPmcStop1 (void)**	Stop PMC1 only. (PentiumPro)

Table D-2 **Architecture-Specific Routines** *(Continued)*

Routine	Function Header	Description
pentiumPmcGet( )	**void pentiumPmcGet (long long int * pPmc0; long long int * pPmc1;)**	Get the contents of PMC0 and PMC1. (PentiumPro)
pentiumPmcGet0( )	**void pentiumPmcGet0 (long long int * pPmc0)**	Get the contents of PMC0. (PentiumPro)
pentiumPmcGet1( )	**void pentiumPmcGet1 (long long int * pPmc1)**	Get the contents of PMC1. (PentiumPro)
pentiumPmcReset( )	**void pentiumPmcReset (void)**	Reset PMC0 and PMC1. (PentiumPro)
pentiumPmcReset0( )	**void pentiumPmcReset0 (void)**	Reset PMC0. (PentiumPro)
pentiumPmcReset1( )	**void pentiumPmcReset1 (void)**	Reset PMC1. (PentiumPro)
pentiumSerialize( )	**void pentiumSerialize (void)**	Serialize by executing the CPUID instruction. (Pentium and PentiumPro.)
pentiumPmcShow( )	**void pentiumPmcShow (BOOL zap)**	Show PMC0 and PMC1, and reset them if the parameter zap is TRUE. (Pentium and PentiumPro.)
pentiumTlbFlush( )	**void pentiumTlbFlush (void)**	Flush the TLBs (Translation Lookaside Buffers). (Pentium and PentiumPro.)
pentiumTscReset( )	**void pentiumTscReset (void)**	Reset the TSC. (PentiumPro)
pentiumTscGet32( )	**void pentiumTscGet32 (void)**	Get the lower half of the 64-bit TSC. (PentiumPro)
pentiumTscGet64( )	**void pentiumTscGet64 (long long int * pTsc)**	Get the 64-bit TSC. (PentiumPro)
sysCpuProbe( )		Use CPUID to get information about the CPU.
sysInByte( )	**UCHAR sysInByte (int port)**	Read one byte from I/O.
sysInWord( )	**USHORT sysInWord (int port)**	Read one word (two bytes) from I/O.
sysInLong( )	**ULONG sysInLong (int port)**	Read one long word (four bytes) from I/O.

Table D-2 **Architecture-Specific Routines** *(Continued)*

Routine	Function Header	Description
***sysOutByte*( )**	**void sysOutByte (int port, char data)**	Write one byte to I/O.
***sysOutWord*( )**	**void sysOutWord (int port, short data)**	Write one word (two bytes) to I/O.
***sysOutLong*( )**	**void sysOutLong (int port, long data)**	Write one long word (four bytes) to I/O.
***sysInWordString*( )**	**void sysInWordString (int port, short *address, int count)**	Read word string from I/O.
***sysInLongString*( )**	**void sysInLongString (int port, short *address, int count**	Read long string from I/O.
***sysOutWordString*( )**	**void sysOutWordString (int port, short *address, int count)**	Write word string to I/O.
***sysOutLongString*( )**	**void sysOutLongString (int port, short *address, int count)**	Write long string to I/O.
***sysDelay*( )**	**void sysDelay (void)**	Allow enough recovery time for port accesses.
***sysIntDisablePIC*( )**	**STATUS sysIntDisablePIC (int intLevel)**	Disable a Programmable Interrupt Controller (PIC) interrupt level.
***sysIntEnablePIC*( )**	**STATUS sysIntEnablePIC (int intLevel)**	Enable a PIC interrupt level.
***sysCpuProbe*( )**	**UINT sysCpuProbe (void)**	Check for type of CPU (i386, i486, or Pentium).

Breakpoints and the *bh*( ) Routine

VxWorks for the x86 supports both software and hardware breakpoints. When you set a software breakpoint, VxWorks replaces an instruction with an **int 3** software interrupt instruction. VxWorks restores the original code when the breakpoint is removed. The instruction queue is purged each time VxWorks changes an instruction to a software break instruction.

A hardware breakpoint uses the processor's debug registers to set the breakpoint. The x86 architectures have four breakpoint registers. If you are using the target shell, you can use the ***bh*( )** routine to set hardware breakpoints. The routine is declared as follows:

```
STATUS bh
    (
    INSTR        *addr,        /* where to set breakpoint, or       */
                               /* 0 = display all breakpoints      */
    int          task,         /* task to set breakpoint;           */
                               /* 0 = set all tasks                */
    int          count,        /* number of passes before hit       */
    int          type,         /* breakpoint type; see below       */
    INSTR        *addr0        /* ignored for x86 targets          */
    )
```

The ***bh*( )** routine takes the following types in parameter *type*:

BRK_INST	Instruction hardware breakpoint (0x1000)
BRK_DATAW1	Data write 1-byte breakpoint (0x1400)
BRK_DATAW2	Data write 2-byte breakpoint (0x1500)
BRK_DATAW4	Data write 4-byte breakpoint (0x1700)
BRK_DATARW1	Data read-write 1-byte breakpoint (0x1c00)
BRK_DATARW2	Data read-write 2-byte breakpoint (1d00)
BRK_DATARW4	Data read-write 4-byte breakpoint (1f00)

Disassembler: ***l*( )**

If you are using the target shell, note that the VxWorks disassembler ***l*( )** does not support 16-bit code compiled for earlier generations of 80*x*86 processors. However, the disassembler does support 32-bit code for both the i386 and i486 processors.

***vxMemProbe*( )**

The ***vxMemProbe*( )** routine, which probes an address for a bus error, is supported on the x86 architectures by trapping both general protection faults and page faults.

a.out-Specific Tools for x86

The following tools are specific to the **a.out** format for x86 processors and the PC simulator. For more information, see the reference entries for each tool.

hexDec

converts an **a.out**-format object file into Motorola hex records. The syntax is:

hexDec [-a *adrs*] **[-l] [-v] [-p** *PC*] **[-s** *SP*] *file*

aoutToBinDec

extracts text and data segments from an **a.out** file and writes it to standard output as a simple binary image. The syntax is:

aoutToBinDec < *inFile* **>** *outfile*

xsymDec

extracts the symbol table from an **a.out** file. The syntax is:

xsymDec < *objMod* **>** *symTbl*

D.4 Architecture Considerations

This section describes the following characteristics of the Intel x86 architectures that you should keep in mind as you write a VxWorks application:

- Operating mode, privilege protection, and byte order
- Memory segmentation and the MMU
- I/O and memory mapped devices
- Memory considerations for VME
- Interrupts and exceptions
- Registers
- Counters
- Context switching
- ISA/EISA bus
- PC104 bus
- PCI bus
- Software floating-point emulation
- VxWorks memory layout

Consult Intel's *Intel486 Microprocessor Family Programmer's Reference Manual* for details on the x86 architectures.

Operating Mode, Privilege Protection, and Byte Order

VxWorks for the x86 runs in the 32-bit protected mode.

No privilege protection is used, thus there are no call gates. The privilege level is always 0, the most privileged level (Supervisor mode).

The x86 byte order is little-endian, but network applications must convert some data to a standard network order, which is big-endian. In particular, in network applications, be sure to convert the port number to network byte order using ***htons*( )**.

See *VxWorks Network Programmer's Guide: TCP/IP under VxWorks* for more information about macros and routines to convert byte order (from little-endian to big-endian or vice versa).

Memory Segmentation

The Intel x86 processors support both I/O-mapped devices and memory-mapped devices.

I/O Mapped Devices

For I/O mapped devices, developers may use the following routines from *installDir***/target/config/***bspName***/sysALib.s**:

***sysInByte*( )**	– input one byte from I/O space
***sysOutByte*( )**	– output one byte to I/O space
***sysInWord*( )**	– input one word from I/O space
***sysOutWord*( )**	– output one word to I/O space
***sysInLong*( )**	– input one long word from I/O space
***sysOutLong*( )**	– output one long word to I/O space
***sysInWordString*( )**	– input a word string from I/O space
***sysOutWordString*( )**	– output a word string to I/O space
***sysInLongString*( )**	– input a long string from I/O space
***sysOutLongString*( )**	– output a long string to I/O space

Memory Mapped Devices

For memory mapped devices, there are two kinds of memory protection provided by VxWorks: the Memory Management Unit and the Global Descriptor Table.

Because VxWorks operates at the highest processor privilege level, no "protection rings" exist.

The x86 processors allow you to configure the memory space into valid and invalid areas, even under Supervisor mode. Thus, you receive a page fault only if the processor attempts to access addresses mapped as invalid, or addresses that have not been mapped. Conversely, if the processor attempts to access a nonexistent address space that has been mapped as valid, no page fault occurs.

Memory Management Unit (MMU)

If **INCLUDE_MMU_BASIC** is selected for inclusion in the project facility VxWorks view, then VxWorks enables the MMU with the **mmuPhysDesc[]** table which includes PCI memory mapping information. This is the default.

If you have other memory mapped devices and if **INCLUDE_MMU_BASIC** is included (the default), you may need to add your device address space into the MMU table by manually editing the MMU configuration structure **sysPhysMemDesc[]** in **sysLib.c**. For information on editing the **sysPhysMemDesc[]** structure, see *7.3 Virtual Memory Configuration*, p.290. Do not overlap any existing MMU entries, and be sure all entries are page aligned. We recommend that you also maintain a 1:1 correlation between virtual and physical memory, since VxWorks and all tasks use a common address space.

Attempts to access areas not mapped as valid in the MMU result in page faults.

⚠ **CAUTION:** The i386 MMU does not have write-protect capability.

PentiumPro MMU

PentiumPro's enhanced MMU supports two additional page attribute bits.

The global bit (G) indicates a global page when set. When a page is marked global and the page global enable (PGE) bit in register CR4 is set, the page-table or page-directory entry for the page is not invalidated in the TLB when register CR3 is loaded or a task switch occurs. This bit is provided to prevent frequently used pages (such as pages that contain kernel or other operating system or executive code) from being flushed from the TLB.

The page-level write-through/back bit (PWT) controls the write-through or write-back caching policy of individual pages or page tables. When the PWT bit is set, write-through caching is enabled for the associated page or page table. When the bit is clear, write-back caching is enabled for the associated page and page table.

The following macros describe these attribute bits in the physical memory descriptor table **sysPhysMemDesc[]** in **sysLib.c**.

VM_STATE_WBACK	use write-back cache policy for the page
VM_STATE_WBACK_NOT	use write-through cache policy for the page
VM_STATE_GLOBAL	set page global bit
VM_STATE_GLOBAL_NOT	not set page global bit

Support is provided for two page sizes, 4KB and 4MB. The linear address for 4KB pages is divided into three sections:

Page directory entry	bits 22 through 31
Page table entry	bits 12 through 21
Page offset	bits 0 through 11

The linear address for 4MB pages is divided into two sections:

Page directory entry	bits 22 through 31
Page offset	bits 0 through 21

The page size is configured using **VM_PAGE_SIZE**. The default is 4 KB pages. If you wish to reconfigure 4 MB pages, you must change **VM_PAGE_SIZE** in **config.h**. (See *8. Configuration and Build*.)

Global Descriptor Table (GDT)

The GDT is defined as the table **sysGDT[]** in **sysALib.s**. The table has five entries: a null entry, an entry for program code, an entry for program data, an entry for ISRs, and a reserved entry. It is initially set so that the available memory range is 0x0-0xffffffff. For boards that support PCI, **INCLUDE_PCI** is defined in **config.h** and VxWorks does not alter the pre-set memory range. This memory range is available at run-time with the MMU configuration.

If **INCLUDE_PCI** is not defined (the default for boards that do not support PCI), VxWorks adjusts the GDT using the ***sysMemTop*( )** routine to check the actual memory size during system initialization and set the table so that the available memory range is 0x0-**sysMemTop**. This causes a General Protection Fault to be generated for any memory access outside the memory range 0x0-**sysMemTop**.

Memory Considerations for VME

The global descriptors for x86 targets are configured for a flat 4GB memory space.

If you are running VxWorks for the x86 on a VME board, be aware that addressing nonexistent memory or peripherals does not generate a bus error or fault.

Interrupts and Exceptions

Interrupt Descriptor Table

The Interrupt Descriptor Table (IDT) occupies the address range 0x0 to 0x800 (also called the Interrupt Vector Table, see Figure D-2). Vector numbers 0x0 to 0x1f are handled by the default exception handler. Vector numbers 0x20 to 0xff are handled by the default interrupt handler.

By default, vector numbers 0x20 to 0x2f are mapped to IRQ levels 0 to 15. To redefine the base address, edit **sysVectorIRQ0** in **sysLib.c**.

For vector numbers 0x0 to 0x11, no task gates are used, only interrupt gates. By default, vector numbers 0x12 to 0xff are trap gates, but this can be changed by redefining the global variable **sysIntIdtType**.

The difference between an interrupt gate and a trap gate is its effect on the IF flag: using an interrupt gate clears the IF flag, which prevents other interrupts from interfering with the current interrupt handler.

Each vector of the IDT contains the following information:

offset:	offset to the interrupt handler
selector:	0x0018, third descriptor (code) in GDT for exception; 0x0020, fourth descriptor (code) in GDT for interrupt.
descriptor privilege level:	3
descriptor present bit:	1

The interrupt handler calls ***intEnt*( )** and saves the volatile registers (**eax**, **edx**, and **ecx**). It then calls the ISR, which is usually written in C. Finally, the handler restores the saved registers and calls ***intExit*( )**.

There is no designated interrupt stack. The interrupt's stack frame is built on the interrupted task's stack. Thus, each task requires extra stack space for interrupt nesting; the amount of extra space varies, depending on your ISRs and the potential nesting level.

Some device drivers (depending on the manufacturer, the configuration, and so on) generate a stray interrupt on IRQ7, which is used by the parallel driver. The global variable **sysStrayIntCount** (see Table D-3) is incremented each time such an interrupt occurs, and a dummy ISR is connected to handle these interrupts.

The chip generates an exception stack frame in one of two formats, depending on the exception type: (EIP + CS + EFLAGS) or (ERROR + EIP + CS + EFLAGS).

Machine Check Architecture (MCA)

The Pentium processor introduced a new exception called the machine-check exception (interrupt-18). This exception is used to signal hardware-related errors, such as a parity error on a read cycle. The PentiumPro processor extends the types of errors that can be detected and that generate a machine- check exceptions. It also provides a new machine-check architecture that records information about a machine-check error and provides the basis for an extended error logging capability.

MCA is enabled and its status registers are set to zero in ***sysHwInit*( )**. Its registers are accessed by ***pentiumMsrSet*( )** and ***pentiumMsrGet*( )**.

Registers

Memory Type Range Register (MTRR)

MTRR is a feature of the PentiumPro processor that allow the processor to optimize memory operations for different types of memory, such as RAM, ROM, frame buffer memory, and memory-mapped I/O. MTRRs configure an internal map of how physical address ranges are mapped to various types of memory. The processor uses this internal map to determine the cacheability of various physical memory locations and the optimal method of accessing memory locations.

For example, if a memory location is specified in an MTRR as write-through memory, the processor handles accesses to this location either by reading data from that location in lines and caching the read data or by mapping all writes to that location to the bus and updating the cache to maintain cache coherency. In mapping the physical address space with MTRRs, the processor recognizes five types of memory: uncacheable (UC), write-combining (WC), write-through (WT), write-protected (WP), and write-back (WB).

The MTRR table is defined as follows:

```
typedef struct mtrr_fix   /* MTRR - fixed range register */
{
char type[8];             /* address range: [0]=0-7 ... [7]=56-63 */
} MTRR_FIX;

typedef struct mtrr_var   /* MTRR - variable range register */
{
long long int base;       /* base register */
long long int mask;       /* mask register */
} MTRR_VAR;
typedef struct mtrr       /* MTRR */
{
int cap[2];               /* MTRR cap register */
int deftype[2];           /* MTRR defType register */
MTRR_FIX fix[11];         /* MTRR fixed range registers */
MTRR_VAR var[8];          /* MTRR variable range registers */
} MTRR;
```

Model Specific Register (MSR)

The PentiumPro processor implements the concept of model-specific registers (MSRs) to control hardware functions in the processor or to monitor processor activity. The new registers control the debug extensions, the performance counters, the machine-check exception capability, the machine check architecture, and the MTRRs. The MSRs can be read and written to using the RDMSR and WRMSR instructions, respectively.

Counters

Performance Monitoring Counters (PMC)

The PentiumPro processor has two performance-monitoring counters for use in monitoring internal hardware operations. These counters are duration or event counters that can be programmed to count any of approximately 100 different types of events, such as the number of instructions decoded, number of interrupts received, or number of cache loads.

PMC is enabled in ***sysHwInit*( )**. Selected events in the default configuration are PMC0 = number of hardware interrupts received and PMC1 = number of misaligned data memory references.

Time Stamp Counter (TSC)

The PentiumPro processor provides a 64-bit time-stamp counter that is incremented every processor clock cycle. The counter is incremented even when the processor is halted by the HLT instruction or the external STPCLK# pin. The time-stamp counter is set to 0 following a hardware reset of the processor. The RDTSC instruction reads the time stamp counter and is guaranteed to return a monotonically increasing unique value whenever executed, except for 64-bit counter wraparound. Intel guarantees, architecturally, that the time-stamp counter frequency and configuration will be such that it will not wraparound within 10 years after being reset to 0. The period for counter wrap is several thousands of years in the PentiumPro and Pentium processors.

Double-word Integers: **long long**

The double-word integer **long long** is not supported, except as an artifact of your particular architecture and compiler. For more information about handling unsupported features, please see the *Customer Support User's Guide*.

Context Switching

Hardware multitasking and the TSS descriptor are not used. VxWorks creates a dummy exception stack frame, loads the registers from the TCB, and then starts the task.

ISA/EISA Bus

The optional PC-compatible hardware cards supported in this release (the Ethernet adapter cards and the Blunk Microsystems ROM Card) use the ISA/EISA bus architecture.

PC104 Bus

The PC104 bus is supported and tested with the NE2000-compatible Ethernet card (4i24: Mesa Electronics). Ampro's Ethernet card (Ethernet-II) is also supported.

PCI Bus

The PCI bus is supported and tested with the Intel EtherExpress PRO100B Ethernet card. Several functions to access PCI configuration space are supported. Functions addressed here include:

- Locate the device by deviceID and vendorID.
- Locate the device by classCode.
- Generate the special cycle.
- Access its configuration registers.

Software Floating-Point Emulation

The software floating-point library is supported for the x86 architectures; select **INCLUDE_SW_FP** for inclusion in the project facility VxWorks view to include the library in your system image. This library emulates each floating point instruction, by using the exception "Device Not Available." For other floating-point support information, see *Supported Routines in mathALib*, p.434.

VxWorks Memory Layout

Two memory layouts for the x86 are shown in the following figures: Figure D-2 illustrates the typical upper memory configuration, while Figure D-1 shows a lower memory option. These figures contain the following labels:

Interrupt Vector Table	Table of exception/interrupt vectors.
GDT	Global descriptor table.
	Anchor for the shared memory network (if there is shared memory on the board).
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of the fatal exception message.
FD DMA Area	Diskette (floppy device) direct memory access area.
Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.
System Image	Entry point for VxWorks.
WDB Memory Pool	Size depends on the macro **WDB_POOL_SIZE** which defaults to one-sixteenth of the system memory pool. This space is used by the target server to support host-based tools. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
Interrupt Stack	Size is defined by **ISR_STACK_SIZE** under **INCLUDE_KERNEL**. Location depends on system image size.
System Memory Pool	Size depends on size of system image and interrupt stack. The end of the free memory pool for this board is returned by ***sysMemTop*( )**.

All addresses shown in Figure D-2 are relative to the start of memory for a particular target board. The start of memory (corresponding to 0x0 in the memory-layout diagram) is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

In general, the boot image is placed in lower memory and the VxWorks image is placed in upper memory, leaving a gap between lower and upper memory. Some BSPs have additional configurations which must fit within their hardware constraints. For details, see the reference entry for each specific BSP.

Figure D-1 **VxWorks System Memory Layout (x86 Lower Memory)**

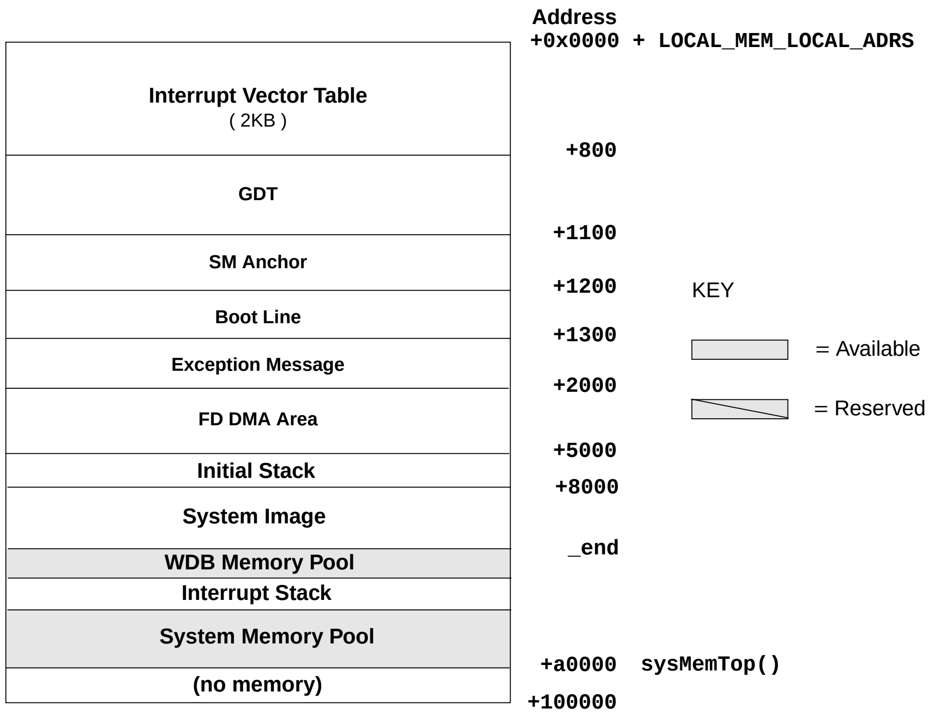
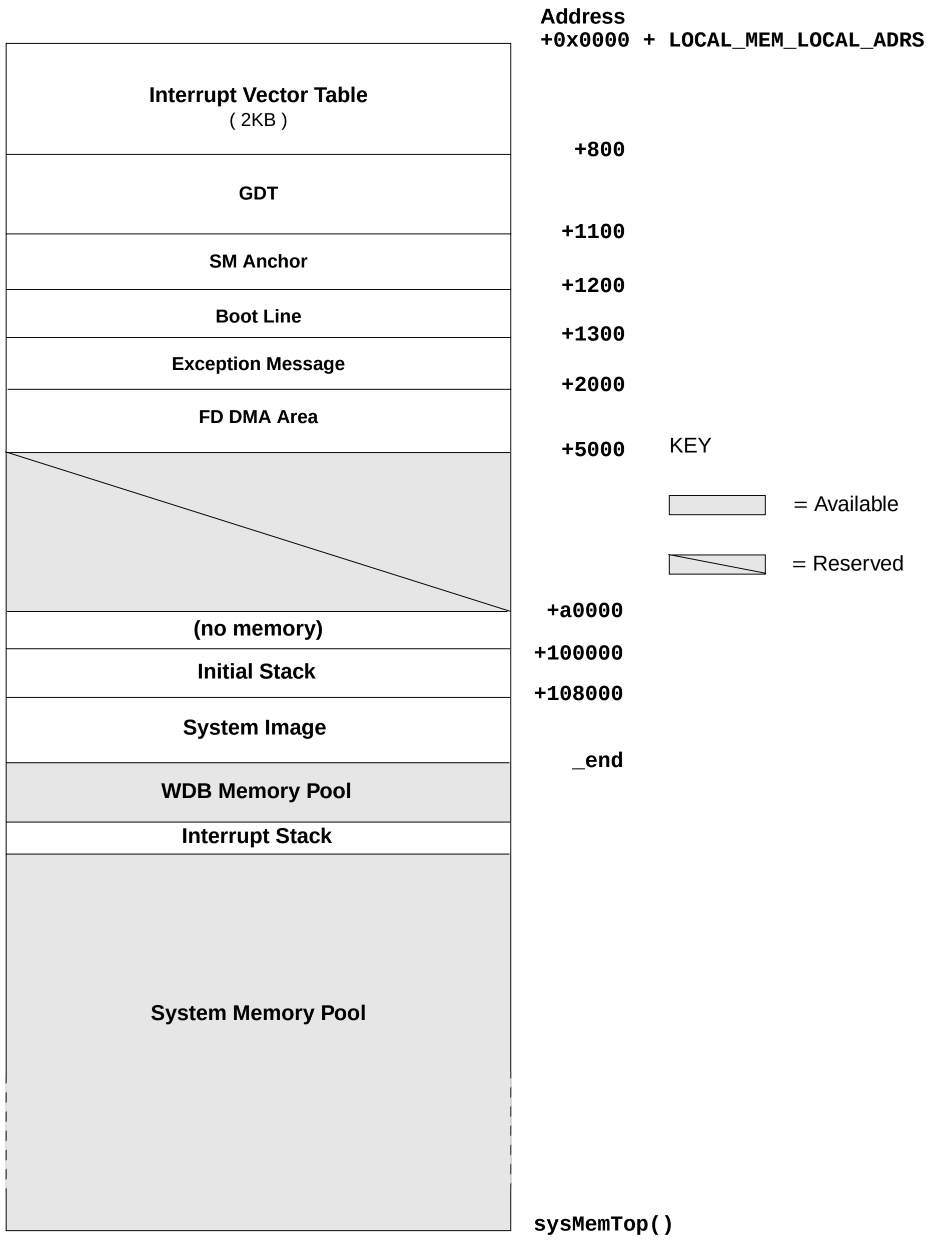


Figure D-2 **VxWorks System Memory Layout (x86 Upper Memory)**



D.5 Board Support Packages

Boot Considerations for PC Targets

For general information on booting VxWorks, see *Tornado Getting Started*.

This section describes how to build a boot disk, how to boot VxWorks, and how to mount a DOS file system. VxWorks for x86 targets includes the following DOS diskettes (in 3.5" (1.44MB) format):

- The diskette labeled “VxWorks Utility Disk” contains the DOS executables **vxsys.com**, **vxcopy.exe**, **vxload.com**, and **mkboot.bat**.
- The diskette labeled “VxWorks Boot Disk” contains the VxWorks bootstrap loader file; the minimal boot program, **bootrom.sys**, (renamed from **bootrom_uncmp**); and standalone VxWorks, **vxWorks.st**. These files work for all PC BSPs. (For additional boot images, see *VxWorks Images*, p.463.)

These utilities help you build new boot disks and are described in the following subsections.

NOTE: These utilities are also included in the Tornado tree at *installDir***/host/x86-win32/bin**.

Boot Process

When a standard PC-AT computer is powered on, the system BIOS code loads and executes the *bootstrap loader*. The bootstrap loader is written in 8088 16-bit assembly language. The BIOS obtains the bootstrap loader from the boot sector, which may be in one of several locations: a diskette, a hard disk, or some other alternatives such as a ROM.[2] When it finds the bootstrap loader, it executes it to find out where to find the **bootrom.sys** file.

The VxWorks bootstrap loader must be written to the boot sector instead of the standard bootstrap loader in order to create a VxWorks boot disk (or diskette). In addition, you must create the appropriate **bootrom.sys** file. This can be a bootable VxWorks kernel or it can be an intermediate kernel designed to load VxWorks from another source, such as a diskette, a hard disk, ROM, or flash. The following subsections describe how to do this from MS-DOS, from Solaris, and from VxWorks.

2. You can use a boot ROM if you install the Blunk Microsystems ROM Card 1.0; see *ROM Card and EPROM Support*, p.465.

Building a Boot Disk/Diskette from MS-DOS

The VxWorks Utility Disk includes several utility programs for creating VxWorks boot disks. These utilities write the VxWorks bootstrap loader to the boot sector, and then copy the VxWorks executables from the host to the disk in a format suitable for the bootstrap loader. The utilities mimic the corresponding MS-DOS utilities, but they can be run under a DOS session of Windows, not "pure" DOS. They are summarized as follows and described in more detail later in this section:

vxsys.com
installs a VxWorks bootstrap loader in a disk's boot sector.

vxcopy.exe
copies a VxWorks **a.out** executable to the boot disk in the required format.

vxload.com
loads and executes VxWorks from MS-DOS (must be run under "pure" DOS).

mkboot.bat
an MS-DOS batch file that creates boot disks.

▪ Creating a Boot Disk for PC-Compatible Targets

To create a diskette or a bootable hard disk for PC-compatible targets, follow these steps:

1. On the development host, change to the BSP directory, for example, **config/pc386**. Use **make** to produce the minimal boot program (the target **bootrom_uncmp**) or a bootable VxWorks (the targets **vxWorks_rom**, **vxWorks_rom_low**, or **vxWorks.st_rom**).[3] We recommend you copy the resulting file to a legal MS-DOS file name, such as **bootrom.dat**, to simplify the rest of the process.

   The commands for this sequence in a Windows DOS shell are as follows:

   ```
   C:\> cd installDir\target\config\pc386
   C:\> make bootrom_uncmp
   C:\> copy bootrom_uncmp bootrom.dat
   ```

2. Transfer the executable image to a PC running MS-DOS. In many cases, the PC is networked with the workstation, using PC-NFS or a similar networking package. For example:

3. Before making either version of the image, make sure that **DEFAULT_BOOT_LINE** in **config.h** is set correctly, and that the size of the boot image (text+data+bss) is less than 512KB. It cannot be larger than this, because x86 chips boot in "real" mode and therefore do have access to all available memory until later in the boot process.

```
C:\> copy drive:bootrom.dat c:
```

where *drive* refers to the mounted file system on your PC.

3. Use the **mkboot** utility (or a combination of **vxsys** and **vxcopy**) to create the boot disk. If this boot disk is a diskette, it must be a high-density diskette. The following example shows this step, assuming the diskette is in drive **A**:

   ```
   C:\> mkboot a: bootrom.dat
   ```

   The **mkboot** utility uses **vxsys** to create the VxWorks bootstrap loader in the disk's boot sector. **mkboot** then runs **vxcopy** to copy **bootrom.dat** to the boot file **bootrom.sys** on the target disk, excluding the **a.out** header.

4. Check that **bootrom.sys** is contiguous on the boot disk, using the MS-DOS **chkdsk** utility. (The **mkboot** utility runs **chkdsk** automatically.) If **chkdsk** shows that there are non-contiguous blocks, delete all files from the disk and repeat the **vxcopy** operation to ensure that MS-DOS lays down the file contiguously.

   The following example shows **chkdsk** output where the boot file is not contiguous (note especially the last line of output):

   ```
   C:\> chkdsk a:bootrom.sys

   Volume Serial Number is 2A35-18ED
   1457664 bytes total disk space
    895488 bytes in 11 user files
    562176 bytes available on disk

    512 bytes in each allocation unit
    2847 total allocation units on disk
    1098 available allocation units on disk

    655360 total bytes memory
    602400 bytes free

   A:\BOOTROM.SYS Contains 2 non-contiguous blocks
   ```

5. To test your boot disk, first make sure that the correct drive holds the boot disk (in this example case, drive **A:** holds the boot diskette).

6. Reboot the PC.

   Depending on the configuration of your VxWorks image, if the boot is successful, the VxWorks boot prompt appears either on the VGA console or on the COM1 serial port. You can boot VxWorks by entering @:

   ```
   [VxWorks Boot]: @
   ```

- **The MS-DOS Boot Utilities in More Detail**

vxsys *drive*:
This command installs a VxWorks bootstrap loader in a drive's boot sector. The drive can be either a diskette (drive **A:**), or a hard disk that is searched by the BIOS bootstrap (drive **C:**).[4] The VxWorks bootstrap loader searches for the file **bootrom.sys** in the root directory and loads it directly into memory at 0x8000. Execution then jumps to ***romInit*( )** at 0x8000.

NOTE: After a bootstrap loader is installed in the disk's boot sector, you do not need to repeat the **vxsys** operation for new ROM images. Just use **vxcopy** to make a new version of **bootrom.sys**.

vxcopy *source_file target_file*
This command copies the VxWorks image file from *source_file* to *target_file*. Normally this copies the **bootrom_uncmp** output to **bootrom.sys** on the boot disk. **vxcopy** strips the 32-byte **a.out** header from *source_file* as it copies.

mkboot *drive*: *source_file*
This command is an MS-DOS batch file that uses **vxsys** to install the VxWorks bootstrap loader in the drive's boot sector, and then uses **vxcopy** to transfer *source_file* to *drive***:bootrom.sys**. It also runs the MS-DOS utility **chkdsk** to check whether **bootrom.sys** is contiguous.

vxload [*image_file*]
This command is used during an MS-DOS session to load and execute the VxWorks image (normally **vxWorks.st** or **bootrom_uncmp**). It can be more convenient or quicker than loading the image via the PC boot cycle. **vxload** takes an optional parameter, the image file name; the default is **vxWorks.st** in the current directory.

⚠ **CAUTION:** **vxload** cannot be used to load VxWorks if the MS-DOS session has a protected mode program in use. Typical examples include the MS-DOS RAM disk driver, **vdisk.sys**, and the extended memory manager, **emm386.exe**. To use **vxload**, remove or disable such facilities.

Because **vxload** must read the image file to memory at 0x8000, it checks to see that this memory is not in use by MS-DOS, and generates an error if it is. If you receive such an error, reconfigure your PC target to make the space available by loading MS-DOS into high memory and reducing the number of device

4. For embedded applications, actual disk drives are often replaced by solid state disks. Because there are no moving parts, boot performance and reliability are increased.

drivers. Or start **vxload** instead of the MS-DOS command interpreter **command.com**. (If you take this approach, remember to first ensure that you can restore your previous configuration.)

The following is a sample **config.sys** file that shows these suggestions:

```
device=c:\dos\himem.sys
dos=high,umb
shell=c:\vxload.com c:\bootrom.dat
```

The file **bootrom.dat** must have an **a.out** header, unlike the **bootrom.sys** file made by **mkboot**.

Building a Boot Disk/Diskette from a Solaris Host

Use **/usr/bin/fdformat** that comes with Solaris. It requires a bootstrap loader file called **vxld.bin**, which can be downloaded from WindSurf.

Copy **vxld.bin** to your Solaris file system, insert a 1.44 MB diskette into the Sun diskette drive, and issue the **fdformat** command to format the diskette and install the boot block.

```
fdformat -U -d -B vxld.bin

Formatting 1.44 MB in /vol/dev/rdiskette0/no_name#7
Press return to start formatting floppy.
......................................................................
fdformat: using "vxld.bin" for MS-DOS boot loader
```

Now create the **bootrom.sys**:

```
% cd installDir/target/config/bspName
% make bootrom_uncmp
% aoutToBinDec < bootrom_uncop > bootrom.sys
```

Copy the new **bootrom.sys** file to your boot diskette.

Building a Boot Disk/Diskette from VxWorks

The routine ***mkbootFd*( )** produces a VxWorks boot diskette, and ***mkbootAta*( )** produces a VxWorks boot disk (an IDE or ATA hard disk). Both run on any VxWorks x86 target. They are provided in *installDir*/**target/config/***bspname*/**mkboot.c**. Use a DOS-formatted disk or diskette.

CAUTION: The ***mkbootFd*( )** routine supports only high-density diskettes.

The ***mkbootFd*( )**, ***mkbootAta*( )**, and ***mkbootTffs*( )** routines write the boot sector so that it contains the VxWorks bootstrap loader and make a boot image named

bootrom.sys. The boot image can be derived from one of the images listed in *VxWorks Images*, p. 463. Before making any version of the image, make sure that **DEFAULT_BOOT_LINE** in **config.h** is set correctly (see *Tornado User's Guide: Setup and Startup*), and that the size of the boot image (text+data+bss) is verified to be less than 512KB. It cannot be larger than this, because it is written into lower memory.

During the booting process, the VxWorks bootstrap loader reads **bootrom.sys** and then jumps to the entry point of the boot image.

The ***mkbootFd*( )** routine requires the following parameters:

```
STATUS mkbootFd (int drive, int fdType, char *filename)
```

The first two parameters specify the drive number and diskette type, specified as in *Booting VxWorks from a Diskette, an ATA/IDE Disk, a PC Card, or a Flash File System*, p. 457. The third parameter specifies the file name of the boot image.

The ***mkbootAta*( )** routine requires the following parameters:

```
STATUS mkbootAta (int ctrl, int drive, char *filename)
```

The first two parameters specify the controller number and drive number, specified as in *Booting VxWorks from a Diskette, an ATA/IDE Disk, a PC Card, or a Flash File System*, p. 457. The third parameter specifies the file name of the boot image.

The ***mkbootTffs*( )** routine requires the following parameters:

```
STATUS mkbootTffs (int drive, int removeBit, char *filename)
```

The first two parameters specify the drive number and removable bit, specified as in *Booting VxWorks from a Diskette, an ATA/IDE Disk, a PC Card, or a Flash File System*, p. 457. The third parameter specifies the file name of the boot image.

For example, to create a boot disk for the pc386 BSP if you are using a UNIX host, first use the following commands on the host to create the **mkboot.o** object from **mkboot.c**:

```
% cd installDir/target/config/pc386
% make mkboot.o
```

Then, from the Tornado shell, move to the appropriate directory, load **mkboot.o**, and then invoke ***mkbootFd*( )**, ***mkbootAta*( )**, or ***mkbootTffs*( )**. Remember to place a formatted, empty diskette in the appropriate drive if you use ***mkbootFd*( )**.

In this example, ***mkbootAta*( )** builds a local IDE disk on drive **C:** from **bootrom_uncmp** with the default **ataResources[]** table (see *ATA/IDE Disk Driver*, p. 471):

```
-> cd "installDir/target/config/pc386"
-> ld < mkboot.o
-> mkbootAta 0,0,"bootrom_uncmp"
```

Booting VxWorks from a Diskette, an ATA/IDE Disk, a PC Card, or a Flash File System

Four boot devices are available in VxWorks for the x86, one for diskettes, one for ATA/IDE hard disks, one for PCMCIA PC cards, and one for flash files. You can also build your own VxWorks boot ROMs using optional hardware; see *ROM Card and EPROM Support*, p.465. Alternatively, as with other VxWorks platforms, you can also boot over an Ethernet (using one of the supported Ethernet cards), or over a SLIP connection.

⚠ **CAUTION:** Because standard PC BIOS components do not support initial booting from PCMCIA devices, systems which load VxWorks from these devices must use a VxWorks boot disk/diskette. See *Building a Boot Disk/Diskette from MS-DOS*, p.452, *Building a Boot Disk/Diskette from a Solaris Host*, p.455, and *Building a Boot Disk/Diskette from VxWorks*, p.455.

When booting from a diskette, an ATA/IDE disk, a PC card, or a flash file system, first make sure that the boot device is formatted for an MS-DOS file system. The VxWorks boot program mounts the boot device by automatically calling either ***usrFdConfig*( )** in **usrFd.c** for diskettes, ***usrAtaConfig*( )** in **usrAta.c** for ATA/IDE hard disks, ***usrPcmciaConfig*( )** in **usrPcmcia.c** for PC cards, or ***usrTffsConfig*( )** for flash file systems. (All files are located in *installDir*/**target/src/config**.)

⚠ **CAUTION:** Because the boot program uses ***usrFdConfig*( )** for floppy diskettes, and because ***usrFdConfig*( )** does not provide the **DOS_VOL_CONFIG** structure required to use ***dosFsVolUnmount*( )**, you must instead use ***ioctl*( )** with **FIOUNMOUNT** before removing the floppy diskette.

In each case, a *mount point* name is taken from the file name specified as one of the boot parameters. You might choose diskette zero (drive **A:**) to be mounted as **/fd0** (by supplying a boot file name that begins with that string). Similarly, you might choose ATA/IDE hard disk zero (drive **C:**) to be mounted as **/ata0**, you might choose the PC card in socket 0 to be mounted as **/pc0**, or you might choose the flash file system called drive 1 as **/tffs0**. In each case, the name of the directory mount point (**fd0**, **ata0**, **pc0**, or **tffs0** in these examples) can be any legal file name. (For more information on ***usrFdConfig*( )**, ***usrAtaConfig*( )**, ***usrPcmciaConfig*( )**, or ***usrTffsConfig*( )**, see *Mounting a DOS File System*, p.460.)

Because the PC hardware does not have a standard NVRAM interface, the only way to change default boot parameters is to rebuild the bootstrap code with a new definition for **DEFAULT_BOOT_LINE** in **config.h**. See *Boot Process*, p.451 for instructions on how to rebuild the bootstrap code.

⚠ **CAUTION:** To enable rebooting with **CTRL+X**, you must set some of the BSP-specific global variables **sysWarmType**, **sysWarmFdType**, **sysWarmFdDrive**, **sysWarmAtaCtrl**, **sysWarmAtaDrive**, and **sysWarmTffsDrive**, depending on which boot device you use. For more information, see Table D-3.

Booting from Diskette

To boot from a diskette, specify the boot device as **fd** (for *floppy device*). First, specify the *drive number* on the **boot device:** line of the boot parameters display. Then, specify the *diskette type* (3.5" or 5.25"). The format is as follows:

```
boot device: fd=drive number, diskette type
```

drive number
a digit specifying the diskette drive:

0 = default; the first diskette drive (drive **A:**)
1 = the second diskette drive (drive **B:**)

diskette type
a digit specifying the type of diskette:

0 = default; 3.5" diskette
1 = 5.25" diskette

Thus, to boot from drive **B:** with a 5.25" diskette, enter the following:

```
boot device: fd=1,1
```

The default value of the file-name boot parameter is **/fd0/vxWorks.st**. You can specify another boot image; for example, assume that you have placed your **vxWorks** and **vxWorks.sym** files in the root directory of the 5.25" diskette in drive **A:** as the files **A:\\_vxworks** and **A:\vxworks.sym**, and that the mount point for this drive is **/fd0**. To boot this image, enter the following in the boot parameters display:

```
boot device: fd=0,1
...
file name: /fd0/vxworks
```

- **Booting from ATA/IDE Disk**

To boot from an ATA/IDE disk, specify the boot device as **ata**. First, specify the *controller number* on the boot device line of the boot parameters display. Then, specify the *drive number*. The format is as follows:

```
boot device: ata=controller number, drive number
```

controller number
a digit specifying the controller number:

0 = a controller described in the first entry of the **ataResources** table (in the default configuration, the local IDE disk is the first controller)
1 = a controller described in the second entry of the **ataResources** table (in the default configuration, the ATA PCMCIA PC card is the second controller)

drive number
a digit specifying the hard drive:

0 = the first drive on the controller (drive **C:** or **E:**)
1 = the second drive on the controller (drive **D:** or **F:**)

If your **vxWorks** and **vxWorks.sym** files are in the root directory of your IDE hard disk drive **C:** as the files **C:\vxworks** and **C:\vxworks.sym**, where **C:** is the first IDE disk drive on the system and the mount point for the drive is **/ata0**, then enter the following in the boot parameters display:

```
boot device: ata=0,0
...
file name: /ata0/vxworks
```

- **Booting from PCMCIA PC Card**

To boot from a PCMCIA PC card, specify the boot device as **pcmcia**. Specify the *socket number* on the **boot device:** line of the boot parameters display. The format is as follows:

```
boot device: pcmcia=socket number
```

socket number
a digit specifying the socket number:

0 = the first PCMCIA socket
1 = the second PCMCIA socket

If your **vxWorks** and **vxWorks.sym** files are in the root directory of your ATA or SRAM PCMCIA PC card drive **E:** as the files **E:\vxworks** and **E:\vxworks.sym**, and the mount point for your PC card drive is **/pc0**, then enter the following:

```
    boot device: pcmcia=0
    ...
    file name: /pc0/vxworks
```

If you are using an Ethernet PC card, the boot device is the same and the file name is:

```
    file name: /usr/wind/target/config/pc386/vxWorks
```

Booting from Flash File System

To boot from an TFFS disk, specify the boot device as **tffs**. Specify both the drive number and the removable bit on the **boot device:** line of the boot parameters display. The format is as follows:

```
    boot device: tffs=drive number, removable bit
```

drive number
: a digit specifying the drive number; it should be in the range of 0 to (**noOfDrives** - 1). The global variable **noOfDrives** holds the number of registered drives, and is initialized by ***sysTffsInit*( )** in **tffsDrv**.

removable bit
: a digit specifying whether or not the drive is removable.

  0 = non-removable flash media
  1 = removable flash media, such as a Flash PC Card

If your **vxWorks** and **vxWorks.sym** files are in the root directory of your TFFS (Disk On Chip) drive **E:** as the file **E:\vxWorks** and **E:\vxWorks.sym**, and the mount point for your TFFS drive is **/tffs0**, then enter the following:

```
    boot device: tffs=0,0
    ...
    file name: /tffs0/vxWorks
```

Mounting a DOS File System

You can mount a DOS file system from a diskette, an ATA/IDE disk, a PC card (SRAM or ATA), or a flash file system to your VxWorks target.

Diskette

Use the routine ***usrFdConfig*( )** to mount the file system from a diskette. It takes the following parameters:

drive number
: the drive that contains the diskette: MS-DOS drive **A:** is 0; drive **B:** is 1.

diskette type
: 0 (3.5" 2HD) or 1 (5.25" 2HD).

mount point
: from where on the file system to mount, for example, **/fd0/**.

⚠ **CAUTION:** Because the boot program uses ***usrFdConfig*( )** for floppy diskettes, and because ***usrFdConfig*( )** does not provide the **DOS_VOL_CONFIG** structure required to use ***dosFsVolUnmount*( )**, you must instead use ***ioctl*( )** with **FIOUNMOUNT** before removing the floppy diskette.

ATA/IDE Hard Drive

Use the routine ***usrAtaConfig*( )** to mount the file system from an ATA/IDE disk. It takes the following parameters:

controller number
: the controller: a controller described in the first entry of the **ataResources[]** table is 0; a controller described in the second entry is 1. In the default configuration, the local IDE disk is 0; the PCMCIA ATA drive is 1.

drive number
: the drive: the first drive of the controller is 0; the second drive of the controller is 1. In the default configuration, MS-DOS drive **C:** is 0; drive **D:** is 1.

mount point
: from where on the file system to mount, for example, **/ata0/**.

PCMCIA Card

Use ***pccardMount*( )** to mount the file system from a PC card (SRAM or ATA). This routine differs from ***usrPcmciaConfig*( )** in that ***pccardMount*( )** uses the default device. A default device is created by the enabler routine when the PC card is initialized. The default device is removed automatically when the PC card is removed. ***pccardMount*( )** takes the following parameters:

socket number
: the socket that contains the PC card; the first socket is 0.

mount point
from where on the file system to mount, for example, /**pc0**/.

Use ***pccardMkfs*( )** to initialize a PC card and mount the file system from a PC card (SRAM or ATA). It takes the following parameters:

socket number
the socket that contains the PC card; the first socket is 0.

mount point
from where on the file system to mount, for example, /**pc0**/.

The ***pccardMount*( )** and ***pccardMkfs*( )** routines are provided in source form in **src/drv/pcmcia/pccardLib.c**.

TFFS Drive

Use the routine ***usrTffsConfig*( )** to mount the file system from an TFFS drive. It takes the following parameters:

drive number
the drive number in the range of 0 to (**noOfDrives** - 1). The global variable **noOfDrives** holds a number of registered drives that is initialized in ***sysTffsInit*( )** in **tffsDrv**.

removable bit
the removable bit of the drive is 0 for non-removable flash media and 1 for removable flash media.

mount point
from where on the file system to mount, for example, **/tffs0/**.

DMA Buffer Alignment and cacheLib

If you write your own device drivers that use direct memory access into buffers obtained from **cacheLib**, the buffer must be aligned on a 64KB boundary.

Support for Third-Party BSPs

To support third party pc386 and pc486 BSPs, the global variable **sysCodeSelector** and the routines ***sysIntVecSetEnt*( )** and ***sysIntVecSetExit*( )** are defined in **sysLib.c**.

VxWorks Images

The executable target **bootrom_uncmp** uses lower memory (0x0 - 0xa0000), while **vxWorks** and **vxWorks.st** use upper memory (0x100000 - *pcMemSize*). A minimum of 1MB of memory in upper memory is required for **vxWorks** and **vxWorks.st**.

The VxWorks makefile targets listed below are supported in these BSPs. They should be placed on a bootable diskette by **mkboot** (a DOS utility) or by ***mkbootFd*( )** or ***mkbootAta*( )** or ***mkbootTffs*( )** (VxWorks utilities). The makefile target **vxWorks_rom** should be downloaded by the **bootrom_high** bootROM image; for information on all VxWorks makefile targets, see *8.6.2 Executing VxWorks from ROM*, p.346:

vxWorks_rom	bootable VxWorks:	upper memory
vxWorks_rom_low	bootable VxWorks:	lower memory
vxWorks.st_rom	bootable VxWorks.st (compressed):	upper memory
bootrom	bootROM (compressed):	lower memory
bootrom_uncmp	bootROM:	lower memory
bootrom_high	bootROM (compressed):	upper memory

BSP-Specific Global Variables for 386 and 486

The BSP-specific global variables shown in Table D-3 apply to pc386, pc486, and epc4.

Configuring the Pentium BSP

The project facility configures the Pentium BSP with hardware floating point support and user data cache support set to copyback by default. This configuration is equivalent to the default configuration in **config.h**:

```
#undef   INCLUDE_SW_FP         /* Pentium has hardware FPP */
#undef   USER_D_CACHE_MODE     /* Pentium write-back data cache support */
#define  USER_D_CACHE_MODE  CACHE_COPYBACK
#define  INCLUDE_MTRR_GET      /* get MTRR to sysMtrr[] */
#define  INCLUDE_PMC          /* include PMC */
```

Configuring the PentiumPro BSP

The project facility configures the PentiumPro BSP automatically to use the board's special functionality. This configuration is equivalent to the default configuration

Table D-3 **BSP-Specific Global Variables**

Location	Global Variable	Value	Description
sysLib.c	**sysWarmType** **sysWarmFdType** **sysWarmFdDrive** **sysWarmAtaCtrl** **sysWarmAtaDrive** **sysWarmTffsDrive**	0 = ROMBIOS 1 (default) = Diskette 2 = ATA 3 = TFFS	**sysWarmType** controls how **CTRL+X** is processed. If 0, VxWorks asserts SYSRESET line, and **CTRL+X** produces cold start. If 1, VxWorks reads a boot image from the diskette specified by **sysWarmFdType** and **sysWarmFdDrive**, and jumps to the boot image entry point. If 2, VxWorks reads a boot image from the ATA/IDE disk specified by **sysWarmAtaCtrl** and **sysWarmAtaDrive** and jumps to the boot image entry point. If 3, VxWorks reads a boot image from the TFFS Disk On Chip specified by **sysWarmTffsDrive** and jumps to the boot image entry point.
	sysFdBufAddr **sysFdBufSize**	0x2000 0x3000	Address and size of diskette DMA buffer.
	sysStrayIntCount		VxWorks increments this when it catches a stray interrupt on IRQ7.

in **config.h**. Changes to floating point and cache support can be made in the project facility. If you must change the default setting for other functionality, you must change **config.h**. (See *8. Configuration and Build*.)

```
#undef   INCLUDE_SW_FP         /* PentiumPro has hardware FPP *
#undef   USER_D_CACHE_MODE     /* PentiumPro write-back data cache support */
#define  USER_D_CACHE_MODE  (CACHE_COPYBACK|CACHE_SNOOP_ENABLED)
#define  INCLUDE_MTRR_GET      /* get MTRR to sysMtrr[] */
#define  INCLUDE_PMC           /* include PMC */
#undef   VIRTUAL_WIRE_MODE     /* Interrupt Mode: Virtual Wire Mode */
#undef   SYMMETRIC_IO_MODE     /* Interrupt Mode: Symmetric IO Mode */

#if defined(VIRTUAL_WIRE_MODE) || defined(SYMMETRIC_IO_MODE)
#define  INCLUDE_APIC_TIMER    /* include Local APIC timer */
#define  PIT0_FOR_AUX          /* use channel 0 as an Aux Timer */
#endif      /* defined(VIRTUAL_WIRE_MODE) || defined(SYMMETRIC_IO_MODE) */

#define  INCLUDE_TIMESTAMP_TSC /* include TSC for timestamp */
#define  PENTIUMPRO_TSC_FREQ 0 /* auto detect TSC freq */
#if  FALSE
#define  PENTIUMPRO_TSC_FREQ 150000000 /* use specified TSC freq */
#endif                         /* FALSE */

#define  INCLUDE_MMU_PENTIUMPRO /* include 32bit MMU for PentiumPro */
#ifdef   INCLUDE_MMU_PENTIUMPRO

#undef   VM_PAGE_SIZE          /* page size could be 4KB or 4MB */
```

```
#define  VM_PAGE_SIZE  PAGE_SIZE_4KB    /* 4KB page */
#if  FALSE
#define  VM_PAGE_SIZE  PAGE_SIZE_4MB    /* 4MB page */
#endif                         /* FALSE */

#undef   VM_STATE_MASK_FOR_ALL
#undef   VM_STATE_FOR_IO
#undef   VM_STATE_FOR_MEM_OS
#undef   VM_STATE_FOR_MEM_APPLICATION
#undef   VM_STATE_FOR_PCI

#define VM_STATE_MASK_FOR_ALL \
VM_STATE_MASK_VALID | VM_STATE_MASK_WRITABLE | \
VM_STATE_MASK_CACHEABLE | VM_STATE_MASK_WBACK | VM_STATE_MASK_GLOBAL

#define VM_STATE_FOR_IO \
VM_STATE_VALID | VM_STATE_WRITABLE | \
VM_STATE_CACHEABLE_NOT | VM_STATE_WBACK_NOT | VM_STATE_GLOBAL_NOT

#define VM_STATE_FOR_MEM_OS \
VM_STATE_VALID | VM_STATE_WRITABLE | \
VM_STATE_CACHEABLE | VM_STATE_WBACK | VM_STATE_GLOBAL_NOT

#define VM_STATE_FOR_MEM_APPLICATION \
VM_STATE_VALID | VM_STATE_WRITABLE | \
VM_STATE_CACHEABLE | VM_STATE_WBACK | VM_STATE_GLOBAL_NOT

#define VM_STATE_FOR_PCI \
VM_STATE_VALID | VM_STATE_WRITABLE | \
VM_STATE_CACHEABLE_NOT | VM_STATE_WBACK_NOT | VM_STATE_GLOBAL_NOT

#endif                       /* INCLUDE_MMU_PENTIUMPRO */
```

ROM Card and EPROM Support

A boot EPROM (type 27020 or 27040) is supported with Blunk Microsystems' ROM Card 1.0. For information on booting from these devices, see the Blunk Microsystems documentation.

The following program is provided to support VxWorks with the ROM Card:

config/*bspname***/romcard.s**
a loader for code programmed in to the EPROM.

In addition, the following configurations are defined in the makefile to generate Motorola S-record format from **bootrom_uncmp** or from **vxWorks_boot.st**:

romcard_bootrom_512.hex
boot ROM image for 27040 (512 KB)

romcard_bootrom_256.hex
boot ROM image for 27020 (256 KB)

romcard_vxWorks_st_512.hex
bootable VxWorks image for 27040 (512 KB)

Neither the ROM Card nor the EPROM is distributed with VxWorks. To contact Blunk Microsystems, see their Web site at **http://www.blunkmicro.com**.

Device Drivers

VxWorks for the x86 includes a console driver, network drivers for several kinds of hardware, a diskette driver, an ATA/IDE hard disk driver, and a line printer driver.

VGA and Keyboard Drivers

The keyboard and VGA drivers are character-oriented drivers; thus, they are treated as additional serial devices. Because the keyboard deals only with input and the VGA deals only with output, they are integrated into a single driver in the module *installDir***/target/src/drv/serial/pcConsole.c**.

To include the console drivers in your configuration, select the macro **INCLUDE_PC_CONSOLE** for inclusion in the project facility VxWorks view. When this macro is defined, the serial driver automatically initializes the console drivers.

The console drivers do not change any hardware initialization that the BIOS has done. The I/O addresses for the keyboard and the console, and the base address of the on-board VGA memory, are defined in *installDir***/target/config/***bspname***/pc.h**.

The macro **PC_KBD_TYPE** specifies the type of keyboard. The default is a PS/2 keyboard with 101 keys. If the keyboard is a portable PC keyboard with 83 keys, define the macro as **PC_XT_83_KBD** in *installDir***/target/config/***bspname***/config.h**.

In the default configuration, **/tyCo/0** is serial device 1 (COM1), **/tyCo/1** is serial device 2 (COM2), and **/tyCo/2** is the console.

You can define the following configuration macros for the console drivers in **pc.h**:

- **INCLUDE_ANSI_ESC_SEQUENCE** supports the ANSI terminal escape sequences. The VGA driver does special processing for recognized escape sequences.
- **COMMAND_8042**, **DATA_8042**, and **STATUS_8042** refer to the I/O base addresses of the various keyboard controller registers.

- **GRAPH_ADAPTER** can be set to either **VGA** or **MONOCHROME**.

Network Drivers

Several network drivers are available, corresponding to an assortment of boards from different manufacturers. To include specific network drivers in your configuration, see the project facility under network components.

For all network drivers, the I/O address, RAM address, RAM size, and interrupt request (IRQ) levels are defined on the driver Params tab in the project facility (the I/O address must match the value recorded in the EEPROM). Use the configuration program supplied by the manufacturer to set the I/O address; in some cases you can set IRQ levels with the same configuration program.

You can set the board-specific macro listed in Table D-4 (defined on the Params tab) to specify whether you are using EEPROM, thin coaxial cable (BNC), twisted-pair cable (RJ45), thick coaxial cable (AUI), or some combination (for example, RJ45+AUI and/or RJ45+BNC). The exceptions are the Intel EtherExpress32, which uses EEPROM only, and the Novell/Eagle NE2000, which uses a hardware jumper.

For most network drivers, a board-specific routine *board**Show*( )** [5] displays statistics collected in the interrupt handler on the standard output device. This routine requires two parameters: *interface unit* and *zap*. For all boards currently supported, *interface unit* is 0; *zap* can be either 0 or 1. If *zap* is 1, all collected statistics are cleared to zero.

Table D-4 shows the software configuration details for each network driver.

Table D-4 **Network Drivers**

Network Board	IRQ Levels Supported	Ethernet Configuration Macro	Show Routine
SMC Elite 16	2, 3, 4, 5, 7, 9, 10, 11, 15	**CONFIG_ELC**	***elcShow*[*]( )**
SMC Elite 16 Ultra	2, 3, 5, 7, 10, 11	**CONFIG_ULTRA**	***ultraShow*( )***
Intel EtherExpress[†]	2, 3, 4, 5, 9, 10, 11	**CONFIG_EEX**	(none)
Intel EtherExpress32**†**	3, 5, 7, 9, 10, 11, 12, 15	(EEPROM)	(none)
Intel EtherExpress PRO100B	0 - 15	(EEPROM)	(none)

5. The prefix *board* is an abbreviation for the corresponding network board. For example, the abbreviation for the 3Com EtherLink III board is *elt*, so the show routine is ***eltShow*( )**.

Table D-4 **Network Drivers** *(Continued)*

Network Board	**IRQ Levels Supported**	**Ethernet Configuration Macro**	**Show Routine**
3Com EtherLink III	3, 5, 7, 9, 10, 11, 12, 15	**CONFIG_ELT**	***eltShow*( )***
Novell/Eagle NE2000	2, 3, 4, 5, 10, 11, 12, 15	(jumper)	***eneShow*( )***
Ampro Ethernet-II	2, 3, 10, 11	**CONFIG_ESMC**	***esmcShow*( )***

* These routines are automatically included when the board is configured. When you invoke them, their output is sent to the standard output device.
† Auto-detect mode is not supported for these boards.

Certain network boards are also configurable in hardware. Use the jumper settings shown in Table D-5 with the network drivers supplied.

Table D-5 **Network Board Hardware Configuration**

Network Board	**Jumpers**	**Settings**
SMC Elite 16	W1 W2	SOFT NONE/SOFT
SMC Elite 16 Ultra	W1	SOFT
Intel EtherExpress	(none)	
Intel EtherExpress32	(none)	
Intel EtherExpress PRO100B	(none)	
3Com EtherLink III	(none)	
Novell/Eagle NE2000	various	follow manufacturer's instructions
Ampro Ethernet-II	W1 W3 W4	PROM size: 16K or 32K No.0: 0x300 Select IRQ-10,11

Diskette Driver

To include the diskette driver in your configuration, select the macro **INCLUDE_FD** for inclusion in the project facility VxWorks view ("fd" stands for *floppy disk*). When **INCLUDE_FD** is included, the initialization routine ***fdDrv*( )** is called automatically from ***usrRoot*( )** in *installDir***/target/config/all/usrConfig.c**. To change the interrupt vector and level used by ***fdDrv*( )**, edit the definitions of **FD_INT_VEC** and **FD_INT_LVL** on the Params tab of the Properties window.

The ***fdDevCreate*( )** routine installs a diskette device in VxWorks. You must call ***fdDevCreate*( )** explicitly for each diskette device you wish to install; it is not called automatically. The ***fdDevCreate*( )** routine requires the following parameters:

drive number
: the diskette drive that corresponds to this device: MS-DOS drive **A:** is 0; drive **B:** is 1.

diskette type
: 0 (3.5" 2HD) or 1 (5.25" 2HD). These numbers are indices to the structure table **fdTypes[]** in *installDir***/target/config/***bspname***/sysLib.c**, which is described below.

number of blocks
: the size of the device.

offset
: the number of blocks to leave unused at the start of a diskette.

As shipped, the **fdTypes[]** table in **sysLib.c** describes two diskette types: the 3.5" 1.44MB 2HD diskette and the 5.25" 1.2MB 2HD diskette. (In particular, there is no entry for low-density diskettes.) To use another type of diskette, add the appropriate disk descriptions to the **fdTypes[]** table, shown below. Note that each entry in the table is a structure. The entry **dataRate** is described in more detail in Table D-6 and the entries **stepRate**, **headUnload**, and **headLoad** are described in Table D-7.

```
int sectors;         /* number of sectors                         */
int sectorsTrack;    /* sectors per track                         */
int heads;           /* number of heads                           */
int cylinders;       /* number of cylinders                       */
int secSize;         /* 128 << secSize gives bytes per sector     */
char gap1;           /* suggested gap value in read/write cmds    */
                     /* to avoid splice point between data field  */
                     /* and ID field of contiguous sections       */
char gap2;           /* suggested gap values for format-track cmd */
char dataRate;       /* data transfer rate                        */
char stepRate;       /* stepping rate                             */
char headUnload;     /* head unload time                          */
char headLoad;       /* head load time                            */
char mfm;            /* 1-->MFM (double density),
                        0--> FM (single density)                  */
char sk;             /* if 1, skip bad sectors on read-data cmd   */
char *name;          /* name                                    */
```

The **dataRate** field must have a value ranging from 0 to 3. The bit value controls the data transfer rate by setting the configuration control register in some IBM diskette controllers. The values correspond to transfer rates as shown in Table D-6.

Table D-6 **Diskette Data Transfer Rates**

dataRate	**MFM (double density)**	**FM (single density)**
3	1Mbps	invalid
0	500Kbps	250Kbps
1	300Kbps	150Kbps
2	250Kbps	125Kbps

The **stepRate**, **headUnload**, and **headLoad** parameters describe time intervals related to physical operation of the diskette drive. The time intervals are a simple function of the parameter value and of a multiplier corresponding to the data transfer rate, except that 0 has a special meaning for **headUnload** and **headLoad**, as shown in Table D-7.

Table D-7 **Time Interval Parameters in fdTypes[]**

			Time (ms) by transfer rate			
Description	**Field**	**Value**	**1M**	**500K**	**300K**	**250K**
		Transfer rate multiplier (T):	*1*	*2*	*3.33*	*4*
Interval between stepper pulses	**stepRate**	0	8	16	26.7	32
		0–15	(8 – 0.5 × **stepRate**) × *T*			
Interval from end of read or write to head unload	**headUnload**	0	128	256	426	512
		1–15	8 × **headUnload** × *T*			
Interval from end of head load to start of read or write	**headLoad**	0	128	256	426	512
		1–127	**headLoad** × *T*			

Interleaving is not supported when the driver formats a diskette; the driver always uses a 1:1 interleave. Use the MS-DOS format program to get the recommended DOS interleave factor.

The driver uses memory area 0x2000 to 0x5000 for DMA, for the following reasons:

- The DMA chip has an addressing range of only 24 bits.
- A buffer must fit in one page; that is, a buffer cannot cross the 64KB boundary.

Another routine associated with the diskette driver is ***fdRawio*( )**. This routine allows you to read and write directly to the device; thus, the overhead associated with moving data through a file system is eliminated. The ***fdRawio*( )** routine requires the following parameters:

drive number
: the diskette drive that corresponds to this device: MS-DOS drive **A:** is 0; drive **B:** is 1.

diskette type
: 0 (3.5" 2HD) or 1 (5.25" 2HD). These numbers are indices to the structure table **fdTypes[]** in *installDir***/target/config/***bspname***/sysLib.c**.

FD_RAW ptr
: pointer to the **FD_RAW[]** structure, where the data that is being read and written is stored; see below.

The following is the definition of the **FD_RAW[]** structure:

```
typedef struct fdRaw
    {
    UINT     cylinder;  /* cylinder (0 -> (cylinders-1))   */
    UINT     head;      /* head (0 -> (heads-1))           */
    UINT     sector;    /* sector (1 -> sectorsTrack)      */
    UINT     *pBuf;     /* ptr to buff (bytesSector*nSecs) */
    UINT     nSecs;     /* # of sectors (1-> sectorsTrack) */
    UINT     direction; /* read=0, write=1                 */
    } FD_RAW;
```

ATA/IDE Disk Driver

To include the ATA/IDE disk device driver in your configuration, select the macro **INCLUDE_ATA** for inclusion in the project facility VxWorks view. When **INCLUDE_ATA** is defined, the initialization routine ***ataDrv*( )** is called automatically from ***usrRoot*( )** in **usrConfig.c** for the local IDE disk. To change the interrupt vector and level and the configuration type used by ***ataDrv*( )**, edit the definitions of the constants **ATA0_INT_VEC**, **ATA0_INT_LVL**, and **ATA0_CONFIG** in **pc.h**. The default configuration is suitable for the i8259 interrupt controller; most PCs use that chip. The ***ataDrv*( )** routine requires the following parameters:

controller number
: the controller: a controller described in the first entry of the **ataResources[]** table is 0; a controller described in the second entry is 1. In the default configuration, the local IDE disk is 0; the PCMCIA ATA drive is 1.

number of drives
number of drives on the controller: maximum of two drives per controller is supported.

interrupt vector
interrupt vector

interrupt level
IRQ level

configuration type
configuration type

semaphore timeout
timeout value for the semaphore in the device driver.

watchdog timeout
timeout value for the watchdog in the device driver.

The ***ataDevCreate*( )** routine installs an ATA/IDE disk device in VxWorks. You must call ***ataDevCreate*( )** explicitly for each local IDE disk device you wish to install; it is not called automatically. The ***ataDevCreate*( )** routine requires the following parameters:

controller number
the controller: a controller described in the first entry of the **ataResources[]** table is 0; a controller described in the second entry is 1. In the default configuration, the local IDE disk is 0; the PCMCIA ATA drive is 1.

drive number
the drive: the first drive of the controller is 0; the second drive of the controller is 1. In the default configuration, MS-DOS drive **C:** is 0 on controller 0.

number of blocks
the size of the device.

offset
the number of blocks to leave unused at the start of a disk.

If the configuration type specified with ***ataDrv*( )** is 0, the ATA/IDE driver does not initialize drive parameters. This is the right value for most PC hardware, where the ROMBIOS initialization takes care of initializing the ATA/IDE drive. If you have custom hardware and the ATA/IDE drive is not initialized, set the configuration type to 1 to cause the driver to initialize drive parameters.

The drive parameters are the number of sectors per track, the number of heads, and the number of cylinders. The table has two other members used by the driver:

the number of bytes per sector, and the precompensation cylinder. For each drive, the information is stored in an **ATA_TYPE** structure, with the following elements:

```
int cylinders;       /* number of cylinders           */
int heads;           /* number of heads               */
int sectorsTrack;    /* number of sectors per track    */
int bytesSector;     /* number of bytes per sector     */
int precomp;        /* precompensation cylinder      */
```

A structure for each drive is stored in the **ataTypes[]** table in **sysLib.c**. That table has two sets of entries: the first is for drives on controller 0 (the local IDE disk) and the second is for drives on controller 1 (the PCMCIA ATA card). The table is defined as follows:

```
ATA_TYPE ataTypes[ATA_MAX_CTRLS][ATA_MAX_DRIVES] =
    {
    {{761, 8, 39, 512, 0xff},        /* ctrl 0 drive 0 */
     {761, 8, 39, 512, 0xff}},       /* ctrl 0 drive 1 */
    {{761, 8, 39, 512, 0xff},        /* ctrl 1 drive 0 */
     {761, 8, 39, 512, 0xff}},       /* ctrl 1 drive 1 */
    };
```

The ***ioctl*( )** function **FIODISKFORMAT** always returns **ERROR** for this driver, because ATA/IDE disks are always preformatted and bad sectors are already mapped.

If **INCLUDE_ATA_SHOW** is selected for inclusion, the routine ***ataShow*( )** displays the table and other drive parameters on the standard output device. This routine requires two parameters: *controller number*, which must be either 0 (local IDE) or 1 (PCMCIA ATA), and *drive number*, which must be either 0 or 1.

Another routine associated with the ATA/IDE disk driver is ***ataRawio*( )**. This routine allows you to read and write directly to the device; thus, the overhead associated with moving data through a file system is eliminated. The ***ataRawio*( )** routine requires the following parameters:

controller number
: the controller: a controller described in the first entry of the **ataResources[]** table is 0; a controller described in the second entry is 1. In the default configuration, the local IDE disk is 0; the PCMCIA ATA drive is 1.

drive number
: the drive: the first drive of the controller is 0; the second drive of the controller is 1. In the default configuration, MS-DOS drive **C:** is 0 on controller 0.

ATA_RAW ptr
: pointer to the **ATA_RAW** structure, where the data that is being read and written is stored; see below.

The following is the definition of the **ATA_RAW** structure:

```
typedef struct ataRaw
    {
    UINT     cylinder;  /* cylinder (0 -> (cylinders-1))   */
    UINT     head;      /* head (0 -> (heads-1))           */
    UINT     sector;    /* sector (1 -> sectorsTrack)      */
    UINT     *pBuf;     /* ptr to buff (bytesSector*nSecs) */
    UINT     nSecs;     /* #of sectors (1 -> sectorsTrack) */
    UINT     direction; /* read=0, write=1                 */
    } ATA_RAW;
```

The resource table used by ***ataDrv( )***, **ataResources[]**, is defined in **sysLib.c** as follows:

```
ATA_RESOURCE ataResources[ATA_MAX_CTRLS] =
    {
    {
    {
    5, 0,
    {ATA0_IO_START0, ATA0_IO_START1}, {ATA0_IO_STOP0, ATA0_IO_STOP1},
     0, 0, 0, 0, 0, 0
     }
    IDE_LOCAL, 1, ATA0_INT_VEC, ATA0_INT_LVL, ATA0_CONFIG,
    ATA_SEM_TIMEOUT, ATA_WDG_TIMEOUT, 0, 0
    },   /* ctrl 0 */
    {
    {
    5, 0,
    {ATA1_IO_START0, ATA1_IO_START1}, {ATA1_IO_STOP0, ATA1_IO_STOP1},
     0, 0, 0, 0, 0, 0
     }
    ATA_PCMCIA, 1, ATA1_INT_VEC, ATA1_INT_LVL, ATA1_CONFIG,
    ATA_SEM_TIMEOUT, ATA_WDG_TIMEOUT, 0, 0
    },   /* ctrl 1 */
    };
```

Each resource in the table is an **ATA_RESOURCE** structure, defined as follows:

```
typedef struct ataResource      /* PCCARD ATA resources */
    {
    PCCARD_RESOURCE resource;  /* must be the first member           */
    int     ctrlType;          /* controller type: IDE_LOCAL         */
                               /* or ATA_PCMCIA                      */
    int     drives;            /* 1,2: number of drives              */
    int     intVector;         /* interrupt vector                   */
    int     intLevel;          /* IRQ level                          */
    int     configType;        /* 0,1: configuration type            */
    int     semTimeout;        /* timeout seconds for sync semaphore */
    int     wdgTimeout;        /* timeout seconds for watch dog      */
    int     sockTwin;          /* socket number for twin card        */
    int     pwrdown;           /* power down mode                    */
    } ATA_RESOURCE;
```

⚠ **CAUTION:** This structure applies to both ATA PCMCIA PC cards and local IDE hard disks. For the definition of **PCCARD_RESOURCE**, see *PCMCIA for x86 Release Notes and Supplement*.

Line Printer Driver

This release of VxWorks for the x86 supports write operations to an LPT line printer driver.

To include the line printer driver in your configuration, select the macro **INCLUDE_LPT** for inclusion in the project facility VxWorks view. When **INCLUDE_LPT** is included, the initialization routine ***lptDrv*( )** is called automatically from ***usrRoot*( )** in **usrConfig.c**.

The resource table used by ***lptDrv*( )** is stored in the structure **lptResource[]** in **sysLib.c**. The resources are defined as follows:

```
int   ioBase;             /* IO base address             */
int   intVector;          /* interrupt vector            */
int   intLevel;           /* interrupt level             */
BOOL  autofeed;           /* TRUE if enable autofeed     */
int   busyWait;           /* loop count for BUSY wait    */
int   strobeWait;         /* loop count for STROBE wait  */
int   retryCnt;          /* timeout second for syncSem */
```

***lptDrv*( )** takes two arguments. The first argument is the number of channels (0, 1, or 2). The second argument is a pointer to the resource table.

To change ***lptDrv*( )**'s interrupt vector or interrupt level, change the value of the appropriate constant (**LPT_INT_VEC** or **LPT_INT_LVL**) in **pc.h**.

Many of the LPT driver's routines are accessible only through the I/O system. However, the following routines are available (see the manual pages for details):

***lptDevCreate*( )**
installs an LPT device into VxWorks. Call ***lptDevCreate*( )** explicitly for each LPT device you wish to install; it is not called automatically. This routine takes the following parameters:

name = device name

channel = physical device channel (0, 1, or 2)

***lptAutofeed*( )**
enables or disables the autofeed feature; takes the parameter *channel* (0, 1, or 2).

***lptShow*( )**
if **INCLUDE_LPT** is defined, shows driver statistics; takes the parameter *channel* (0, 1, or 2).

In addition, you can perform the following ***ioctl*( )** functions on the LPT driver:

LPT_GETSTATUS
gets the value of the status register; takes an integer value where status is stored

LPT_SETCONTROL
sets the control register; takes a value for the register

Advanced Programmable Interrupt Controllers (APICs)

This module is a driver for the Intel 82093 I/O APIC (Advanced Programmable Interrupt Controller).

The Local and I/O APICs support 240 distinct vectors in the range of 16 to 255. Interrupt priority is implied by its vector, according to the following relationship:

priority = vector / 16

One is the lowest and 15 is the highest. Vectors 16 through 31 are reserved for exclusive use by the processor. The remaining vectors are for general use. The processor's Local APIC includes an in-service entry and a holding entry for each priority level. To avoid losing interrupts, software should allocate no more than 2 interrupt vectors per priority.

▪ I/O APIC

The I/O APIC unit consists of a set of interrupt input signals, a 24-entry by 64-bit interrupt redirection table, programmable registers, and a message unit for sending and receiving APIC messages over the APIC bus. I/O devices inject interrupts into the system by asserting one of the interrupt lines to the I/O APIC. The I/O APIC selects the corresponding entry in the redirection table and uses the information in that entry to format an interrupt request message. Each entry in the redirection table can be individually programmed to indicate edge/level sensitive interrupt signals, the interrupt vector and priority, the destination processor, and how the processor is selected (statically and dynamically). The information in the table is used to transmit a message to other APIC units (via the APIC bus).

I/O APIC is used in the symmetric I/O mode (define **SYMMETRIC_IO_MODE** in **config.h**). The base address of I/O APIC is determined in ***loApicInit*( )** and stored in the global variable **ioApicBase**. ***ioApicInit*( )** initializes the I/O APIC with information stored in the **redTable[]**. The **redTable[]** has three entries: **lsw**,

vectorNo, and **mask**. The **lsw** entry stores the least significant word of the I/O APIC redirection table. That word indicates the trigger mode, interrupt input pin polarity, destination mode, and delivery mode. The **vectorNo** entry is the vector number of the redirection table. The **mask** entry should be 0; it is used by ***ioApicIntLock*( )** and ***ioApicIntUnlock*( )** to hold the interrupt mask status. ***ioApicShow*( )** shows the contents of the I/O APIC registers.

▪ Local APIC

This module is a driver for the Intel PentiumPro's Local APIC (Advanced Programmable Interrupt Controller).

Local APIC controls the dispatching of interrupts that it receives either locally or from the I/O APIC to its associated processor. It provides facilities for queuing, nesting, and masking interrupts. It handles the interrupt delivery protocol with its local processor, accesses APIC registers, and manages interprocessor interrupts and remote APIC register reads. A timer on the Local APIC allows local generation of interrupts, and local interrupt pins permit local reception of processor-specific interrupts. The Local APIC can be disabled and used in conjunction with a standard 8259-A style interrupt controller.

The base address of the Local APIC is not fixed. The BIOS writes the base address in some standard memory ranges as specified in Intel MP Specification Version 1.4. The initialization routine scans certain memory regions as specified in the specification, to determine the base addresses. It uses the **LOAPIC_BASE** and **IOAPIC_BASE** values defined in **pc.h** if it is not able to find the addresses in the MP configuration table. Local APIC is used in the virtual wire mode (define **VIRTUAL_WIRE_MODE** in **config.h**) and the symmetric I/O mode (define **SYMMETRIC_IO_MODE** in **config.h**), but not in the PIC Mode.

***loApicInit*( )** initializes the Local APIC for the interrupt mode chosen.

***loApicShow*( )** shows the Local APIC registers.

***mpShow*( )** shows the MP configuration table.

▪ Local APIC Timer

This library contains routines for the timer on the Intel PentiumPro's Local APIC.

Local APIC contains a 32-bit programmable timer for use by the local processor. This timer is configured through the timer register in the local vector table. The time base is derived from the processor's bus clock, divided by a value specified in the divide configuration register. After reset, the timer is initialized to zero. The timer supports one-shot and periodic modes. The timer can be configured to interrupt the local processor with an arbitrary vector.

This library gets the system clock from the Local APIC timer and the auxiliary clock from either RTC or PIT channel 0 (define **PIT0_FOR_AUX** in the BSP). The macro **TIMER_CLOCK_HZ** must also be defined in **pc.h** to indicate the clock frequency of the Local APIC Timer.

The macros **SYS_CLK_RATE_MIN**, **SYS_CLK_RATE_MAX**, **AUX_CLK_RATE_MIN**, and **AUX_CLK_RATE_MAX** must be defined to provide parameter checking for the ***sysAuxClkRateSet*( )** and ***sysClkRateSet*( )**routines. They are located in the project facility under **INCLUDE_SYSCLK_INIT** and **INCLUDE_AUX_CLK**.

This driver uses PentiumPro's on-chip TSC (see *Time Stamp Counter (TSC)*, p.446) for the time stamp driver.

The PentiumPro processor provides a 64-bit time-stamp counter that is incremented every processor clock cycle. The counter is incremented even when the processor is halted by the HLT instruction or the external STPCLK# pin. The time-stamp counter is set to 0 following a hardware reset of the processor. The RDTSC instruction reads the time stamp counter and is guaranteed to return a monotonically increasing unique value whenever executed, except for 64-bit counter wraparound. Intel guarantees, architecturally, that the time-stamp counter frequency and configuration will be such that it will not wraparound within 10 years after being reset to 0. The period for counter wrap is several thousands of years in the PentiumPro and Pentium processors.

E
MIPS R3000, R4000, R4650

E.1 Introduction

This appendix provides information specific to VxWorks development on MIPS targets. It includes the following topics:

- Building Applications: how to compile modules for your target architecture.
- Interface Changes: information on changes or additions to particular VxWorks features to support the MIPS processors.
- Architecture Considerations: special features and limitations of the MIPS processors, including a figure showing the VxWorks memory layout for these processors.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

E.2 Building Applications

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for the MIPS targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate architecture-specific features enabled. Define this variable to be **R3000** (for the MIPS R3000 or R3500), **R4000** (for the R4200 or R4600), or **R4650** (for the MIPS R4640 or R4650).

For example, to define **CPU** for an R3500 on the compiler command line, specify the following command-line option when you invoke the compiler:

```
-DCPU=R3000
```

To provide the same information in a header or source file, include the following line in the file:

```
#define CPU R3000
```

All VxWorks makefiles pass along the definition of this variable to the compiler. You can define **CPU** on the **make** command line as follows:

```
% make CPU=R3000 ...
```

You can also set the definition directly in a makefile, with the following line:

```
CPU=R3000
```

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. Tornado is configured to use these tools by default. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables.

Compiling C or C++ Modules

The following is an example of a compiler command line for R3000 cross-development. The file to be compiled in this example has a base name of **applic**.

```
% ccmips -DCPU=R3000 -I/usr/vw/h -mcpu=r3000 -O2 -funroll-loops \
-nostdinc -G 0 -c applic.c
```

This is an example for the R4000:

```
% ccmips -DCPU=R4000 -I/usr/vw/h -mcpu=r4000 -mips3 -mgp32 \
-mfp32 -O2 -funroll-loops -nostdinc -G 0 -c applic.c
```

The options shown in the examples have the following meanings:[1]

-DCPU=R3000
Required; defines the CPU type for the R3000 or R3500. For the R4200 or R4600, specify **R4000**. For the R4640 or R4650, specify **R4650**.

-I $WIND_BASE/target/h
Required; gives access to the VxWorks include files. (Additional **-I** flags may be included to specify other header files.)

-mcpu=r3000
Required; tells the compiler to produce code for the R3000 or R3500. For the R4200 or R4600, specify **r4000**. For the R4640 or R4650, specify **r4650**.

-mips3
Required for R4000 targets (R4200 and R4600) and R4650 targets (R4640 and R4650); tells the compiler to issue instructions from level 3 of the MIPS ISA (64-bit instructions). This compiler option does not apply to R3000 or R3500 targets.

-mfp32
Required for R4000 and R4650 targets; tells compiler to issue instructions assuming that fp registers are 32 bits, required for compatibility with **mathALib**.

-mgp32
Required for R4000 and R4650 targets in code which makes calls to varargs functions provided by VxWorks (***printf*( )**, ***sprintf*( )**, and so forth); tells the compiler to issue instructions assuming that all general-purpose registers are 32 bits.

-msingle-float
Required for R4640 and R4650; tells the compiler to assume that the floating-point processor supports only single-precision operations.

-m4650
Required for R4650 targets; sets **-msingle-float** and **-mmad**[2] flags.

-O2 Optional; tells the compiler to use level 2 optimization.

1. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; a list of these options is included in the *Guide*. Other options are not supported, although they are available with the tools as shipped.
2. Consult *GNU Toolkit User's Guide*.

NOTE: To specify optimization for use with GDB, use the **-O0** flag.

-funroll-loops
Optional; tells the compiler to use loop unrolling optimization.

-nostdinc
Required; searches only the directories specified with the **-I** flag (see above) and the current directory for header files.

-msoft-float
Required for software emulation, tells the compiler to issue library callouts for floating point. For more information, see *Floating-Point Support*, p. 485.

-G 0
Required; tells the compiler not to use the global pointer. For more information, see *Gprel Addressing*, p. 485.

-c Required; specifies that the module is to be compiled only, not linked for execution under the host.

The output is an unlinked object module in **ELF** format with the suffix **.o**; for the example above, the output would be **applic.o**.

The default for **ccmips** is big-endian (set explicitly with **-EB**) and defines **MIPSEB**. Tornado does not support little-endian; do not use **-EL**. Users should not define either **MIPSEB** or **MIPSEL**.

E.3 Interface Variations

This section describes particular routines and tools that are specific to MIPS targets in any of the following ways:

- available only on MIPS targets
- parameters specific to MIPS targets
- special restrictions or characteristics on MIPS targets

For complete documentation, see the reference entries for the libraries, subroutines, and tools discussed below.

cacheR3kLib *and* cacheR4kLib

The libraries **cacheR3kLib** and **cacheR4kLib** are specific to the MIPS release. They each contain a routine that initializes the R3000 or R4000 cache library.

dbgLib

In the MIPS release, the routine ***tt*( )** displays the first four parameters of each subroutine call, as passed in registers **a0** through **a3**. For routines with less than four parameters, ignore the contents of the remaining registers.

For a complete stack trace, use GDB.

intArchLib

In the MIPS release, the routines ***intLevelSet*( )** and ***intVecBaseSet*( )** have no effect. For a discussion of the MIPS interrupt architecture, see *Interrupts*, p. 486.

mathALib

VxWorks for MIPS supports the same set of **mathALib** functions using either hardware facilities or software emulation.[3]

The following double-precision routines are supported for MIPS architectures:

***acos*( )**	***asin*( )**	***atan*( )**	***atan2*( )**	***ceil*( )**	***cos*( )**	***cosh*( )**
***exp*( )**	***fabs*( )**	***floor*( )**	***fmod*( )**	***log10*( )**	***log*( )**	***pow*( )**
***sin*( )**	***sincos*( )**	***sinh*( )**	***sqrt*( )**	***tan*( )**	***tanh*( )**	***trunc*( )**

The following single-precision routines are supported for MIPS architectures:

***acosf*( )**	***asinf*( )**	***atanf*( )**	***atan2f*( )**	***ceilf*( )**	***cosf*( )**	***coshf*( )**
***expf*( )**	***floorf*( )**	***logf*( )**	***log2f*( )**	***log10f*( )**	***sinf*( )**	***sinhf*( )**
***sqrtf*( )**	***tanf*( )**	***tanhf*( )**	***truncf*( )**			

In addition, the single precision routines ***fmodf*( )** and ***powf*( )** are supported for R4650 processors only.

3. To use software emulation, compile your application with the **-msoft-float** compiler option as well as selecting **INCLUDE_SW_FP** for inclusion in the project facility VxWorks view; see *Floating-Point Support*, p. 485. Use of these functions on the R4000 requires that your code be compiled with **-mfp32**.

The following math routines are not supported by VxWorks for MIPS:

***cbrt*( )**	***cbrtf*( )**	***infinity*( )**	***infinityf*( )**	***irint*( )**	***irintf*( )**	***iround*( )**
***iroundf*( )**	***log2*( )**	***round*( )**	***roundf*( )**	***sincosf*( )**		

taskArchLib

The routine ***taskSRInit*( )** is specific to the MIPS release. This routine allows you to change the default status register with which a task is spawned. For more information, see *Interrupt Support Routines*, p. 487.

MMU Support

MIPS targets do not support memory management units (MMUs). Thus, neither **INCLUDE_MMU_BASIC** or **INCLUDE_MMU_FULL** is included in the project facility VxWorks view, and you do not need to define **sysPhysMemDesc[]** in **sysLib.c**. For more information, see *Virtual Memory Mapping*, p. 488.

ELF-specific Tools

The following tools are specific to the ELF format. For more information, see the reference entries for each tool.

elfHex
converts an ELF-format object file into Motorola hex records. The syntax is:

```
elfHex [-a adrs] [-l] [-v] [-p PC] [-s SP] file
```

elfToBin
extracts text and data segments from an ELF file. The syntax is:

```
elfToBin < inFile > outfile
```

elfXsyms
extracts the symbol table from an ELF file. The syntax is:

```
elfXsyms < objMod > symTbl
```

E.4 Architecture Considerations

This section describes the following characteristics of the MIPS architecture that you should keep in mind as you write a VxWorks application:

- Gprel addressing
- Reserved registers
- Floating-point support
- Interrupts
- Virtual memory mapping
- 64-bit support
- Memory layout

Gprel Addressing

The VxWorks kernel uses *gprel* (**gp**-relative) addressing. However, the VxWorks module loader cannot dynamically load tasks that use gprel addressing.

To keep the loader from returning an error, compile application tasks with the **-G 0** option. This option tells the compiler not to use the global pointer.

Reserved Registers

Registers **k0** and **k1** are reserved for VxWorks kernel use, following standard MIPS usage. The **gp** register is also reserved for the VxWorks kernel, because only the kernel uses gprel addressing, as discussed in above. Avoid using these registers in your applications.

Floating-Point Support

R4650

For the R4650, single precision hardware floating-point support is included by **INCLUDE_HW_FP** (which is included by default in the project facility VxWorks view). Double precision floating-point support is provided by software emulation when you use **-msoft-float**. (Note that **INCLUDE_SW_FP** is not required with **-msoft-float** for the R4650.)

R3000 and R4000

If your MIPS board includes a floating-point coprocessor (CP1), we recommend you use it for best performance.

However, if this chip is not available, you can use the GNU compiler **-msoft-float** option. This option keeps all floating-point values in integer registers (a pair of them for double-precision) and emulates all floating-point arithmetic.

To use this software emulation support, select **INCLUDE_SW_FP** in the project facility VxWorks view and unselect **INCLUDE_HW_FP**. Then, in the BSP directory, build VxWorks with the following command:

```
% make [CPU=cpuType] TOOL=sfgnu
```

Interrupts

MIPS Interrupts

The MIPS architecture has inputs for six external hardware interrupts and two software interrupts. In cases where the number of hardware interrupts is insufficient, board manufacturers can multiplex several interrupts on one or more interrupt lines.

The MIPS CPU treats exceptions and interrupts in the same way: it branches to a common vector and provides status and cause registers that let system software determine the CPU state. The MIPS CPU does not switch to an interrupt stack or exception stack, nor does it generate an IACK cycle. These functions must be implemented in software or board-level hardware (for example, the VMEbus IACK cycle is a board-level hardware function). VxWorks for MIPS has implemented a single interrupt stack, and uses task stacks for exception conditions.

Because the MIPS CPU does not provide an IACK cycle, your interrupt handler must acknowledge (or clear) the interrupt condition. If the interrupt handler does not acknowledge the interrupt, VxWorks hangs while trying to process the interrupt condition.

VxWorks for MIPS uses a 256-entry table of vectors. You can attach exception or interrupt handlers to any given vector with the routines ***intConnect*( )** and ***intVecSet*( )**. The files *installDir***/target/h/arch/mips/ivMips.h** and *bspname***.h** list the vectors used by VxWorks.

Interrupt Support Routines

Because the MIPS architecture does not use interrupt levels, the ***intLevelSet*( )** routine is not implemented. The six external interrupts and two software interrupts can be masked or enabled by manipulating eight bits in the status register with ***intDisable*( )** and ***intEnable*( )**. Be careful to pass correct arguments to these routines, because the MIPS status register controls much more than just interrupt generation.

For interrupt control, the routines ***intLock*( )** and ***intUnlock*( )** are recommended. All interrupts are blocked when calling ***intLock*( )**. The routine ***intVecBaseSet*( )** has no meaning on the MIPS; calling it has no effect.

To change the default status register with which all tasks are spawned, use the routine ***taskSRInit*( )**. If used, call this routine before ***kernelInit*( )** in ***sysHwInit*( )**. ***taskSRInit*( )** is provided in case your BSP must mask interrupts from all tasks. For example, the FPA interrupt must be disabled for all tasks.

VMEbus Interrupt Handling

The processing of VMEbus interrupts is the only case where it is not necessary for an interrupt handler to acknowledge the interrupt condition. If you define the option **VME_VECTORED** as TRUE in **config.h** (and rebuild VxWorks), *all* VMEbus interrupts are acknowledged by the low-level exception/interrupt handling code. The VxWorks interrupt vector number corresponds to the VMEbus interrupt vector returned by the VMEbus IACK cycle. With this interrupt handling scheme, VxWorks for MIPS allows multiple VMEbus boards to share the same VMEbus interrupt level without requiring further decoding by a user-attached interrupt handler.

You can still bind to VMEbus interrupts without vectored interrupts enabled, as long as the VMEbus interrupt condition is acknowledged with ***sysBusIntAck*( )** (as defined in **sysLib.c**). In this case, there is no longer a direct correlation with the vector number returned during the VMEbus IACK cycle. The vector number used to attach the interrupt handler corresponds to one of the seven VMEbus interrupt levels as defined in *bspname***.h.** The mapping of the seven VMEbus interrupts to a single MIPS interrupt is board-dependent.

Vectored interrupts do not change the handling of any interrupt condition except VMEbus interrupts. All the necessary interrupt-acknowledge routines are provided in either **sysLib.c** or **sysALib.s**.

CAUTION: Not all boards support VME-vectored interrupts. For more information, see the BSP reference entries.

Virtual Memory Mapping

VxWorks for MIPS operates exclusively in kernel mode and makes use of the **kseg0** and **kseg1** address spaces. A physical addressing range of 512 MB is available. Use of the on-chip *translation lookaside buffer* (TLB) is not supported.

- **kseg0 .** When the most significant three bits of the virtual address are 100, the 2^{29}-byte (512 MB) kernel physical space labeled **kseg0** is the virtual address space selected. References to **kseg0** are not mapped through the TLB; the physical address selected is defined by subtracting 0x8000 0000 from the virtual address. Caches are always enabled for accesses to these addresses.
- **kseg1.** When the most significant three bits of the virtual address are 101, the 2^{29}-byte (512 MB) kernel physical space labeled **kseg1** is the virtual address space selected. References to **kseg1** are not mapped through the TLB; the physical address selected is defined by subtracting 0xa000 0000 from the virtual address. Caches are always disabled for accesses to these addresses; physical memory or memory-mapped I/O device registers are accessed directly.

64-bit Support (R4000 Targets Only)

With VxWorks for MIPS, real-time applications have access to the MIPS R4000 64-bit registers. This lets applications perform 64-bit math for enhanced performance.

To specify 64-bit integers in C, declare them as **long long**. Pointers, integers, and longs are 32-bit quantities in this release of VxWorks.

Memory Layout

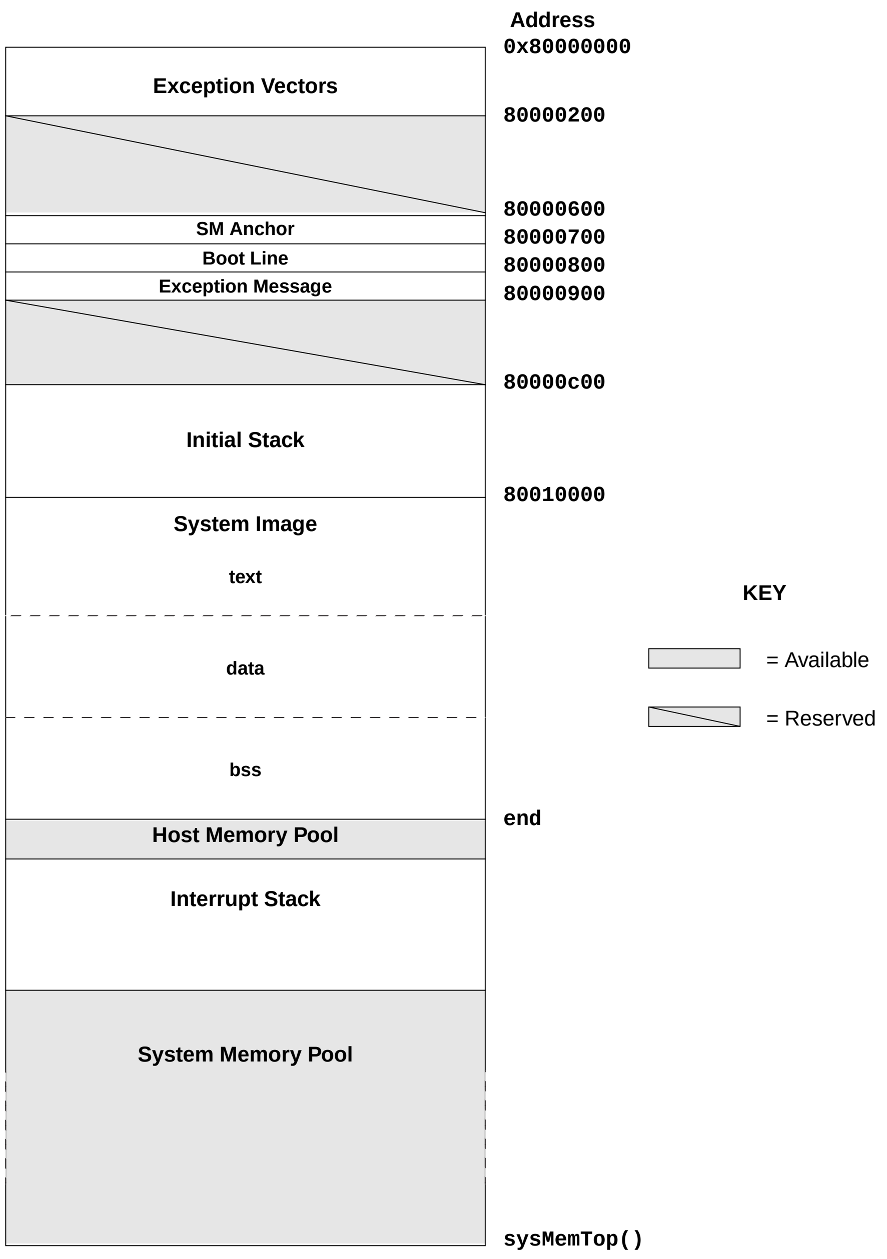
The memory layout of the MIPS is shown in Figure E-1. The figure contains the following labels:

Exception Vectors	Table of exception/interrupt vectors.
SM Anchor	Anchor for the shared memory network (if there is shared memory on the board).
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of the fatal exception message.

Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.
System Image	Entry point for VxWorks.
Host Memory Pool	Memory allocated by host tools. The size depends on the system image and is defined in the macro **WDB_POOL_SIZE**. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
Interrupt Stack	Size is defined by **ISR_STACK_SIZE** under **INCLUDE_KERNEL**. Location depends on system image size.
System Memory Pool	Size depends on size of system image and interrupt stack. The end of the free memory pool for this board is returned by ***sysMemTop*( )**.

All addresses shown in Figure E-1 depend on the start of memory for a particular target board. The start of memory is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

Figure E-1 **VxWorks System Memory Layout (MIPS)**



F
PowerPC

F.1 Introduction

This appendix provides information specific to VxWorks development on PowerPC targets. It includes the following topics:

- Building Applications: how to compile modules for your target architecture.
- Interface Changes: information on changes or additions to particular VxWorks features to support the PowerPC processors.
- Architecture Considerations: special features and limitations of the PowerPC processors, including a figure showing the VxWorks memory layout for these processors.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

F.2 Building Applications

NOTE: The compiler for PowerPC conforms to the Embedded Application Binary Interface (EABI) protocol. Therefore type checking is more rigorous than for other architectures.

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for PowerPC targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications are compiled with the appropriate architecture-specific features enabled. This variable should be set to one of the following values, depending on the processor you are using:

– **PPC403**
– **PPC603**
– **PPC604**
– **PPC860**

For example, to specify **CPU** for a PowerPC 603 on the compiler command line, use the following command-line option when you invoke the compiler:

```
-DCPU=PPC603
```

To provide the same information in a header or source file, include the following line in the file:

```
#define CPU PPC603
```

All VxWorks makefiles pass along the definition of this variable to the compiler. You can define **CPU** on the **make** command line as follows:

```
% make CPU=PPC603 …
```

You can also set the definition directly in a makefile, with the following line:

```
CPU=PPC603
```

⚠ **CAUTION:** If you are using a PowerPC 821 processor, define **CPU** to be **PPC860**.

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. Tornado is configured to use these tools by default. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables.

Compiling C and C++ Modules

The following is an example of a compiler command line for PowerPC 603 cross-development. The file to be compiled in this example has a base name of **applic**.

```
% ccppc -O2 -mcpu=603 -I$WIND_BASE/target/h -fno-builtin \
-fno-for-scope -nostdinc -DCPU=PPC603 -D_GNU_TOOL -c applic.language_id
```

The options shown in the example have the following meanings:

-O2
Optional; performs level 2 optimization.

-mcpu=603
Optional for 603 and 604; required for other processors (specify the appropriate processor values: **601**, **403**, **860**, or **821**); instructs the compiler to produce code for the specified PowerPC architecture. The default is 604, which applies to 603 as well.

-I$WIND_BASE/target/h
Required; gives access to the VxWorks include files. (Additional **-I** flags may be included to specify other header files.)

-fno-builtin
Required; uses library calls even for common library subroutines.

-fno-for-scope
Required; allows the scope of variables declared within a for loop to be outside of the for loop.

-nostdinc
Required; searches only the directory or directories specified with the **-I** flag (see above) and the current directory for header files. It does not search host-system include files.

-DCPU=PPC603
Required; defines the CPU type. If you are using another PowerPC processor, specify the appropriate value (see *Defining the CPU Type*, p.492).

-D_GNU_TOOL
Required; defines the compilation toolkit used to compile VxWorks or applications.

-c Required; specifies that the module is to be compiled only, and not linked for execution under the host.

applic.*language_id*
Required; specifies the file(s) to compile. For C compilation, specify a suffix of **.c**. For C++ compilations, specifies a suffix of **.cpp**. The output is an unlinked object module in **ELF** format with the suffix **.o**. For the example above, the output would be **applic.o**.

Compiling Modules for GDB

To compile C modules for debugging in GDB, we recommend using the **-gdwarf** flag to generate DWARF debug information instead of the **-g** flag, which generates STABS information. For example:

```
% ccppc -mcpu=603 -I$WIND_BASE/target/h -fno-builtin -nostdinc \
-DCPU=PPC603 -c -gdwarf test.c
```

where **$WIND_BASE** is the location of your Tornado tree and **-DCPU** specifies the CPU type.

The compiler does not support DWARF debug information for C++. If you are using C++, you must use the **-g** flag:

```
% ccppc -mcpu=603 -I$WIND_BASE/target/h -fno-builtin -nostdinc \
-DCPU=PPC603 -c -g test.cpp
```

Unsupported Features

Prefixed Underscore

In the PowerPC architecture, the compiler does not prefix underscores to symbols. In other words, **symbol** is not equivalent to **_symbol** as it is in other architecture implementations.

Small Data Area

The compiler supports the small data area. However, for this release of Tornado for PowerPC, VxWorks does not support the small data area. Therefore the **-msdata** compiler flag must not be used.

F.3 Interface Changes

This section describes particular routines and tools that are specific to PowerPC targets in any of the following ways:

- available only for PowerPC targets
- parameters specific to PowerPC targets
- special restrictions or characteristics on PowerPC targets

For complete documentation, see the online documentation.

Memory Management Unit

VxWorks provides two levels of virtual memory support: the basic level bundled with VxWorks, and the full level that requires the optional product VxVMI.Check with your sales representative for the availability of VxVMI for PowerPC.

For detailed information on VxWorks MMU support, see *7. Virtual Memory Interface*. The following subsections augment the information in that chapter.

Instruction and Data MMU

The PowerPC MMU introduces a distinction between instruction and data MMU and allows them to be separately enabled or disabled. Two parameters, **USER_I_MMU_ENABLE** and **USER_D_MMU_ENABLE**, are enabled by default in the Params tab of the Properties window under **SELECT_MMU**. To enable/disable one or both MMUs, select the corresponding parameter and remove the **TRUE**.

60X Memory Mapping

The PowerPC 603 and 604 MMU supports two models for memory mapping. The first, the BAT model, allows mapping of a memory block ranging in size from 128KB to 256MB into a BAT register. The second, the segment model, gives the ability to map the memory in pages of 4KB. Tornado for PowerPC supports both memory models.

- **603/604 Block Address Translation Model**

The size of a BAT register is two words of 32 bits. For the PowerPC 603 and PowerPC 604, eight BAT registers are implemented: four for the instruction MMU and four for the data MMU.

The data structure **sysBatDesc[]**, defined in **sysLib.c**, handles the BAT register configuration. The registers will be set by the initialization software in the MMU library. By default these registers are cleared and set to zero.

All the configuration constants used to fill the **sysBatDesc[]** are defined in *installDir***/target/h/arch/ppc/mmu603Lib.h** for both the PowerPC 603 and the PowerPC 604.

603/604 Segment Model

This model specifies the configuration for each memory page. The entire physical memory is described by the data structure **sysPhysMemDesc[]**, defined in **sysLib.c**. This data structure is made up of configuration constants for each page or group of pages. All the configuration constants defined in Table 7-1 of *7. Virtual Memory Interface* are available for PowerPC virtual memory pages.

Use of the **VM_STATE_CACHEABLE** constant listed in Table 7-1 for each page or group of pages, sets the cache to copy-back mode.

In addition to **VM_STATE_CACHEABLE**, the following additional constants are supported:

– **VM_STATE_CACHEABLE_WRITETHROUGH**
– **VM_STATE_MEM_COHERENCY**
– **VM_STATE_MEM_COHERENCY_NOT**
– **VM_STATE_GUARDED**
– **VM_STATE_GUARDED_NOT**

The first constant sets the page descriptor cache mode field in cacheable write-through mode. Cache coherency and guarded modes are controlled by the other constants.

For more information regarding cache modes, refer to *PowerPC Microprocessor Family: The Programming Environments.*

For more information on memory page states, state flags, and state masks, see *7. Virtual Memory Interface*.

The page table size depends on the total memory to be mapped. The larger the memory to be mapped, the bigger the page table will be. The VxWorks implementation of the segment model follows the recommendations given in *PowerPC Microprocessor Family: The Programming Environments*. During MMU library initialization, the total size of the memory to be mapped is computed, allowing dynamic determination of the page table size. The following table shows the correspondence between the total amount of memory to map and the page table size.

Table 9-4 **Page table size**

Total Memory to map	Page table size
8 MB or less	64 KB
16 MB	128 KB
32 MB	256 KB
64 MB	512 KB
128 MB	1 MB
256 MB	2 MB
512 MB	4 MB
1 GB	8 MB
2 GB	16 MB
4 GB	32 MB

HI and HIADJ Macros

The **HI** and **HIADJ** macros are used in PowerPC assembly code. The macro **HI(x)** is the simple high order 16 bits of the value **x**. The macro **HIADJ(x)** is the high order 16 bits adjusted by bit 15. If bit 15 is set, then the value is adjusted by adding 1.

The macro **HIADJ(x)** must be used whenever the low order 16 bits are to be used with an instruction that interprets them as a signed quantity (for instance, **addi**, **lwz**). If the low order bits are used in an instruction that interprets them as an unsigned quantity (for instance, **ori**) then the proper macro is **HI**, not **HIADJ**.

For example, addi uses a SIGNED quantity, so **HIADJ** is the proper macro:

```
lis   rx, HIADJ(VALUE)
addi  rx, rx, LO(VALUE)
```

However, ori uses an UNSIGNED quantity, so **HI** is the proper macro:

```
lis   rx, HI(VALUE)
ori   rx, rx, LO(VALUE)
```

ELF-Specific Tools

The following tools are specific to the ELF format. For more information, see the reference entries for each tool.

elfHex
converts an ELF-format object file into Motorola hex records. The syntax is:

```
elfHex [-a adrs] [-l] [-v] [-p PC] [-s SP] file
```

elfToBin
extracts text and data segments from an ELF file. The syntax is:

```
elfToBin < inFile > outfile
```

elfXsyms
extracts the symbol table from an ELF file. The syntax is:

```
elfXsyms < objMod > symTbl
```

F.4 Architecture Considerations

This section describes the following characteristics of the PowerPC processors that will affect your VxWorks application:

- supervisor/user mode
- 24-bit addressing
- byte order
- PowerPC register usage
- caches
- memory management unit (MMU)
- floating-point support
- memory layout

For a more comprehensive documentation of PowerPC architectures, see the appropriate Motorola microprocessor user's manual or the IBM user's manual.

Processor Mode

VxWorks always runs in Supervisor mode on processors in the PowerPC family.

24-bit Addressing

The PowerPC architecture limits its relative addressing to 24-bit offsets to conform to the EABI (Embedded Application Binary Interface) standard.

Byte Order

The byte order used by VxWorks for the PowerPC family is big-endian.

PowerPC Register Usage

The PowerPC conventions regarding register usage, stack frame formats, parameter passing between routines, and other factors involving code interoperability, are defined by the ABI (Application Binary Interface) and the EABI (Embedded Application Binary Interface) protocols. The VxWorks implementation for the PowerPC follows these protocols. Table F-1 shows PowerPC register usage in VxWorks.

Table F-1 **PowerPC Registers**

Register Name	Usage
gpr0	Volatile register which may be modified during function linkage.
gpr1	Stack frame pointer, always valid.
gpr2	Second small data area pointer register (_SDA2_BASE_).
gpr3 -gpr4	Volatile registers used for parameter passing and return value.
gpr5-gpr10	Volatile registers used for parameter passing.
gpr11-gpr12	Volatile registers that may be modified during function linkage.
gpr13	Small data area pointer register (_SDA_BASE_).
gpr14-gpr30	Non-volatile registers used for local variables.
gpr31	Used for local variables or "environment pointers."
fpr0	Volatile floating-point register.
fpr1	Volatile floating-point register used for parameter passing and return value.

Table F-1 **PowerPC Registers** *(Continued)*

Register Name	Usage
fpr2-fpr8	Volatile floating-point registers used for parameter passing.
fpr9-fpr13	Volatile floating-point registers.
fpr14-fpr31	Non-volatile floating-point registers used for local variables.

Caches

The following subsections augment the information in *3. I/O System*.

PowerPC processors contain an instruction cache and a data cache. In the default configuration, VxWorks enables both caches. To disable the instruction cache, highlight the **USER_I_CACHE_ENABLE** macro in the Params tab under **INCLUDE_CACHE_ENABLE** and remove the **TRUE**; to disable the data cache, highlight the **USER_D_CACHE_ENABLE** macro and remove the **TRUE**.

For most boards, the cache capabilities must be used with the MMU to resolve cache coherency problems. The page descriptor for each page selects the cache mode. This page descriptor is configured by filling the data structure **sysPhysMemDesc[]** defined in **sysLib.c**. (For more information about cache coherency, see the reference entry for **cacheLib**. For information about the MMU and VxWorks virtual memory, see *7. Virtual Memory Interface*. For MMU information specific to the PowerPC family, see *Memory Management Unit*, p.500.)

The state of both data and instruction caches is controlled by the WIMG[1] information saved either in the BAT (Block Address Translation) registers or in the segment descriptors. Since a default cache state cannot be supplied, each cache may be enabled separately after the corresponding MMU is turned on. For more information on these cache control bits, refer to *PowerPC Microprocessor Family: The Programming Environments*, published jointly by Motorola and IBM.

Memory Management Unit

The PowerPC MMU architecture required some extensions to the standard VxWorks MMU interface. See *Memory Management Unit*, p.495.

1. W: the **WRITETHROUGH** or **COPYBACK** attribute.
I: the inhibited attribute.
M: the memory coherency attribute
G: the guarded attribute

Floating-Point Support

PowerPC 403 and 860

The PowerPC 403 and 860 do not support hardware floating-point instructions. However, VxWorks provides a floating-point library that emulates these mathematical functions. All ANSI floating-point functions have been optimized using libraries from U. S. Software.

***acos*( )**	***asin*( )**	***atan*( )**	***atan2*( )**
***ciel*( )**	***cos*( )**	***cosh*( )**	***exp*( )**
***fabs*( )**	***floor*( )**	***fmod*( )**	***log*( )**
***log10*( )**	***pow*( )**	***sin*( )**	***sinh*( )**
***sqrt*( )**	***tan*( )**	***tanh*( )**	

In addition, the following single-precision functions are also available:

***acosf*( )**	***asinf*( )**	***atanf*( )**	***atan2f*( )**
***cielf*( )**	***cosf*( )**	***expf*( )**	***fabsf*( )**
***floorf*( )**	***fmodf*( )**	***logf*( )**	***log10f*( )**
***powf*( )**	***sinf*( )**	***sinhf*( )**	***sqrtf*( )**
***tanf*( )**	***tanhf*( )**		

The following floating-point functions are not available on PowerPC 403 and 860 processors:

***cbrt*( )**	***infinity*( )**	***irint*( )**	***iround*( )**
***log2*( )**	***round*( )**	***sincos*( )**	***trunc*( )**
***trunc*( )**	***cbrtf*( )**	***infinityf*( )**	***irintf*( )**
***iroundf*( )**	***log2f*( )**	***roundf*( )**	***sincosf*( )**
***truncf*( )**			

PowerPC 60X

The following floating-point functions are available for PowerPC 60X processors:

***acos*( )**	***asin*( )**	***atan*( )**	***atan2*( )**
***ciel*( )**	***cos*( )**	***cosh*( )**	***exp*( )**
***fabs*( )**	***floor*( )**	***fmod*( )**	***log*( )**
***log10*( )**	***pow*( )**	***sin*( )**	***sinh*( )**
***sqrt*( )**	***tan*( )**	***tanh*( )**	

A subset of the ANSI functions is optimized using libraries from Motorola:

***acos*( )**	***asin*( )**	***atan*( )**	***atan2*( )**
***cos*( )**	***exp*( )**	***log*( )**	***log10*( )**
***pow*( )**	***sin*( )**	***sqrt*( )**	

The following floating-point functions are not available on PowerPC 60X processors:

***cbrt*( )**	***infinity*( )**	***irint*( )**	***iround*( )**
***log2*( )**	***round*( )**	***sincos*( )**	***trunc*( )**
***trunc*( )**	***sin*( )**	***sqrt*( )**	

No single-precision functions are available for 60X processors.

Handling of floating-point exceptions is supported for PowerPC 60X processors. By default the floating-point exceptions are disabled.

To change the default for a task spawned with the **VX_FP_TASK** option, modify the values of the Machine State Register (MSR) and the Floating Point Status and Control Register (FPSCR) at the beginning of the task code.

– The MSR's FE0 and FE1 bits select the floating-point exception mode.

– The FPSCR's VE, OE, UE, ZE, XE, NI, and RN bits enable or disable the corresponding floating-point exceptions and rounding mode. (See **archPpc.h** for the macros **PPC_FPSCR_VE** and so forth.)

Register values may be accessed by the routines ***vxMsrGet*( )**, ***vxMsrSet*( )**, ***vxFpscrGet*( )**, and ***vxFpscrSet*( )**.

VxMP Support for Motorola PowerPC Boards

VxMP is an optional VxWorks component that provides shared-memory objects dedicated to high-speed synchronization and communication between tasks running on separate CPUs. For complete documentation of the optional component VxMP, see *6. Shared-Memory Objects*.

Normally, boards that make use of VxMP must support hardware test-and-set (*TAS*: atomic read-modify-write cycle). Motorola PowerPC boards do not provide atomic (indivisible) TAS as a hardware function. VxMP for PowerPC provides special software routines which allow these Motorola boards to make use of VxMP.

Boards Affected

The current release of VxMP provides a software implementation of a hardware TAS for PowerPC-based VME boards of the 1300, 1600, and 2600 families manufactured by Motorola. No other PowerPC boards are affected.

NOTE: Some PowerPC board manufacturers, for example Cetia, claim to equip their boards with hardware support for true atomic operations over the VME bus. Such boards do not need the special software written for the Motorola boards.

Implementation

The VxMP product for Motorola PowerPC boards has special software routines which compensate for the lack of atomic TAS operations in the PowerPC and the lack of atomic instruction propagation to and from these boards. This software consists of the routines ***sysBusTas*( )** and ***sysBusTasClear*( )**.

The software implementation uses ownership of the VME bus as a semaphore; in other words, no TAS operation can be performed by a task until that task owns the VME bus. When the TAS operation completes, the VME bus is released. This method is similar to the special read-modify-write cycle on the VME bus in which the bus is owned implicitly by the task issuing a TAS instruction. (This is the hardware implementation employed, for example, with a 68K processor.) However, the software implementation comes at a price. Execution is slower because, unlike true atomic instructions, ***sysBusTas*( )** and ***sysBusTasClear*( )** require many clock cycles to complete.

Configuring Hardware TAS

To invoke this feature, set **SM_TAS_TYPE** to **SM_TAS_HARD** on the Params tab of the project facility under **INCLUDE_SM_OBJ**.

Restrictions for Multi-Board Configurations

Systems using multiple VME boards where at least one board is a Motorola PowerPC board must have a Motorola PowerPC board as the board with a processor ID equal to 0 (the board whose memory is allocated and shared). This is because a TAS operation on local memory by, for example, a 68K processor does not involve VME bus ownership and is, therefore, not atomic as seen from a Motorola PowerPC board.

This restriction does not apply to systems that have globally shared memory boards which are used for shared memory operations. Specifying **SM_OFF_BOARD** as TRUE on the Params tab of the properties window for the processor with ID of 0 and setting the associated parameters will enable you to assign processor IDs in any configuration. (See *6.4.3 Initializing the Shared-Memory Objects Package*, p.280.)

Memory Layout

The VxWorks memory layout is the same for all PowerPC processors. Figure F-1 shows the memory layout, labeled as follows:

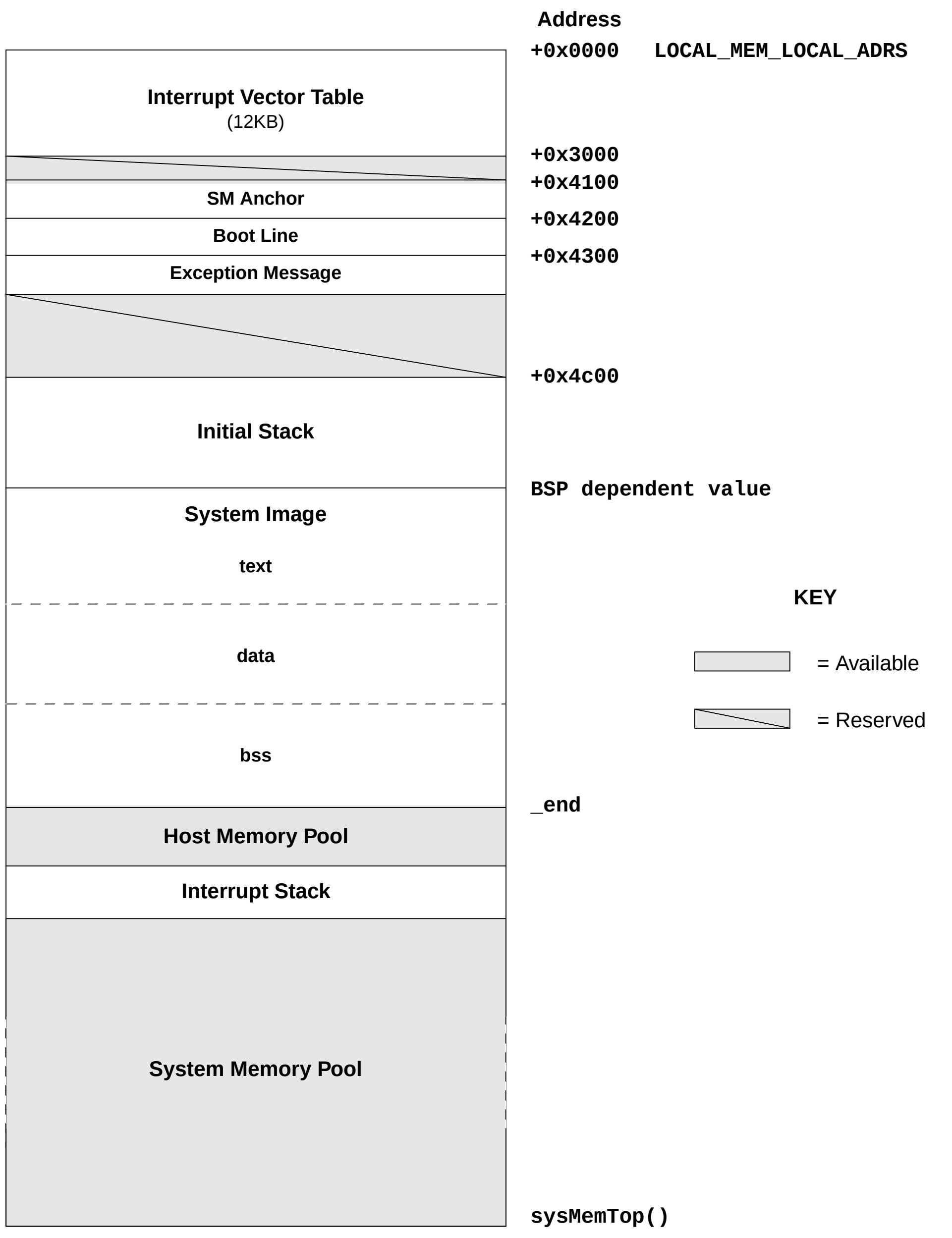
Interrupt Vector Table	Table of exception/interrupt vectors.
SM Anchor	Anchor for the shared memory network and VxMP shared memory objects (if there is shared memory on the board).
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of the fatal exception message.
Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.
System Image	VxWorks itself (three sections: text, data, bss). The entry point for VxWorks is at the start of this region, which is BSP dependent. The entry point for each BSP is as follows:

cetCvme604:	0x100,000
evb403, ads850:	0x10,000
mv1603/4:	0x30,000
ultra60X:	0x10,000

Host Memory Pool	Memory allocated by host tools. The size depends on the the macro **WDB_POOL_SIZE**. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
Interrupt Stack	Size is defined by **ISR_STACK_SIZE** under **INCLUDE_KERNEL**. Location depends on system image size.
System Memory Pool	Size depends on the size of the system image. The ***sysMemTop*( )** routine returns the address of the end of the free memory pool.

All addresses shown in Figure F-1 are relative to the start of memory for a particular target board. The start of memory (corresponding to 0x0 in the memory-layout diagram) is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

Figure F-1 **VxWorks System Memory Layout (PowerPC)**



G
ARM

G.1 Introduction

Tornado for ARM provides the Tornado development tools and the VxWorks RTOS for the Advanced RISC Machines (ARM) family of architectures. ARM is a compact core which operates at a low power level. In addition to the standard 32-bit instruction set, it is available with a 16-bit instruction set (the Thumb instruction set), which permits applications to be developed with very compact code.

This appendix provides information specific to VxWorks development on ARM targets. It includes the following topics:

- Building Applications: how to compile modules for the ARM architecture.
- Toolchain Information: updates to the assembler, CrossWind, and the included toolchain files not yet included in *GNU ToolKit* or *Debugging with GDB*.
- Interface Changes: information on changes or additions to particular VxWorks features to support the ARM processors.
- Architecture Considerations: special features and limitations of the ARM processors, including a figure showing the VxWorks memory layout for these processors.

For general information on the Tornado development environment's cross-development tools, see the *Tornado User's Guide: Projects*.

G.2 Building Applications

The Tornado 2.0 project facility is correctly preconfigured for building WRS BSPs. However, if you choose not to use the project facility or if you need to customize your build, you may need the information in the following sections. This includes a configuration constant, an environment variable, and compiler options that together specify the information the GNU toolkit requires to compile correctly for ARM/Thumb targets.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate architecture-specific features enabled. Define this variable to one of the following values, to match the processor you are using:

ARM7TDMI	ARM-7TDMI (ARM state)
ARM7TDMI_T	ARM-7TDMI (Thumb state)
ARMSA110	StrongARM-110 or StrongARM-1100
ARM710A	ARM-710A
ARM810	ARM-810

For example, to define **CPU** for an ARM-7TDMI on the compiler command line, specify the following command-line option when you invoke the compiler:

```
-DCPU=ARM7TDMI
```

To provide the same information in a header or source file instead, include the following line in the file:

```
#define CPU ARM7TDMI
```

Configuring the GNU ToolKit Environment

Tornado includes the GNU compiler and associated tools. No change is required to the execution path, because the compilation chain is installed in the same **bin** directory as the other Tornado executables. For more information, see *Tornado Getting Started*.

Compiling C and C++ Modules

The following is an example of a compiler command line for ARM cross-development. The file to be compiled in this example has a base name of **applic**.

```
% ccarm -DCPU=ARM7TDMI -mcpu=arm7tdmi -mno-sched-prolog \
-I $WIND_BASE/target/h -fno-builtin -O2 -nostdinc -c applic.language_id
```

The options shown in the example have the following meanings:[1]

ccarm
Required; use **ccarm** for GNU C and C++ support.

-DCPU=ARM7TDMI
Required; defines the CPU type. See the table on page 508.

-mcpu=arm7tdmi
Required for ARM; specifies the instruction set. Use the following:

-mcpu=arm7tdmi	for the ARM-7TDMI
-mcpu=arm710	for the ARM-710A
-mcpu=arm810	for the ARM-810
-mcpu=strongarm110	for the StrongARM-110 and StrongARM-1100

CAUTION: To compile for Thumb state, do not specify **-mcpu**. Specify both **-mthumb** and **-mthumb-interwork**. Although **-mthumb-interwork** is required in this release in order to compile code correctly for Thumb state, the ARM interwork feature is not supported. See *Additional ARM Compiler Options*, p.512.

-mno-sched-prolog
Do not perform scheduling in function prologs and epilogs. This is required for reliable debugging.

-I $WIND_BASE/target/h
Required; includes VxWorks header files. (Additional **-I** flags may be included to specify other header files.)

-fno-builtin
Required; uses library calls even for common library subroutines.

-O2
Optional; performs level 2 optimization.

1. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; see the *Guide* for a list. Other options are not supported, although they are available with the tools as shipped.

-nostdinc
Required; searches only the directories specified with the **-I** flag (see above) and the current directory for header files. Does not search host-system include files.

-c Required; specifies that the module is to be compiled only, and not linked for execution under the host.

applic.*language_id*
Required; the files to compile. For C compilation, specify a suffix of **.c**. For C++ compilation, specify a suffix of **.cpp**. The output is an unlinked object module in **COFF** format with the suffix **.o**; for the example, the output is **applic.o**.

Following C++ compilation, the compiled object module (*applic***.o**) is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks run-time support can use to call the object constructors and destructors. See*5.2.5 Munching C++ Application Modules*, p.232.

Boot Loader Changes

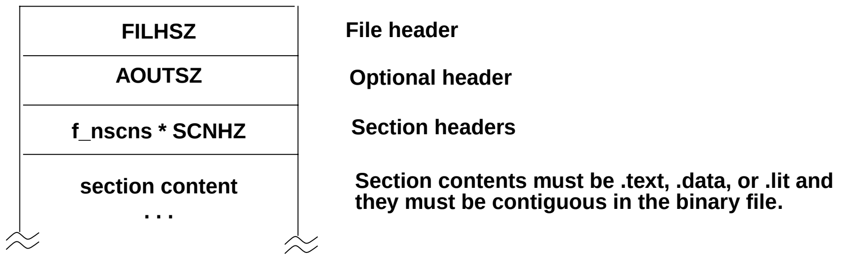
The target-resident loader for ARM targets loads **COFF** format VxWorks images which are composed of multiple text sections and multiple data sections. The ability to load **COFF** files with multiple text and data sections facilitates the use of linker scripts which scatter-load the VxWorks image at boot time. In addition, because the number of relocation entries for any particular **COFF** section may not exceed 65,535 entries, it may be necessary to split very large images into multiple sections.

It is assumed that users implementing linker scripts are comfortable with the GNU linker, the GNU linker command language, the particular OMF used by the GNU tools, and the target memory architecture. In addition to the aforementioned requisite background, the target-resident loader implementation places certain restrictions on how fully-linked **COFF** files (for example, a VxWorks image) are organized.

The target-resident loader assumes that a **COFF** format VxWorks image is ordered such that the **COFF** file header, optional header, and section headers are followed immediately by the section contents for text, data, or lit sections in the binary file. Moreover, it is assumed that the section contents are contiguous in the binary file. Figure G-1 shows typical headers in the binary file.

The fact that text, data, and lit sections must be contiguous with each other and follow the section headers in the binary file does not preclude using a linker script

Figure G-1 **COFF File Headers**


FILHSZ
AOUTSZ
f_nscns * SCNHZ
section content
. . .
File header
Optional header
Section headers
Section contents must be .text, .data, or .lit and they must be contiguous in the binary file.

to locate multiple text and data sections at non-contiguous RAM addresses. For more information on the GNU linker and GNU linker command language, see the *GNU ToolKit User's Guide*.

The target-resident loader for ARM reports the sizes of individual text and data sections in addition to the bss section when VxWorks is booted. For example, if a multiple text section image is booted, output similar to the following might be seen:

```
Attaching network interface oli0... done.
Attaching network interface lo0... done.
Loading... 277764 + 82348 + 66664 + 7948 + 29692
Starting at 0x1000...

Attached TCP/IP interface to oli unit 0
Attaching network interface lo0... done.
NFS client support not included.

               VxWorks

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           CPU: ARM PID - ARM7TDMI (Thumb)
       VxWorks: 5.4
   BSP version: 1.2/0
 Creation date: Feb 10 1999
           WDB: Ready.
```

This format is a slight cosmetic modification to the section size values which WRS boot loaders have traditionally reported as *size of text* + *size of data* + *size of bss*. Reporting the size of individual text and data sections rather than summing them up is intended to be an aid for developers working on VxWorks images which are organized by way of a linker script. This change is not likely to be noticed when the default VxWorks image types are used.

G.3 Toolchain Information

Assembler Pseudo Operations

.arm	no arguments	Generate ARM (32-bit) code.
.thumb	no arguments	Generate Thumb (16-bit) code.
.code	**16** or **32**	Generate 16- or 32-bit code.
.thumb_func	no arguments	Flag this function as a Thumb function.

Additional ARM Compiler Options

In addition to the new ARM compiler options described in *Compiling C and C++ Modules*, p.509, the following compiler options are added to the GNU compiler with Tornado for ARM:

-mapcs-32
Specifies the use of the 32-bit ARM Procedure Call Standard. This is the default. Note that **-mapcs-26** is not supported.

-marm
Generates plain ARM code. This is the default in all current configurations; the option is supplied for symmetry.

-mthumb
Required to generate Thumb code. Requires an ARM CPU with Thumb support.

-mthumb-interwork
Required to generate Thumb code.

⚠ **CAUTION:** The **-mthumb-interwork** option is required to compile code for Thumb state in this release. Although you must use this option in order to use Thumb state, ARM interworking (switching between ARM and Thumb modes in the same application, running ARM code under the Thumb kernel, or running Thumb code under the ARM kernel) is not supported for this release.

-mapcs-frame
-mapcs-leaf-frame
Creates a "stack backtrace" structure for non-leaf and leaf functions respectively. Applies when ARM code is generated. These are the default for ARM state and are automatically disabled when **-mthumb** is active.

-mtpcs-frame
-mtpcs-leaf-frame
Create a "stack backtrace" structure for non-leaf and leaf functions respectively. Analogous to **-mapcs-frame** and **-mapcs-leaf-frame** but apply when **-mthumb** is active.

CrossWind and GDB

CrossWind for Tornado for ARM is based on GDB 4.16. The following new debugger commands are implemented:

VxWorks-timeout *args*
All VxWorks-based targets now support the option **vxworks-timeout**. *args* represents the number of seconds the debugger waits for responses to RPCs.

complete *arg*
List possible completions for *arg*.

hbreak
Set a hardware-assisted breakpoint (if applicable).

set print static-members [on,off]
Print static members when displaying a C++ object. The default is **on**.

show input-radix
Display the current default base for numeric entry.

show output-radix
Display the current default base for numeric display.

set output-radix *base*
Set the default base for numeric display. Supported choices for *base* are decimal 8, 10, or 16. *base* must itself be specified either unambiguously or using the current default radix.

Commands whose functionality has changed in this release are as follows:

- The **watch** command has been greatly expanded with regard to hardware watchpoints (on applicable systems). New related commands include:

  rwatch *args*
  Set a watchpoint that breaks when watch *args* is read.

  awatch *args*
  Set watchpoint that breaks when watch *args* is read or written.

  For more information on the **watch** command, see *Debugging With GDB*.

- The **step** command no longer steps into functions that contain no debugging information. Use the **stepi** command to enter functions with no debugging symbols.

  Additionally, **step** only enters a subroutine if line number information exists; otherwise, it acts like **next**.

G.4 Interface Variations

This section describes particular features and routines that are specific to ARM targets in one of the following ways:

- available only on ARM targets
- parameters specific to ARM targets
- special restrictions or characteristics on ARM targets.

For more complete documentation on these routines, see the reference entries.

Restrictions on ***cret( )*** *and* ***tt( )***

These routines make assumptions about the standard prologue for routines. If routines are written in assembly language, or in another language that generates a different prologue, unexpected results may occur.

tt( ) does not report the parameters to C functions as it cannot determine these from the code generated by the compiler.

⚠ **CAUTION:** The Thumb kernel is compiled without backtrace structures. This means that ***tt( )*** does not work within kernel routines and ***cret( )*** occasionally does the wrong thing. Thumb breakpoints and single-stepping work even if the code is compiled without backtrace structures. One solution for debugging is to use ARM state and then switch to Thumb state for your final debugging and production.

cacheLib

The ***cacheLock( )*** and ***cacheUnlock( )*** routines always return ERROR (see *Caches*, p.522). Use of the cache and MMU are very closely linked on ARM processors. Consequently, if **cacheLib** is used, **vmLib** is also required. In addition, the **cacheLib** and **vmLib** calls need to be coordinated, see *Memory Management Unit*, p.524.

dbgLib

Many ARM processors have no debug or trace mode and no support for hardware-assisted debugging. Because of this, VxWorks for ARM uses only software breakpoints. When you set a software breakpoint, VxWorks replaces an instruction with a known undefined instruction. VxWorks restores the original code when the breakpoint is removed; if memory is examined or disassembled, the original code is shown.

dbgArchLib

If you are using the target shell, note that the following additional architecture-specific routines are available to you:

psrShow( )

Display the symbolic meaning of a specified PSR value on the standard output.

cpsr( )

Return the contents of the Current Processor Status Register (CPSR) of the specified task.

intALib

intLock( ) and *intUnlock( )*

The routine ***intLock( )*** returns the I bit from the CPSR as the lock-out key for the interrupt level prior to the call to ***intLock( )***. The routine ***intUnlock( )*** takes this value as a parameter. For ARM, these routines control the CPU interrupt mask directly. They do not manipulate the interrupt levels in the interrupt controller chip.

intArchLib

ARM processors generally have no on-chip interrupt controllers to handle the interrupts multiplexed on the IRQ pin. Control of interrupts is a BSP-specific matter. All of these routines are connected by function pointers to routines which must be provided in ARM BSPs by a standard interrupt controller driver. For general information on interrupt controller drivers, see *Wind Technical Note #46*. For special requirements or limitations, see the appropriate interrupt controller device driver documents.

intLibInit( )

STATUS intLibInit(*nLevels***,** *nVecs***,** *mode***)**

This routine initializes the interrupt architecture library. It is usually called from ***sysHwInit2*( )** in the BSP code. The *mode* argument specifies whether interrupts are handled in preemptive mode (**INT_PREEMPT_MODEL**) or non-preemptive mode (**INT_NON_PREEMPT_MODEL**).

intEnable( ) and *intDisable*( )

The ***intEnable*( )** and ***intDisable*( )** calls affect the masking of interrupts in the BSP interrupt controller and do not affect the CPU interrupt mask.

intVecSet( ) and *intVecGet*( )

Not supported, not present.

intLockLevelSet( ) and *intLockLevelGet*( )

Not supported. Present, but not functional.

intVecBaseSet( ) and *intVecBaseGet*( )

Not supported. Present, but not functional.

intUninitVecSet( )

The user can use this function to install a default interrupt handler for all uninitialized interrupt vectors. The routine is called with the vector number as a single argument.

mmuALib

The routine ***mmuReadId*( )** is provided on processors with MMUs to return the processor ID (the SA-110, the SA-1100, the ARM-710A, and the ARM-810). This routine is not available on the ARM-7TDMI, as it has no MMU to return the processor ID.

usrLib

The interrupt stack display produced by ***checkStack*( )** in the target shell shows two interrupt stacks. For details, see section *Interrupt stacks*, p.521.

vmLib

As mentioned above for **cacheLib**, caching and virtual memory are linked on ARM processors. Use of **vmLib** requires that **cacheLib** be included as well and that calls to the two libraries be coordinated. See *Memory Management Unit*, p.524.

vxALib

The test-and-set primitive ***vxTas*( )** provides a C-callable interface to the ARM SWPB (swap byte) instruction.

vxLib

The ***vxMemProbe*( )** routine, which probes an address for a bus error, is supported by trapping data aborts. If the BSP hardware does not generate data aborts when illegal addresses are accessed, ***vxMemProbe*( )** does not return the expected results, The BSP can provide an alternate routine by inserting the address of the alternate routine in the global variable **_func_vxMemProbeHook**.

COFF-Specific Tools For ARM

The following tools are specific to the **COFF** format on ARM processors. For more information, see the reference entries for each tool.

coffHexArm
converts an **COFF**-format object file into Motorola hex records. The syntax is:

coffHexArm [-a *offset***] [-l]** *file*

coffArmToBin
extracts text and data segments from a **COFF** file and writes it to standard output as a simple binary image. The syntax is:

coffArmToBin < *infile* **>** *outfile*

xsymcArm
extracts the symbol table from a **COFF** file. The syntax is:

xsymcArm < *objMod* **>** *symTbl*

G.5 Architecture Considerations

This section describes the following characteristics of the ARM processors that you may need to keep in mind as you write a VxWorks application:

- processor mode and byte order
- ARM/Thumb state
- interrupts and exceptions
- floating point support
- caches
- memory management unit
- WindView
- memory layout

For comprehensive documentation of the ARM architecture and for specific processors, you may wish to refer to the *ARM Architecture Reference Manual* and the appropriate data sheets of the processors.

Processor Mode and Byte Order

VxWorks for ARM executes mainly in 32-bit supervisor mode (SVC32). When exceptions occur which cause the CPU to enter other modes, the kernel generally switches to SVC32 mode for most of the processing. No code should execute in user mode. No support is included for the 26-bit modes, which are obsolete.

ARM CPUs include some support for both little-endian and big-endian byte orders. This release includes only support for little-endian byte order, but network applications must convert some data to a standard network order, which is big-endian. In particular, in network applications, be sure to convert the port number to network byte order using ***htons*( )**.

For more information about macros and routines to convert byte order from little-endian to big-endian or vice-versa, see the *VxWorks Network Programmer's Guide: TCP/IP Under VxWorks*.

ARM/Thumb State

This release of Tornado for ARM supports both 32-bit instructions (ARM state) and 16-bit instructions (Thumb state).

Thumb Limitation

When running a Thumb kernel and using either the host or target shell, passing a function name as a parameter to a function does not pass an address suitable for calling. The failure is due to the fact that addresses in Thumb state must have bit zero set, but the symbol table has bit zero clear.

Example: At the shell prompt, type the following:

```
-> sp func1,func2
```

where **func1** and **func2** are names of functions. Function **func1** is spawned as a task and passed the address of **func2** as a parameter. Unfortunately, that address is not suitable for use as a Thumb function pointer by **func1** because, when the shell looks up **func2** in the symbol table, it gets back an address with bit zero clear. Calling that address causes it to be entered in ARM state, not Thumb state.

The simplest workaround is to type the following:

```
-> sp func1,func2 | 1
```

An alternative is to write **func1** as follows:

```
extern int func2(void);
int func1(void)
    {
    return func2();
    }
```

In this case, the loader provides the correct address for **func2** when the object file is loaded. Thus **func2** is entered in Thumb state as required when you type the following:

```
-> sp func1
```

A more flexible alternative is to write **func1** as follows:

```
int func1(FUNCPTR f)
    {
    f = (FUNCPTR)((UINT32)f | 1);
    return f();
    }
```

This allows you to call the function successfully as follows:

```
-> sp func1,func2
```

Interrupts and Exceptions

When an ARM interrupt or exception occurs, the CPU switches to one of several exception modes, each of which has a number of dedicated registers. In order to make the handlers reentrant, the stub routines that VxWorks installs to trap interrupts and exceptions switch from the exception mode to SVC mode for further processing; the handler cannot be reentrant while executing in an exception mode because reentry would destroy the link register. When an exception or base-level interrupt handler is installed by a call to VxWorks, the address of the handler is stored for use by the stub when the mode switching is complete. The handler returns to the stub routine to restore the processor state to what it was before the exception occurred. Exception handlers (excluding interrupt handlers) can modify the state to be restored by changing the contents of the register set passed to the handler.

ARM processors do not, in general, have on-chip interrupt controllers. All interrupts are multiplexed on the IRQ pin except for FIQs (see *Fast Interrupt (FIQ)*, p.521). Therefore routines must be provided within the BSP to enable and disable specific device interrupts, to install handlers for specific device interrupts, and to determine the cause of the interrupt and dispatch the correct handler when an interrupt occurs. These routines are installed by setting function pointers. For examples, see the interrupt control modules in *installDir***/target/src/drv/intrCtl**. A device driver then installs an interrupt handler by calling ***intConnect*( )**. For more information, see *Wind Technical Note #46*.

Exceptions other than interrupts are handled in a similar fashion: the exception stub switches to SVC mode and then calls any installed handler. Handlers are installed by calls to ***excVecSet*( )** and the addresses of installed handlers can be read by calls to ***excVecGet*( )**.

Thumb State Interrupt Handling

When an interrupt occurs in a Thumb kernel (in other words, a kernel built with **CPU=ARM7TDMI_T**) the CPU switches to ARM state. The kernel code then saves appropriate state information and calls the interrupt demultiplexing code. This code can, in theory, be ARM or Thumb code but only Thumb code is supported and tested.

The interrupt demultiplexing code then calls the device-specific ISR (the routine installed by a call to ***intConnect*( )**). Again, in theory, that code could be ARM or Thumb code but only Thumb code is supported and tested.

⚠ **CAUTION:** In non-Thumb kernels (kernels built with **CPU=ARM7TDMI** rather than **CPU=ARM7TDMI_T**) only ARM code ISRs will be entered correctly.

Interrupt stacks

VxWorks for ARM uses a separate interrupt stack to avoid having to make task interrupt stacks big enough to accommodate the needs of interrupt handlers. The ARM architecture has a dedicated stack pointer for its IRQ interrupt mode. However, because the low-level interrupt handling code must be reentrant, IRQ mode is only used on entry and exit from the handler; an interrupt destroys the IRQ mode link register. The majority of interrupt handling code runs in SVC mode on a dedicated SVC-mode interrupt stack.

Fast Interrupt (FIQ)

Fast Interrupt (FIQ) is not handled by VxWorks. BSPs can use FIQ as they wish, but VxWorks code should not be called from FIQ handlers. If this functionality is required, the preferred mechanism is to downgrade the FIQ to an IRQ by software access to appropriately-designed hardware which generates an IRQ. The IRQ handler can then make the call to VxWorks.

Floating-Point Support

In this release, no support is included for floating-point coprocessors. Support for floating-point arithmetic is provided as part of the GNU ARM distribution from the Free Software Foundation, in **libgcc.a**. The GNU implementation utilizes call-outs rather than emulation of floating-point instructions.

WARNING: On ARM processors, **double** variables have a different format from IEEE double on most other processors. The bit pattern used by the ARM hardware and software floating point implementations follows the IEEE standard; however, the byte order is different from standard practice leading to a *cross-endian* implementation. Be careful when sharing **double** values in memory between ARM and other processors.

On ARM, while each word of a **double** is stored little-endian, the most significant word (the word containing the sign bit) is at the lower address. This is neither *pure big-endian* (as implemented in 68k processors) nor *pure little-endian* (as implemented in x86 processors). Cygnus added a new binary floating point format, **littlebyte_bigword**, to GNU **libiberty** and changed GDB to use this format for ARM; this implementation is adopted for WRS ARM BSPs and for CrossWind.

This format is chosen to be consistent with the ARM hardware floating point implementation, the ARM7500FE FPA Coprocessor Macrocell. However, since most IEEE floating point implementations are *pure big-* or *little-endian*, shared memory exchange of **double** variables is complicated by the unique *cross-endianness* of ARM **double** variables.

Caches

The ARM-7TDMI processor does not have a cache or an MMU. The ARM SA-110 processor has a 16 KB instruction cache, a 16 KB data cache, a write buffer, and an MMU on the chip. The ARM SA-1100 has a 16 KB instruction cache, an 8 KB data cache, and a 512 byte minicache. The ARM-710A and ARM-810 each have an 8KB mixed instruction and data cache, with write buffer and an MMU on chip. The following subsections augment the information in *7. Virtual Memory Interface*.

For all of the ARM caches, the cache capabilities must be used with the MMU to resolve cache coherency problems. When the MMU is enabled, the page descriptor for each page selects the cache mode, which can be cacheable or non-cacheable. This page descriptor is configured by filling in the **sysPhysMemDesc[ ]** structure defined in the BSP *installDir***/target/config/***bspname***/sysLib.c** file. (For more information about cache coherency, see the **cacheLib** reference entry. For information on VxWorks's MMU support, see *7. Virtual Memory Interface*. For MMU information specific to the ARM family, see *Memory Management Unit*, p.524.)

VxWorks for ARM does not support locking and unlocking of ARM caches. Not all ARM caches support cache locking and unlocking. Thus the ***cacheLock*( )** and ***cacheUnlock*( )** routines have no effect on ARM targets and always return **ERROR**.

The effects of the ***cacheClear*( )** and ***cacheInvalidate*( )** routines depend on the CPU type and on which cache is specified.

SA-110 and SA-1100 Caches

The SA-110 and SA-1100 processors contain an instruction cache and a data cache. By default, VxWorks uses both caches; that is, both are enabled. To disable the instruction cache, highlight the **USER_I_CACHE_ENABLE** macro in the Params tab under **INCLUDE_CACHE_ENABLE** and remove the **TRUE**; to disable the data cache, highlight the **USER_D_CACHE_ENABLE** macro and remove the **TRUE**.

The data cache, if enabled, must be set to cacheable copyback mode. Although the cache appears to support a write-through mode, the effect of the write-buffer is to make this effectively a copyback mode, as all writes from the cache are buffered. The **USER_D_CACHE_MODE** parameter in the Params tab under **INCLUDE_CACHE_MODE** should not, therefore be changed from the default setting of **CACHE_COPYBACK**.

It is not appropriate to think of the mode of the instruction cache. The instruction cache is a read cache that is not coherent with stores to memory so code that writes to cacheable instruction locations must ensure instruction cache validity. You should set the **USER_I_CACHE_MODE** parameter in the Params tab under **INCLUDE_CACHE_MODE**.to **CACHE_WRITETHROUGH** and not change it.

With the data cache specified, ***cacheClear*( )** first pushes dirty data to memory and then invalidates the cache lines, while ***cacheInvalidate*( )** just invalidates the lines (in which case any dirty data contained in the lines is lost).

With the instruction cache specified, both routines have the same result: they invalidate all of the instruction cache. As the instruction cache is a separate cache from the data cache, there can be no dirty entries in the instruction cache, so no dirty data can be lost.

ARM-710A Caches

The ARM-710A has a combined instruction and data cache. The cache is actually a write-through cache, but the separate write-buffer makes this a copyback cache if the write-buffer is enabled. VxWorks uses the **USER_D_CACHE_MODE** parameter in the Params tab under **INCLUDE_CACHE_MODE** (which must be the same as **USER_I_CACHE_MODE**) to determine whether to enable the write buffer.

With either cache specified, ***cacheClear*( )** flushes the write-buffer and invalidates all the ID-cache, while ***cacheInvalidate*( )** just invalidates all the ID-cache. As the cache is a combined, writethrough cache, no dirty data can be lost.

ARM-810 Caches

The ARM-810 has a combined instruction and data cache. Although the ARM-810 cache appears to support a write-through mode, the effect of the write-buffer is to make this effectively a copyback mode, as all writes from the cache are buffered. The **USER_D_CACHE_MODE** parameter in the Params tab under **INCLUDE_CACHE_MODE** should not, therefore, be changed from the default setting of **CACHE_COPYBACK**. The ARM-810 also has a Branch Prediction capability, but this feature is not supported in this release.

The ARM-810 has a copyback, combined instruction and data cache and invalidating a part of the cache is not possible without invalidating other, unintended parts of the cache which might contain dirty data. Before invalidating a cache line, others may need to be pushed to memory.

With the data cache specified, ***cacheClear*( )** has the same effect as for the SA-110: it first pushes dirty data to memory and then invalidates the cache lines. For ***cacheInvalidate*( )**, unless **ENTIRE_CACHE** is specified, the behavior is the same as ***cacheClear*( )**. If **ENTIRE_CACHE** is specified, the entire ID-cache is invalidated.

With the instruction cache specified, the behavior of the ***cacheClear*( )** and ***cacheInvalidate*( )** routines is identical: both just flush the Prefetch Unit, so no dirty data is lost from the ID-cache.

Memory Management Unit

VxWorks provides two levels of virtual memory support. The basic level is bundled with VxWorks. The full level requires the optional product VxVMI. Both are supported by the ARM SA-110, SA-1100, ARM-710A and ARM-810 processors; the ARM-7TDMI supports neither since it does not have an MMU.

For detailed information on VxWorks's MMU support, see *7. Virtual Memory Interface*. The following subsections augment the information in that chapter.

ARM Cache/MMU

The caching and memory management functions on the ARM are both provided on-chip and are very closely interlinked. In general, caching functions on the ARM require the MMU to be enabled. Consequently, if cache support is configured into VxWorks, MMU support is also included by default. On the SA-110, the instruction cache can be enabled without enabling the MMU, but no specific support for this mode of operation is included in this release.

Only certain combinations of MMU and cache enabling are valid, and there are no hardware interlocks to enforce this. In particular, enabling the data cache without enabling the MMU can lead to undefined results. Consequently, if an attempt is made to enable the data cache via ***cacheEnable*( )** before the MMU has been enabled, the data cache is not enabled immediately. Instead, flags are set internally so that if the MMU is enabled later, the data cache is enabled with it. Similarly, if the MMU is disabled, the data cache is also disabled, until the MMU is reenabled.

All memory management is performed on “small pages” which are 4 KB in size. No use is made of the ARM concepts of “sections” or “large pages.”

Support is provided for BSPs that include separate static RAM for the MMU translation tables. This support requires the ability to specify an alternate source of memory other than the system memory partition. A global function pointer, **_func_armPageSource** should be set by the BSP to point to a routine that returns a memory partition identifier describing memory to be used as the source for translation table memory. If this function pointer is **NULL**, the system memory partition is used. The BSP must modify the function pointer before calling ***mmuLibInit*( )**. The initial memory partition must be large enough for all requirements; it does not expand dynamically or overflow into the system memory partition if it fills.

Support is also provided for those SA-110/SA-1100 BSPs that provide a special area in the address space to be read, to flush the data cache. All SA-110/SA-1100 BSPs must declare a pointer (**sysCacheFlushReadArea**) to a readable, cached block of address space, used for nothing else. If the BSP has an area of the address space that does not actually contain memory, but is readable, it may set the pointer to point to that area. If it does not, it should allocate some RAM for this area. In either case, the area must be marked as readable and cacheable in the page tables. The declaration can be in the BSP **sysLib.c** file, for example:

```
UINT32 sysCacheFlushReadArea[D_CACHE_SIZE/sizeof(UINT32)];
```

or in the BSP **romInit.s** and **sysALib.s** files, for example:

```
.globl  _sysCacheFlushReadArea
.equ    _sysCacheFlushReadArea, 0x50000000
```

Note that a declaration in **sysLib.c** of the form:

```
UINT32 * sysCacheFlushReadArea = (UINT32 *) 0x50000000;
```

cannot be used as this introduces another level of indirection, causing the wrong address to be used for the cache flush buffer.

During certain cache/MMU operations (for example, cache flushing), interrupts must be disabled and BSPs may wish to have control over this. The contents of the variable **cacheArchIntMask** determine which interrupts are disabled. This has the default value **I_BIT | F_BIT**, indicating that both IRQs and FIQs are disabled during these operations. If a BSP requires leaving FIQs enabled, the contents of **cacheArchIntMask** should be changed to **I_BIT**. Use extreme caution when changing the contents of this variable from its default.

Some systems cannot provide an environment where virtual and physical addresses are the same. (The SA-1100 CPU is an example of this.) This is particularly important for those areas containing page tables. In order to support these systems, the BSP must provide mapping functions to convert between virtual and physical addresses: the global function pointers **_func_armVirtToPhys** and **_func_armPhysToVirt** should be set to point to those functions. If these function pointers are **NULL**, it is assumed that virtual addresses are equal to physical addresses in the initial mapping. The BSP must set the function pointers before either ***mmuLibInit*( )** or ***cacheLibInit*( )** is called.

ARM Memory Management Units

On those ARM CPUs with MMUs, you can set a specific configuration for each memory page. The entire physical memory is described by **sysPhysMemDesc[ ]**, which is defined in *installDir***/target/config/***bspname***/sysLib.c**. This data structure is made up of state flags for each page or group of pages. All the state flags defined in *Page States*, p.294 are available for virtual memory pages.

NOTE: The **VM_STATE_CACHEABLE** flag listed in Table 7-2 sets the cache to copyback mode for each page or group of pages by setting the B and C bits in the page tables. On the ARM-710A only, set the cache to writethrough mode using **VM_STATE_CACHEABLE_WRITETHROUGH** which sets only the C bit in the page tables.

NOTE: The **VM_STATE_BUFFERABLE** flag is also available on the ARM. Setting pages to this state using ***vmStateSet*( )** results in those pages being bufferable but not cacheable (only the B bit in the page tables is set). Thus writes go through the write buffer, but not the cache. If **VM_STATE_CACHEABLE_NOT** is used, pages are set to neither cacheable nor bufferable (both the B and C bits are clear).

ARM -710A

The ARM-710a has an MMU Control Register that is not readable. In order to have access to the information, a soft copy is kept in the architecture code. This soft copy is initialized to the symbolic constant **MMU_INIT_VALUE**. In all WRS ARM-710A BSPs, the initialization code sets the MMU Control Register to this value, so that the register and soft copy are in step.

Writers of other 710a-based BSPs must ensure that the register is set to the initial value of the soft-copy, and that (assuming they use the VxWorks MMU/cache) no discrepancy between the soft copy and the register is allowed to happen.

SA-1100

The SA-1100 CPU has elements of its physical address map fixed such that it is not possible to run VxWorks on it without enabling the MMU to produce a virtual address map of the standard form (in other words, RAM mapped over the exception vectors). BSPs for this CPU (such as Brutus) select **INCLUDE_MMU_BASIC** for inclusion by default, and use the MMU to implement a standard VxWorks virtual address map.

The SA-1100 contains extensions to the SA-110 MMU, including a read buffer, process ID mapping, and a minicache. No support is provided for the read buffer or process ID mapping in this release. However, the extra state **VM_STATE_CACHEABLE_MINICACHE** is available on the SA-1100, which is not available on other ARM CPUs. Setting pages to this state using ***vmStateSet*( )** results in those pages being cached in the minicache and not in the main data cache. Calling ***cacheInvalidate*( )** with the parameters **DATA_CACHE**, **ENTIRE_CACHE** invalidates the minicache and the main data cache.

WARNING: In all other respects, no support is provided for the minicache and the user is entirely responsible for ensuring cache coherency between the minicache, the main cache, and main memory. If no pages are marked with the flag **VM_STATE_CACHEABLE_MINICACHE**, then cache coherency is handled in the normal fashion, using the standard ***cacheLib*( )** routines.

Memory Layout

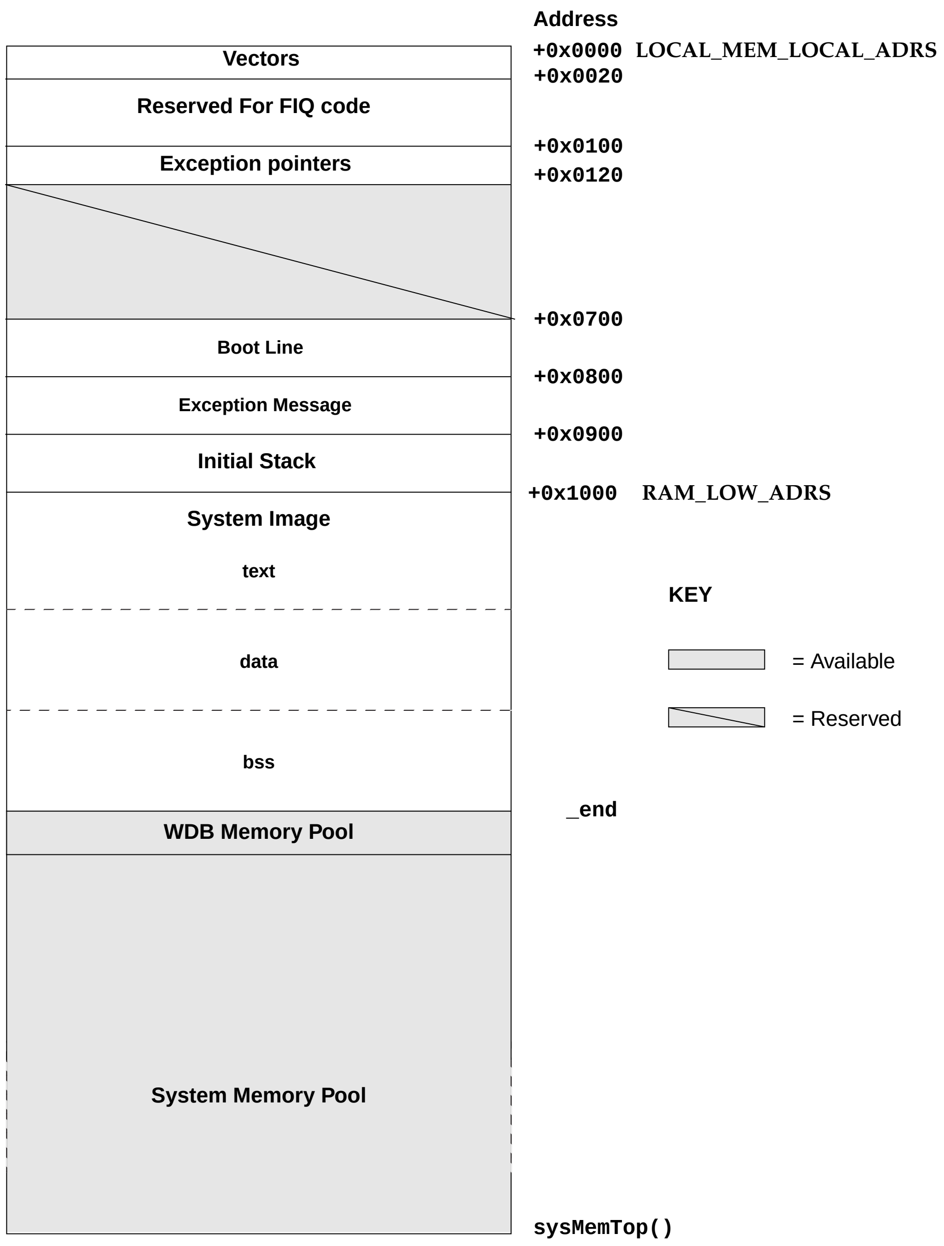
The VxWorks memory layout is the same for all the ARM processors. Figure G-2 shows memory layout, labeled as follows:

Vectors	Table of exception/interrupt vectors.
FIQ Code	Reserved for FIQ handling code.
Exception pointers	Pointers to exception routines, which are used by the vectors.
Boot Line	ASCII string of boot parameters.
Exception Message	ASCII string of fatal exception message.
Initial Stack	Initial stack for ***usrInit*( )**, until ***usrRoot*( )** gets allocated stack.
System Image	VxWorks itself (three sections: text, data, bss). The entry point for VxWorks is at the start of this region.
WDB Memory Pool	Size depends on the macro **WDB_POOL_SIZE** which defaults to one-sixteenth of the system memory pool. This space is used by the target server to support host-based tools. Modify **WDB_POOL_SIZE** under **INCLUDE_WDB**.
System Memory Pool	Size depends on size of the system image.The ***sysMemTop*( )** routine returns the end of the free memory pool.

All addresses shown in Figure G-2 are relative to the start of memory for a particular target board. The start of memory (corresponding to 0x0 in the memory-layout diagram) is defined as **LOCAL_MEM_LOCAL_ADRS** under **INCLUDE_MEMORY_CONFIG** for each target.

NOTE: The initial stack and system image addresses are configured within the BSP.

Figure G-2 **VxWorks System Memory Layout (ARM)**



H
VxSim
Built-in Simulator and Optional Product

H.1 Introduction

VxSim, the VxWorks simulator, is a port of VxWorks to the various host architectures. It provides a simulated target for use as a prototyping and test-bed environment. In most regards, its capabilities are identical to a true VxWorks system running on target hardware. Users link in applications and rebuild the VxWorks image exactly as they do in any VxWorks cross-development environment using a standard BSP.

The difference between VxSim and the VxWorks target environment is that in VxSim the image is executed on the host machine itself as a host process. There is no emulation of instructions, because the code is for the host's own architecture. A communication mechanism is provided to allow VxSim to obtain an Internet IP address and communicate with the Tornado tools on the host (or with other nodes on the network) using the VxWorks networking tools.

Because target hardware interaction is not possible, device driver development may not be suitable for simulation. However, the VxWorks scheduler is implemented in the host process, maintaining true tasking interaction with respect to priorities and preemption. This means that any application that is written in a portable style and with minimal hardware interaction should be portable between VxSim and VxWorks.

The basic functionality of VxSim is included with the Tornado tools and is preconfigured to allow immediate access to the simulated target. The optional component of VxSim provides the simulator with networking capability.

The key differences between VxSim and other BSPs are summarized below. For a detailed discussion of subtle implementation differences which may affect application development, see *H.4 Architecture Considerations*, p.540.

Built-In Simulator

VxSim has only a few differences from VxWorks:

Drivers
: Because device drivers require direct hardware interaction, most VxWorks device drivers are not available with VxSim.

File System
: VxSim defaults to using a pass-through file system (passFs) to access files directly on the workstation. (See the online reference for **passFsLib** under VxWorks Reference Manual> Libraries.) Most VxWorks targets default to using **netDrv** to access files on the host.

Networking
: Networking is not available in the base product.

Optional Product

The optional VxSim component provides full network capability for your simulator. The optional product also allows you to run more than one instance of VxSim on your host.

In order to simulate the network IP connectivity of a VxWorks target, VxSim includes special drivers which operate using IP addresses. The following network interfaces are available, depending on your host type:

ULIP	User-Level Internet Protocol	Solaris 2, Windows NT
PPP	Point-to-Point Protocol	Solaris 2
SLIP	Serial Line Internet Protocol	HP-UX 10

All interfaces provide an I/O-based interface for IP networking that allows VxSim processes to be addressed at the IP level. When multiple programs are run, they can send packets to each other directly. This is because the host hands the packets back and forth; that is, the host OS effectively becomes a router with multiple interfaces.

For more information on PPP and SLIP, see the *VxWorks Networking Guide*. For information on the ULIP-specific library **if_ulip**, see the *VxWorks Reference Manual*.

H.2 The Built-in Simulator

All the functionality of the built-in simulator is available with the optional product. All the information in this section applies to both versions of VxSim. For information specific to the optional product, see *H.5 VxSim Networking Component*, p. 545.

Installation and Configuration

Tornado 2.0 comes configured with basic VxSim on all hosts. Installing and starting Tornado as described in the *Tornado Getting Started Guide* installs and starts the basic VxSim.

Starting VxSim

VxSim automatically starts when you request a function that requires a connection to a target. For example, when you request download of a module, if you have not started a target server VxSim and a target server are automatically started.

You can also start VxSim from the command line or the VxSim icon on the launcher (UNIX) or from the Start>Run dialog box (Windows) using the command **vxWorks**.

Rebooting VxSim

As with other targets, you can reboot VxSim by typing **CTRL+X** in the shell.

Exiting VxSim

Windows: Close the VxSim window.

HP-UX: Close the VxSim window or use **CTRL+\** in the VxSim window.

Solaris: Normally, **CTRL+\** is mapped to **SIGQUIT**, which is the correct way to exit VxSim. however, in Solaris 2.6, the default terminal does not have this mapping. To check your mapping, use:

```
% stty -a
```

To change it to **CTRL+\**, use:

```
% stty quit ^\
```

Then you can exit VxSim by typing **CTRL+\** in the VxSim window.

⚠ **CAUTION:** Do not attempt to exit a VxSim session running ULIP on Solaris 2.5 or 2.6 using **SIGKILL**. This prevents VxSim from restarting properly.

System-Mode Debugging

System-mode debugging allows developers to suspend the entire VxWorks operating system.[1] One notable application of system mode is to debug ISRs, which—because they run outside any task context—are not visible to debugging tools in the default task mode. For more discussion of system mode, see the chapters *Shell* and *Debugger* in the *Tornado User's Guide*.

All three simulators are automatically configured for system mode debugging by including the WDB pipe back end.

File Systems

VxSim can use any VxWorks file system. The default file system is the pass-through file system, passFs, which is unique to VxSim.

passFs allows direct access to any files on the host. Essentially, the VxWorks functions ***open*( )**, ***read*( )**, ***write*( )**, and ***close*( )** eventually call the host equivalents in the host library **libc.a**. With passFs, you can open any file available on the host, including NFS-mounted files. By default, the **INCLUDE_PASSFS** macro (UNIX) or the **INCLUDE_NTPASSFS** (Windows) is enabled to cause this file system to be mounted on startup.

For more information on passFs, see the library entry for **passFsLib** in the *VxWorks Reference Manual* or HTML help. For more information on other VxWorks file systems, see *4. Local File Systems*.

1. System mode is sometimes also called *external mode*, reflecting that the target agent operates externally to the VxWorks system in this mode.

H.3 Building Applications

The following sections describe how to use the VxSim compilers. The recommended way to build VxSim modules is to use the project tool. For complete information on this tool, see the *Tornado User's Guide: Projects*. If you are using manual methods in your project, the information required for manual builds and loading is summarized below.

This information applies to using manual methods on both the built-in version of VxSim and the optional networking product.

Defining the CPU Type

Setting the preprocessor variable **CPU** ensures that VxWorks and your applications build with the appropriate features enabled. Define this variable to one of the following values, to match the host you are using:

SIMSPARCSOLARIS	VxSim for Solaris
SIMHPPA	VxSim for HP-UX
SIMNT	VxSim for Windows NT

The Toolkit Environment

All VxWorks simulators use the GNU C/C++ compiler.

CAUTION: The compiler used by the Tornado tools to compile VxSim applications for Windows is the GNU C/C++ compiler rather than the MicroSoft tools.

Compiling C and C++ Modules

Solaris

The following is an example of a compiler command line for VxSim development. The file to be compiled in this example has a base name of **applic**.

```
% ccsimso -DCPU=SIMSPARCSOLARIS -ansi -nostdinc -g -fno-builtin \
-fvolatile -DRW_MULTI_THREAD -D_REENTRANT -O2 -I. \
-I /wind/target/h -c applic.c
```

HP-UX

The following is an example of a compiler command line for VxSim development. The file to be compiled in this example has a base name of **applic**.

```
% cchppa -g -ansi -nostdinc -DRW_MULTI_THREAD -D_REENTRANT -O2 \
-fvolitile -fno-builtin -I. -I/wind/target/h -DCUP_SIMHPPA \
-c applic.c
```

Windows

The following is an example of a compiler command line for VxSim development. The file to be compiled in this example has a base name of **applic**.

```
% ccsimpc -DCPU=SIMNT -mpentium -ansi -nostdinc -g -nostdlib \
-fno-builtin -fno-defer-pop -Wall -DRW_MULTI_THREAD \
-D_REENTRANT -I. -I C:/Tornado/target/h -c applic.c
```

Option Definitions

The options shown in the example have the following meanings:[2]

ccsimso
: Required; use **ccsimso** for the Solaris simulator, **cchppa** for the HP-UX simulator, and **ccsimpc** for the Windows simulator.

-DCPU=SIMNT
: Required; defines the CPU type. See the table on page *Defining the CPU Type*, p.535.

-mpentium
: Optional for Windows only; specifies Pentium optimizations.

-ansi
: Recommended; supports all ANSI standard C programs.

-nostdinc
: Required; searches only the directories specified with the **-I** flag (see below) and the current directory for header files. Does not search host-system include files.

-O2
: Optional; implements optimization. Not recommended for the PC simulator.

2. For more information on these and other compiler options, see the *GNU ToolKit User's Guide*. WRS supports compiler options used in building WRS software; see the *Guide* for a list. Other options are not supported, although they are available with the tools as shipped.

-g
Optional; produces debugging information.

-nostdlib
Required for Windows; does not use the standard system startup files or libraries when linking.

-fvolatile
Required for Solaris and HP-UX; considers all memory references through pointers to be volatile.

-fno-builtin
Required; uses library calls even for common library subroutines.

-fno-defer-pop
Required for Windows, optional for UNIX. Causes arguments to each function call to be popped as soon as the function returns.

-Wall
Optional; enables most warnings.

-DRW_MULTI_THREAD
Required; specifies Rogue Wave multi-threading.

-D_REENTRANT
Required; causes reentrant code to be generated.

-I $WIND_BASE/target/h
Required; includes VxWorks header files. (Additional **-I** flags may be included to specify other header files.)

-c Required; specifies that the module is to be compiled only, and not linked for execution under the host.

applic.*language_id*
Required; the files to compile. For C compilation, specify a suffix of **.c**. For C++ compilation, specify a suffix of **.cpp**. The output is an unlinked object module with the suffix **.o**; for the example, the output is **applic.o**. The object module format for each simulator is as follows:

SIMSPARCSOLARIS	**ELF**
SIMHPPA	**SOM**
SIMNT	**a.out**

Following C++ compilation, the compiled object module (*applic***.o**) is *munched*. Munching is the process of scanning an object module for non-local static objects, and generating data structures that VxWorks run-time support can use to call the object constructors and destructors. See *5.2.5 Munching C++ Application Modules*, p.232.

Linking an Application to VxSim

By default, applications can be loaded into VxSim while it is running. Alternatively, the application can be statically linked to VxSim by modifying the target makefile.

⚠ **CAUTION:** VxSim for HP-UX uses the HP native linker **ld** rather than the GNU linker (**ldhppa**).

This information applies to using manual methods on both the built-in version of VxSim and the optional networking product.

Dynamic Loading

To load your application dynamically into VxSim, follow these steps:

1. Start VxSim as described in *Starting VxSim*, p.533.
2. From a WindSh window, use the ***ld*( )** function to load the application dynamically. For example:

```
-> ld </usr/tony/application.o
value = 3957696 = 0x3c63c0
```

   A nonzero return value indicates that the load was successful.

As with VxWorks, the Tornado dynamic linker ***ld*( )** requires a relocatable object module. The object format is as follows:

Table H-1 **Object Formats by VxSim Host**

Host Type	**Object Format**	**Produced By…**
Solaris 2	**elf**	**ccsimso**
HP-UX	**som**	**cchppa**
Windows	**a.out**	**ccsimpc**

Static Linking

The other method of linking is to modify the target makefile to link the application code statically into VxSim when VxSim is built. This method is also useful if you have already debugged a module and you do not want to download it to the target every time you start VxSim.

To link the application code statically into VxSim, follow these steps:

1. Add your application modules in the makefile definition of **MACH_EXTRA.** The makefile is **${WIND_BASE}/target/config/***bspname***/Makefile**, where *bspname* is one of **solaris**, **hpux**, or **simpc**:

   ```
   MACH_EXTRA = application.o
   ```

   If your application module is in another directory, specify the pathname.

2. Use **make** to rebuild VxSim with **application.o** linked in.

   For a discussion of using BSP makefiles to incorporate application modules, see *8. Configuration and Build*.

Partial Linking

Large applications may be managed more effectively by using multiple object files. Before downloading the application to VxSim, the objects can be combined into a single file by performing a *partial link* as shown below:

```
% /bin/ldsimso -B immediate -N -r -o application.o module1.o \
module2.o ...

% /bin/ld -B immediate -N -r -o application.o module1.o module2.o ...

% /bin/ldsimpc -B immediate -N -r -o application.o module1.o \
module2.o ...
```

If you want to use CrossWind to debug your application on the HP-UX simulator, you must run **xlinkHppa** on the partially-linked object file before downloading it to VxWorks. For example:

```
% xlinkHppa application.o
```

For more information on **xlinkHppa**, see its reference entry.

Architecture-Specific Tools

The following tools are available to extract the symbol table from an object file created for a simulator. The syntax is:

elfXsyms
is used for an **ELF** file for the Solaris simulator. The syntax is:

`elfXsyms <` *objMod* **`>`** *symTbl*

xsymHppa
is used for a **SOM** file for the HP-UX simulator. The syntax is:

`xsymHppa <` *objMod* **`>`** *symTbl*

No tool is required for the Windows simulator. When a symbol table is required, the loader loads the entire executable but only the symbol table is referenced.

H.4 Architecture Considerations

The information in this section highlights differences between VxSim (both the built-in and optional versions) and other VxWorks BSPs. These differences should be taken into consideration as you develop applications on VxSim that will eventually be ported to another target architecture.

VxSim uses the VxWorks scheduler, which behaves the same way as for any other VxWorks architecture (see 2. *Basic OS*). The BSP is extensible; for example, pseudo-drivers can be written for additional timers, serial drivers, and so forth.

The rest of this section discusses some details of the VxSim implementation. Differences between VxSim and other VxWorks environments are noted where appropriate.

Supported Configurations

Most of the optional features and device drivers for VxWorks are supported by VxSim. The few that are not are hardware devices (SCSI, Ethernet), and ROM configurations, and so on. The BSP makefile builds only the images **vxWorks** and **vxWorks.st** (standalone VxWorks).

The BSP Directory

Aside from the following exceptions, the VxSim BSP is the same as a VxWorks BSP:

- The **sysLib.c** module contains the same essential functions: ***sysModel( )***, ***sysHwInit( )***, and ***sysClkConnect( )*** through ***sysNvRamSet( )***. Because there is no bus, ***sysBusToLocalAdrs( )*** and related functions have no effect.
- **tyCoDrv.c** ultimately calls host ***read( )*** and ***write( )*** routines on the process's true standard input and output. But all the "driver" functions and **tyLib.c** are intact.
- The configuration header **config.h** is minimal:
  - It does not reference a *bspname***.h** file.
  - Most network devices are excluded.
  - The boot line has no fixed memory location. Instead, it is stored in the variable ***sysBootLine*** in **sysLib.c**.
- The **Makefile** is the standard version for VxWorks BSPs. It does not build boot ROM images (although the makefile rules remain intact); it can only build **vxWorks** and **vxWorks.st** (standalone) images. The final linking does not arrange for the TEXT segment to be loaded at a fixed area in RAM, but follows the usual loading model. The makefile macro **MACH_EXTRA** is provided so that users can easily link their application modules into the VxWorks image if they are using manual build methods.

The BSP file **sysLib.c** can be extended to emulate the eventual target hardware more completely.

Interrupts

Solaris and HP-UX

Host signals are used to simulate hardware interrupts. For example, VxSim uses the **SIGALRM** signal to simulate system clock interrupts, the **SIGPROF** signal for the auxiliary clock, and the **SIGVTALRM** signal for virtual timer interrupts. Furthermore, all host file descriptors (such as standard input) are put in asynchronous mode, so that the **SIGIO** signal is sent to VxSim when data becomes ready. The signal handlers are the VxSim equivalent to Interrupt Service Routines (ISRs) on other VxWorks targets.

You can install ISRs in VxSim to handle these "interrupts." Not all VxWorks functions can be called from ISRs; see *2. Basic OS*.

To run ISR code during a future system clock interrupt, use the watchdog timer facilities. To run ISR code during auxiliary clock interrupts, use the ***sysAuxClkxxx*( )** functions.

Table H-2 shows how the interrupt vector table is set up.

Table H-2 **Interrupt Assignments**

Interrupts	Assigned To
1–32	host signals
33–64	host file descriptors 1-32 (**SIGIO**)

Pseudo-drivers can be created to use these interrupts. Interrupt code must be connected with the standard VxWorks ***intConnect*( )** mechanism.

For example, to install an ISR that logs a message whenever host signal ***SIGUSR2*** arrives, execute the following:

```
    -> intConnect (31, logMsg, "Help!\n")
```

Then send signal 31 to VxSim from a host task, for example using the host **kill** command. Every time the signal is received, the ISR (***logMsg*( )** in this case) runs.

⚠ **CAUTION:** Do not use the preprocessor constants **SIGUSR1** or **SIGUSR2** for this purpose in VxWorks applications, since those constants evaluate to the VxWorks definitions for these signals. You need to specify your host's signal numbers instead.

⚠ **CAUTION:** Only **SIGUSR1** (16 on Solaris 2 hosts) and **SIGUSR2** (17 on Solaris 2 hosts) can be used to represent user-defined interrupts.

If a VxSim task reads from a host device, the task would normally require a blocking read; however, this would stop the VxSim process entirely until data is ready. The alternative is to put the device into asynchronous mode so that a **SIGIO** signal is sent whenever data becomes ready. In this case, an input ISR reads the data, puts it in a buffer, and unblocks some waiting task.

To install an ISR that runs whenever data is ready on some underlying host device, first open the host device (use ***u_open*( )**, the underlying host routine, *not* the VxSim ***open*( )** function). Put the file descriptor in asynchronous mode, using the VxSim-specific routine ***s_fdint*( )** so that the host sends a **SIGIO** signal when data is ready. Finally, connect the ISR. The following code fragment does this on one of the host serial ports:

```
...
fd = u_open ("/dev/ttyb", 2);
s_fdint (fd, 1);
intConnect (32 + fd, ISRfunc, 0);
...
```

Since VxSim uses the task's stack when taking interrupts, the task stacks are artificially inflated to compensate. You may notice this if you spawn a task of a certain size and then examine the stack size.

Windows

Windows messages are used to simulate hardware interrupts. For example, VxSim uses messages 0xc000 - 0xc010 to simulate interrupts from ULIP, the pipe back end, and so forth. The messages are the VxSim equivalent to Interrupt Service Routines (ISRs) on other VxWorks targets. You can install ISRs in VxSim to handle these "interrupts." Not all VxWorks functions can be called from ISRs; see *2. Basic OS*. To run ISR code during a future system clock interrupt, use the watchdog timer facilities. To run ISR code during auxiliary clock interrupts, use the ***sysAuxClk**xxx***( )** functions.

Table H-2 shows how the message table is set up.

Table H-3 **Interrupt Assignments**

Interrupts	Assigned To
0xc000-0xc010	host messages
0xc011 on	available for user messages

Pseudo-drivers can be created to use these interrupts. Interrupt code must be connected with the standard VxWorks ***intConnect*( )** mechanism.

For example, to install an ISR that logs a message whenever host message **WM_TIMER_CLOCK** arrives, execute the following:

```
-> intConnect (0xc011, logMsg, "Help!\n")
```

Then send message 0xc011 to VxSim from a host task. Every time the message is received, the ISR (***logMsg*( )** in this case) runs.

If a VxSim task reads from a host device, the task would normally block while reading; however, this would stop the VxSim process entirely until data is ready.

Instead the device is put into asynchronous mode so that a message is sent whenever data becomes ready. In this case, an input ISR reads the data, puts it in a buffer, and unblocks some waiting task.

Since VxSim uses the task's stack when taking interrupts, the task stacks are artificially inflated to compensate. You may notice this if you spawn a task of a certain size and then examine the stack size.

Clock and Timing Issues

Solaris and HP-UX

The execution times of VxSim functions are not, in general, the same as on a real target. For example, the VxWorks ***intLock*( )** function is normally very fast because it just writes to the processor status register. However, under VxSim, ***intLock*( )** is relatively slow because it makes a host system call to mask signals.

The clock facilities are provided by the host routine ***setitimer*( )** (**ITIMER_REAL** for the system clock; **ITIMER_PROF** for the auxiliary clock). The problem with using **ITIMER_REAL** for the system clock is that it produces inaccurate timings when VxSim is swapped out as a host process.[3] On the other hand, the timing of VxSim is, in general, different than on an actual target, so this is not really a problem.

The BSP system clock can be configured to use the virtual timer (**ITIMER_VIRTUAL**) in addition to **ITIMER_REAL**; see **sysLib.c**. In this way, when the process is swapped out by the host, VxSim does not count wall-clock elapsed time as part of simulated elapsed time. VxSim still uses **ITIMER_REAL** to keep track of the elapsed time during the *wind* kernel's idle loop. Although the addition of **ITIMER_VIRTUAL** results in more accurate *relative* time, the problem is that the host system becomes increasingly loaded (due to the extra signal generation) and as a result connections to the outside world (such as the network) become delayed and can fail.

The ***spy*( )** facility is built on top of the auxiliary clock (**ITIMER_PROF**). The task monitoring occurs during each interrupt of the auxiliary clock to see which task is executing or if the kernel is executing. Because the profiling timer includes host system time and user time, discrepancies can occur, especially if intensive host I/O occurs.

3. Because VxSim is a host process, it shares resources with all other processes and is swapped in and out. In addition, the kernel's idle loop has been modified to suspend VxSim until a signal arrives (rather than busy waiting), thus allowing other processes to run.

Windows

The execution times of VxSim functions are not, in general, the same as on a real target. For example, the VxWorks ***intLock*( )** function is normally very fast because it just writes to the processor status register. However, under VxSim, ***intLock*( )** is relatively slow because it takes a host semaphore, allowing other processes to run.

The clock facilities are provided by the host routine ***settimer*( )** for both the system and auxiliary clocks. The problem with using ***settimer*( )** for the target system clock is that it produces inaccurate timings when VxSim is swapped out as a host process.[4] On the other hand, the timing of VxSim is, in general, different than on an actual target, so this is not really a problem.

The ***spy*( )** facility is built on top of the auxiliary clock. The task monitoring occurs during each interrupt of the auxiliary clock to see which task is executing or if the kernel is executing. Because the profiling timer includes host system time and user time, discrepancies can occur, especially if intensive host I/O occurs.

H.5 VxSim Networking Component

This section contains information that pertains only to the VxSim optional product. All information in previous sections also pertains to that product. The VxSim optional product provides networking facilities. Most of the special considerations associated with it are network considerations.

If you purchase the optional VxSim component for networking, you must take additional configuration steps.

- Install the optional VxSim component using **SETUP**, either when you install Tornado 2.0 or at a later time. (For more information, see the *Tornado Getting Started Guide*.)
- Install the appropriate network driver on your host. (See *Installing VxSim Network Drivers*, p. 546.)

4. Because VxSim is a host process, it shares resources with all other processes and is swapped in and out. In addition, the kernel's idle loop has been modified to suspend VxSim until a signal arrives (rather than busy waiting), thus allowing other processes to run.

- Configure VxWorks to use networking, rebuild it, and download it using either the project facility or manual methods. (See *Configuring VxSim for Networking*, p.552.)

WARNING: Project facility configuration and building of projects is independent of the methods used for configuring and building applications prior to Tornado 2.0 (which included manually editing **config.h** and **configAll.h**). Use of the project facility is the recommended, and is much simpler. However, the manual method may still be used (see *8. Configuration and Build* for details). Avoid using the two methods together for the same project except where specific BSP and driver macros are not available in the project facility.

Installing VxSim Network Drivers

The **SETUP** tool writes the appropriate host drivers on your disk, but they must be installed on your host operating system.

Loading ULIP on a Solaris 2 Host

Two network interfaces, ULIP and PPP, are available for Solaris 2 hosts. ULIP is provided as the default network interface. Due to its non-portable nature, we provide PPP as an alternative. At some point in the future, ULIP may no longer be supported for VxSim on Solaris hosts.

CAUTION: ULIP and PPP are not compatible with each other; you *must* uninstall one before using the other. If PPP is already installed on your Solaris host, be sure to remove it (or at least stop service with **/etc/init.d/asppp stop**) before loading ULIP.

Follow these steps to add the ULIP driver to your Solaris 2 host (replace the leading path segment *installDir* with the path to your installed Tornado tree):

```
% su root
password:
# cd installDir/host/sun4-solaris2/bin
# ./installUlipSolaris
# exit
%
```

The **installUlipSolaris** script copies ULIP resources to system directories, installs the loadable ULIP driver into the Solaris kernel, and creates symbolic links which allow **/etc/init.d/ulip** to start and stop ULIP upon changes to the system run level[5].

NOTE: **installUlipSolaris** calls a program called **configUlipSolaris** and copies it to **/etc/init.d/ulip** (in other words, **configUlipSolaris** and **/etc/init.d/ulip** are the same program). If you have questions about the ULIP installation procedure, see the reference entry for **configUlipSolaris** as well as for **installUlipSolaris** in the *VxWorks Reference Manual* or the HTML online reference.

installUlipSolaris creates sixteen ULIP devices, **/dev/ulip0** through **/dev/ulip15**, and uses the host command **ifconfig** to configure the devices with default IP numbers 127.0.1.0 through 127.0.1.15. You will most likely want to match these IP addresses with host names in **/etc/hosts**: for example, **vxsim0** through **vxsim15**.

You can also use the following commands to start or stop the Solaris ULIP driver after the driver has been installed (you must have **root** privileges):

```
# /etc/init.d/ulip start

# /etc/init.d/ulip stop
```

CAUTION: Make sure all VxSim sessions are closed before running **installUlipSolaris** or **/etc/init.d/ulip**.

installUlipSolaris allows two optional arguments:

```
installUlipSolaris [ basic | uninstall ]
```

Using **installUlipSolaris** with no argument sets ULIP to be installed automatically when Solaris reboots.

basic
Do not set ULIP to be installed automatically when Solaris reboots. If you install the ULIP driver using the **basic** option, you must stop and start ULIP services each time you reboot your Solaris workstation by invoking **/etc/init.d/ulip** manually as shown above.

uninstall
Remove the files and symbolic links created by **installUlipSolaris**. This script stops the ULIP driver before uninstalling.

Loading PPP on a Solaris 2 Host

PPP is provided as a portable alternative to ULIP.

5. For more information on run levels, see the Solaris man page for **init**(1M).

⚠ **WARNING:** The *VxWorks Networking Guide* states that "the PPP link can serve as an additional network interface apart from the existing default network interface." This is not the case with VxSim when ULIP is used. ULIP and PPP are not compatible with each other; you *must* uninstall one before using the other. If you wish to use PPP and you have already installed ULIP, you must first uninstall ULIP using **installUlipSolaris uninstall** (see *Loading ULIP on a Solaris 2 Host*, p.546).

Follow these steps to add PPP support to VxSim on your Solaris host.

First, use the command **pkginfo** to check whether the following packages are installed on your host:

SUNWapppr	PPP/IP Asynchronous PPP daemon configuration files
SUNWapppu	PPP/IP Asynchronous PPP daemon and PPP login service
SUNWpppk	PPP/IP and IPdialup Device Drivers
SUNWbnur	Networking UUCP Utilities, (Root)
SUNWbnuu	Networking UUCP Utilities, (Usr)

For example:

```
% pkginfo | egrep 'ppp|bnu'
system  SUNWapppr  PPP/IP Asynchronous PPP daemon configuration files
system  SUNWapppu  PPP/IP Asynchronous PPP daemon and PPP login service
system  SUNWpppk   PPP/IP and IPdialup Device Drivers
system  SUNWbnur   Networking UUCP Utilities, (Root)
system  SUNWbnuu   Networking UUCP Utilities, (Usr)
%
```

If they are not already installed, mount the Solaris installation disk and change your working directory to the location of these packages (for example, on a Solaris 2.5.1 CD-ROM they can be found in **/cdrom/solaris_2_5_1_sparc/s0/Solaris_2.5.1**) and install them with the following commands:

```
% su root
Password:
# pkgadd -d 'pwd' SUNWbnur SUNWbnuu SUNWpppk SUNWapppr SUNWapppu
```

Next, as **root**, copy *installDir***/target/config/solaris/asppp.cf** to the **/etc** directory as follows (replace the leading path segment *installDir***/target/** with the path to your installed Tornado tree):

```
# cp installDir/target/config/solaris/asppp.cf /etc
```

⚠ **CAUTION:** If you already have **aspppd** running, stop it with **asppp stop** before proceeding.

Finally, start the PPP daemon **aspppd** by typing the following as **root**:

```
# /etc/init.d/asppp start
```

The PPP driver is now installed and running on your Solaris system, and will be restarted automatically when Solaris reboots.

The PPP configuration assigns IP addresses 127.0.1.0 through 127.0.1.15 to sixteen devices, and associates with them the peer system names **vxsim0** through **vxsim15**, respectively.

You can also use the following commands to start or stop the Solaris PPP driver after the driver has been installed (you must have **root** privileges):

```
# /etc/init.d/asppp start
```

```
# /etc/init.d/asppp stop
```

Loading SLIP on a HP-UX Host

Some additional configuration of your system is required to complete the connection. Perform the following steps to configure SLIP:

1. Update your **ppl.remotes** file.

   HP-UX uses **ppl** to configure **pty** lines for SLIP (see the HP-UX man page for **ppl**). Each SLIP line requires a **ppl** process. When a **ppl** process is initiated, its configuration parameters are read from the configuration file **/etc/ppl/ppl.remotes**.

   (a) If you use none of your SLIP lines for other applications, you may replace **/etc/ppl/ppl.remotes** with the provided configuration file *installDir***/target/config/hpux/ppl.remotes.hpux10**:

   ```
   % su
   # cd /etc/ppl
   # mv ppl.remotes ppl.remotes.bak
   # cp installDir/target/config/hpux/ppl.remotes.hpux10 ppl.remotes
   ```

   (b) If your system is already using SLIP, **/etc/ppl/ppl.remotes** contains working data, not just comments and a template for future additions.

   Edit **/etc/ppl/ppl.remotes** and import the entries from *installDir***/target/config/hpux/ppl.remotes.hpux10**. Be sure to adhere to the format restrictions of the **ppl.remotes** file, or the PPL software can not parse the entries.

   See your system administrator with any concerns.

2. Start the **ppl** process.

```
% su
# ppl -o -t /dev/ptym/ptyrn 192.168.1.n
```

Each simulator should have a unique pseudo-terminal device, the second argument of the **ppl** command, in the range **ptyr0** to **ptyr9**. If one of these pseudo-terminals is already in use, choose another set of pseudo-terminals to use, such as **ptyq0** to **ptyq9**. (Examine the directory **/dev/ptym** for the complete collection of pseudo-terminal devices.)

NOTE: If you use a **pty** group other than the default, you must redefine **SLIP_PSEUDO_TTY_PATH** in **config.h**. This macro can not be configured using the project facility. For this reason, while you must configure it manually, doing so does not prevent you from using the project facility to configure the rest of your project.

The last argument to **ppl** is the IP address of the VxWorks target. In the case shown above, *n* corresponds to the VxWorks processor number. Each simulator must have its own **ppl** process. For example, to add a PPL connection for VxWorks processor number 5, use the following command:

```
# ppl -o -t /dev/ptym/ptyr5 192.168.1.5
```

CAUTION: HP-UX kernels allow only two SLIP network interfaces to operate at one time. If you want to run more than two simulators, you must rebuild your HP-UX kernel. The parameter that sets the number of interfaces is **NNI** in **/usr/conf/master.d/net**. Do not configure more than 10 network interfaces, as this is the maximum number allowed according to the file **/usr/conf/net/if_ni.h**.

3. Enable IP packet forwarding.

By default, the VxSim BSP is built to use SLIP over the network on an HP-UX host. To ***ping*( )** two VxSim targets, IP packet forwarding must be enabled.

To view the current **ip_forwarding** flag status, use the following command:

```
% ndd /dev/ip ip_forwarding
```

To enable IP packet forwarding, set the parameter **ip_forwarding** in the IP driver to one:

```
% ndd -set /dev/ip ip_forwarding 1
```

NOTE: You have to be 'root' to use **ndd**.

4. Check your network interface.

```
# netstat -i
```

For example, if you started two SLIP connections (0 and 1), you would see the following lines in the network interface table:

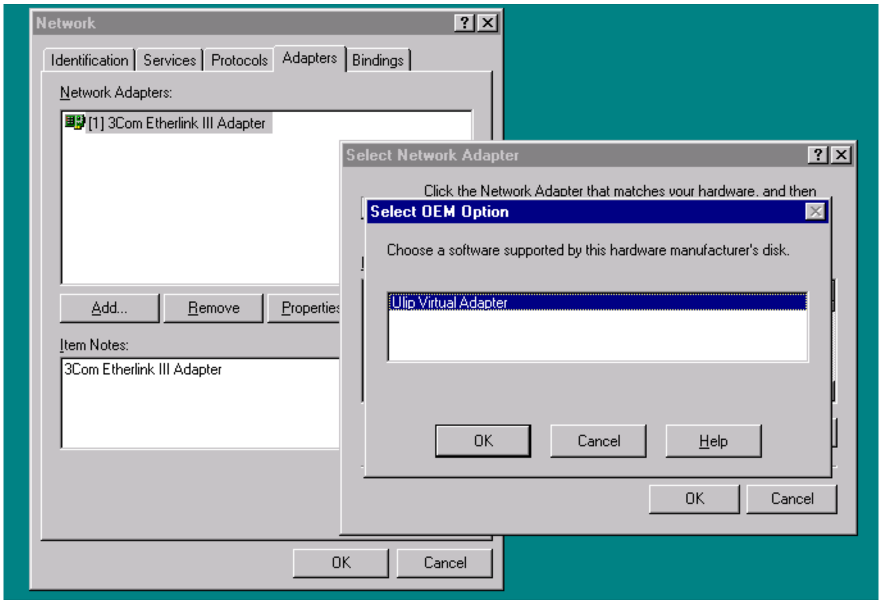
```
Name   Mtu    Network    Address      Ipkts  Ierrs   Opkts  Oerrs  Coll
ni0    1006   192        192.168.2.0    0      0       0      0     0
ni1    1006   192        192.168.2.1    0      0       0      0     0
```

Installing ULIP on a Windows NT Host

For Windows hosts, the VxSim BSP includes an NDIS driver called the ULIP driver. Follow these steps to add the ULIP driver to your Windows host.

From the Start menu select Settings>Control Panel>Network. Click the Adapters tab in the Network window, click the Add button, and click Have Disk in the Select Network Adaptor window. Enter the path to the installation file, for example, **C:\Tornado\host\x86-win32\bin** and click OK. Click on Ulip Virtual Adapter and click OK (see Figure H-1). ULIP is added to the Network Adapters list.

Figure H-1 **Installing the Ulip Virtual Adapter**



Click OK. The TCP/IP Properties window opens. Select Ulip Virtual Adapter in the Adapter drop-down list. Enter an IP address of the form *nn*.0.0.255 (for example, 90.0.0.255). For a discussion of network addressing in general and ULIP in particular, see *IP Addressing*, p.555.

Click OK and restart the computer to cause the new settings to take effect.

Configuring VxSim for Networking

As with any other BSP, adding components to VxWorks requires including them, rebuilding VxWorks, the downloading and restarting it. The easiest method for doing this is to use the project facility. However, if you have used manual methods in your project, you should continue to use those methods.

For a discussion of networking as it relates to VxSim, see *H.5 VxSim Networking Component*, p.545.

Using the Project Tool

Use the Create Project facility to create a bootable VxWorks image. On the VxWorks tab in the Project Workspace window, select the folder called network components. Right click and select Include 'network components' from the context menu. Click OK to accept the defaults. Then rebuild and download VxWorks.

If you want to use multiple simulators simultaneously and you are using ULIP, you must also locate ULIP on the list in the Include Folder and check it before clicking OK. In this case, you must also change your target server configuration from wdbpipe to wdbrpc before connecting it to the new VxWorks image.

If you are using PPP, be sure BSD43 Compatible Sockets is not selected in the Include Folder.

For more information on using the configuration tool, see the *Tornado User's Guide: Projects*.

Using Manual Techniques

For all hosts, be sure that **INCLUDE_NETWORK** is defined in **config.h**. If you want to use multiple simulators simultaneously and you are using ULIP on Solaris, also add the following to **config.h**:

```
#undef WDB_COMM_TYPE
#define WDB_COMM_TYPE   WDB_COMM_NETWORK
```

If you are using ULIP on Windows NT with multiple simulators, also add the following to **config.h**:

```
#define WDB_COMM_END
#define INCLUDE_NT_ULIP
```

If you are using PPP, be sure the following is defined in **config.h**:

```
#ifdef BSD43_COMPATIBLE
#undef BSD43_COMPATIBLE
#endif
```

Then rebuild and download VxWorks.

You must also change your target server configuration from wdbpipe to wdbrpc.

For additional information on configuring BSPs using manual methods, see the *VxWorks Networking Guide*.

Running Multiple Simulators

When you install the optional VxSim component, your system is automatically configured to run up to 16 simulators. When you start VxSim from the GUI, **vxsim0** starts. To start additional instances, use the command line or the Windows Start>Run facility. The command takes the following forms (where *n* is the processor number):

UNIX:	**vxWorks -p** *n*
Windows:	**vxWorks /p** *n*

System Mode Debugging

Including the simulator networking facility means that system mode debugging can be done without using the WDB pipe back end. SLIP, PPP, and ULIP on Windows all allow the network connection to be used for both network packets and host-target communications. However, special considerations apply to using ULIP on Solaris in this way.

Although it is possible to use the network connection for system mode debugging and use a back end other than the WDB pipe back end, the recommended method is to use the default, WDB pipe, even when networking is installed.

ULIP on Solaris Without WDB Pipe Back End

To use system mode debugging with ULIP on Solaris and no WDB pipe back end, you must enable a different ULIP channel for the target agent (the part of Tornado that resides on the target) than is used by the rest of VxWorks. This allows communications with the Tornado tools to proceed independently of the VxWorks operating system.

Changing **WDB_COMM_TYPE** to **WDB_COMM_ULIP** enables additional ULIP channels. This can be done either manually or using the project facility (see *Tornado User's Guide: Projects*).

With no further configuration changes, the target agent uses **/dev/ulip14** and the corresponding IP address (127.0.1.14) as its debugging channel to the Tornado host tools. (VxWorks networking calls continue to connect to whatever ULIP channel you specify with the **-p** option if you start VxSim from the command line.)

Connect the target server to your modified VxSim using the target name **vxsim14**. In system mode, the target name identifies the debugging ULIP channel.

The ULIP channel corresponding to the **-p** option (0 by default) also remains in use for the simulated VxWorks session, even in system mode. Thus, the IP address corresponding to the **-p** option is always the IP address to communicate with applications on the simulated VxWorks target, regardless of whether or not system-mode debugging is in effect. The only VxSim IP traffic that uses a different channel in system mode is between the target agent and the Tornado host tools.

If you wish to arrange another ULIP channel for system-mode debugging, change or override the **WDB_ULIP_DEV** definition in *installDir***/target/config/all/configAll.h**, and use a target name to match.

WARNING: A single Solaris ULIP channel cannot be used for two purposes at one time. Thus, you must not use **-p 14** with a VxSim that has system mode enabled on the default channel. Similarly, you can only use system mode (over the default channel) with one VxSim at a time, though you can still debug multiple VxSim processes in task mode at the same time.

IP Addressing

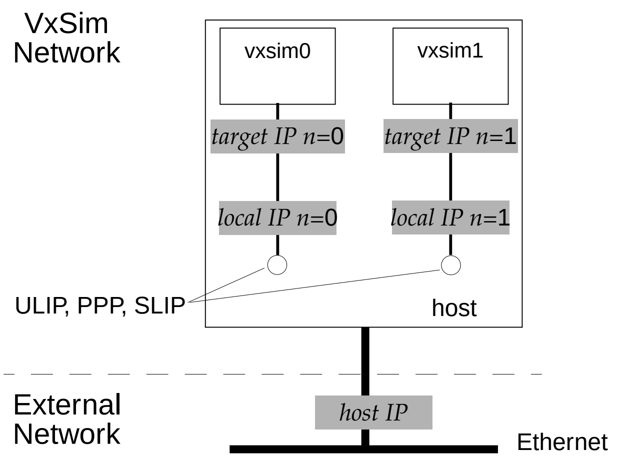
All of the networking facilities available under VxWorks—for example, sockets, RPC, NFS—are available with VxSim. For VxSim to communicate with the outside world, it must have its own target IP address as provided through a network interface.

Internet addressing is handled slightly differently among the available network interfaces. For each VxSim process, there are three associated IP addresses:

- Target IP – the address of each VxSim process, internal to your host.
- Local IP – your host's address on the VxSim network, internal to your host.
- Host IP – your host's address according to the network at your site.

The target IP address and the local IP address communicate according to the protocol of the chosen network interface. The host IP address is not directly relevant to the VxSim network.

Figure H-2 **VxSim IP Addressing**



Addressing is according to processor number, such that when you run VxSim with processor number *n* (with the command **vxWorks -p** *n*), the network addresses packets as shown in Table H-4.

Table H-4 **VxSim Network Addressing**

Network Interface	Local IP	Target IP
ULIP: Solaris	*host IP addr*	127.0.1.*n*
Windows	*host IP addr*	90.0.0.*n*[*]
PPP	127.0.1.254	127.0.1.*n*
SLIP	192.168.2.*n*	192.168.1.*n*

* Note that you can use 90.n.n.n or any other number except 127.n.n.n for a target IP address on a Windows host. 127 is reserved for other purposes on Windows.

Choosing Processor Numbers for Distinct Devices

ULIP (Solaris 2, Windows NT)

When you run VxSim with ULIP and specify processor number *n* (with the command **vxWorks -p** *n*), VxSim for Solaris attaches to **/dev/ulip***n* and uses IP address 127.0.1.*n*. VxSim for Windows attaches to the IP number you specified when installing ULIP, which must not be 127.*n.n.n*.

Only one process at a time can open the same ULIP device; this is enforced in the ULIP driver. Thus, if you want multiple VxSim targets to use ULIP, you *must* give each of them a distinct processor number. If another VxSim process is already running with the same processor number, then the ULIP device cannot be opened (**ulip0** corresponds to processor 0), and the following message is displayed during the startup of VxSim:

Solaris (0xd translates to **S_errno_EACCES**):

```
ulipInit failed, errno = 0xd
```

Windows NT:

```
Error -
An Integrated Simulator is already running.
Only one may be running at a time.
To run multiple simulators, use the optional Full Simulator.
Hit Any Key to Exit
```

When you run VxSim, **usrConfig.c** creates host entries for **vxsim0** through **vxsim15** and adds a default route to the host.

⚠ **WARNING:** The VxSim ULIP driver will not attach to a network interface if it is already in use, that is, **ul0** can be used by only one VxSim process. Use the **-p** flag to run VxSim with a different processor number; see *Starting VxSim*, p.533.

PPP (Solaris 2)

When you run VxSim with PPP and specify processor number *n* (with the command **vxWorks -p** *n*), VxSim creates a network connection to the IP address 127.0.1.*n* by communicating through a pipe. Normally, VxWorks uses PPP over a serial device to connect to the host (see *VxWorks Networking Guide*). The only difference with PPP is that a pipe replaces the physical serial link.

SLIP (HP-UX)

When you run VxSim with SLIP and specify processor number *n* (with the command **vxWorks -p** *n*), VxSim creates a network connection to the IP address specified when you started the **ppl** process (192.168.1.*n*) by attaching to a **pty** device (see *Loading SLIP on a HP-UX Host*, p.549). Normally, VxWorks uses SLIP over a serial device to connect to the host (see *VxWorks Networking Guide*). The only difference with VxSim is that a **pty** device replaces the physical serial link.

Setting Up Remote Access

You can add host-specific routing entries to the local host to allow remote hosts to connect to a local VxSim "target." IP addresses are set up only for the host where the network simulation software is installed (see *Setting Up Remote Access*, p.557). The network interface does not have to be installed remotely; the remote host uses the local host as the gateway to the VxSim target.

In the example shown in Figure H-2, **host1** can communicate with **vxsim0** or **vxsim1** if the following steps are taken:

On UNIX, the following commands are issued on **host1** (as **root**):

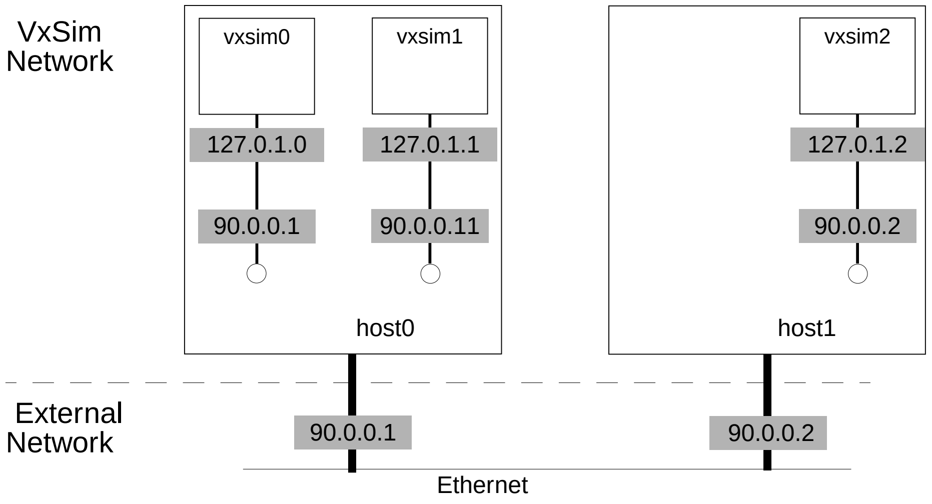
```
% route add host 127.0.1.0 90.0.0.1 1
% route add host 127.0.1.1 90.0.0.1 1
```

On Windows, the following are added to
C:\WINNT\SYSTEM32\drivers\etc\hosts:

```
90.0.1.0         vxsim0
90.0.1.1         vxsim1
```

ULIP is used in this example, but the concept is identical under PPP or SLIP. Contrast Figure H-3 below with Figure H-2, p. 555, to see the way addresses are set up, paying particular attention to the addressing algorithm described in Table H-4.

Figure H-3 **Example of VxSim IP Addressing (ULIP on Solaris)**



Verify the success of the above commands by pinging **vxsim0** from **host1**:

```
% ping 127.0.1.0
```

To allow a VxSim process on one host to communicate with a VxSim process on a different host, you must make sure that the two VxSim processes have different IP addresses. You must also make additional host-specific routes using unique addresses for each process.

For example, to ping **vxsim2** from **host0** above, you must add an additional route from **host0** as follows:

```
% route add host 192.168.1.3 90.0.0.2 1
```

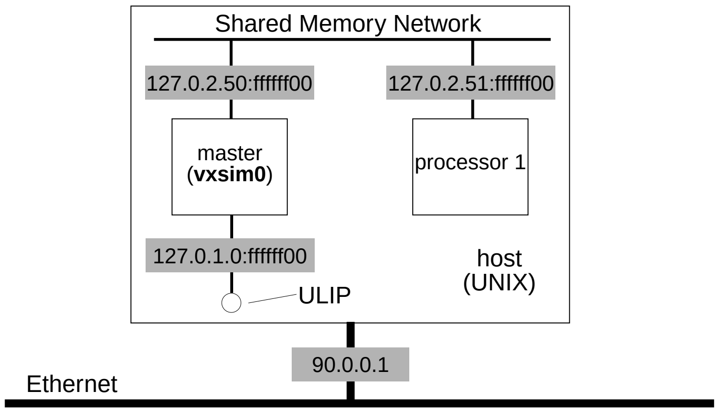
NOTE: The Solaris simulator automatically assigns addresses starting with 127. You assign addresses for the HP-UX and Windows simulators when you install SLIP or ULIP. Windows can not use addresses starting with 127.

Setting up the Shared Memory Network (UNIX only)

Many VxWorks users connect multiple CPU boards through a backplane (for example, VMEbus), which allows the boards to communicate through shared memory. VxWorks provides a standard network driver to access this shared memory so that all the higher level network protocols are available over the backplane. In a typical configuration, one of the CPU boards (CPU 0) communicates with the host using Ethernet. The rest of the CPU boards communicate with each other and the host using the shared memory network, using CPU 0 as a gateway to the outside world. For more information on this configuration in a normal VxWorks environment, see *VxWorks Networking Guide*.

This configuration can be emulated for VxSim. Multiple VxSim processes use a host shared-memory region as the basis for the shared memory network (see Figure H-4).

Figure H-4 **VxSim Shared Memory Network**



To set this up, use a subnet mask of 0xffffff00 to create a 127.0.2.0 subnet (from the 127.0.0.0 network) for the shared memory network. The following steps are required.

1. Use the ***bootChange*( )** command from the Tornado shell to change the following boot parameter on CPU 0. You must specify the subnet mask, as follows:

   ```
   inet on backplane (b): 127.0.2.50:ffffff00
   ```

2. Restart VxSim by typing **^X**. When VxSim boots, it sets up the shared-memory network and prints the address of the shared memory region it has created (in the VxSim console window, with the other boot messages).

3. Start CPU 1 (**vxWorks -p 1**), attach the Tornado target server to it, and then use ***bootChange*( )** to set the following boot parameters on CPU 1. For the boot device parameter, use the address printed in step 2. Leave the "inet on ethernet" parameter blank by typing a period (.).

   ```
       boot device           :  sm=sharedMemoryRegion
       inet on ethernet (e)  :  .
       inet on backplane (b) :  127.0.2.51:ffffff00
       gateway inet (g)      :  127.0.2.50
   ```

4. Quit CPU 1 and restart it. When it comes up again, it should attach to the shared memory network. To verify that everything is working correctly, ping CPU 1 (from a shell attached to CPU 0) with the following command:

   ```
       -> ping "127.0.2.51"
   ```

NOTE: Any time you need to attach a VxSim process within the subnet to the target server, you need to specify it by its new IP address rather than by hostname. All VxSim processors other than 0 are no longer directly accessible to the external network; the processors use **vxsim0** as the gateway. The hostnames normally associated with VxSim IP addresses cannot be used, since the routing table entries point to their usual IP addresses. For example, **vxsim1** is normally associated with IP address 127.0.1.1; with the shared memory network active, CPU 1 must be addressed through the subnet as 127.0.2.51.

5. Until you configure your UNIX routing table or Windows **hosts** file with information on how to reach the new subnet, you will be unable to use network communication between CPU 1 and the host over the shared memory network. To configure the route from UNIX, use the following commands:

   ```
       % su root
       password:
       # route add net 127.0.2.0 127.0.1.0 1
       # exit
       %
   ```

6. Verify that you can now communicate from the host to CPU 1 over the shared memory network by using **ping** from the host to CPU 1.

   ```
   % ping 127.0.2.51
   ```

   Note that if you attempt to access CPU 1 through its normally associated IP address, it appears to be unavailable:

   ```
   % ping 127.0.1.1
   ping: no answer
   ```

For more information on the shared memory network and network configuration, see *VxWorks Networking Guide*.

NOTE: The optional product VxMP can be used with VxSim. This product provides shared semaphores and other shared memory objects to multiple VxWorks targets over the backplane. VxMP is sold separately. It is not available for the PC simulator.

I
Coding Conventions

I.1 Introduction

This document defines the Wind River Systems standard for all C code and for the accompanying documentation included in source code. The conventions are intended, in part, to encourage higher quality code; every source module is required to have certain essential documentation, and the code and documentation is required to be in a format that has been found to be readable and accessible.

The conventions are also intended to provide a level of uniformity in the code produced by different programmers. Uniformity allows programmers to work on code written by others with less overhead in adjusting to stylistic differences. Also it allows automated processing of the source; tools can be written to generate reference entries, module summaries, change reports, and so on.

The conventions described here are grouped as follows:

- **File Headings.** Regardless of the programming language, a single convention specifies a heading at the top of every source file.
- **C Coding Conventions**

I.2 File Heading

Every file containing C code—whether it is a header file, a resource file, or a file that implements a host tool, a library of routines, or an application—must contain a *standard file heading*. The conventions in this section define the standard for the heading that must come at the beginning of every source file.

The file heading consists of the blocks described below. The blocks are separated by one or more empty lines and contain no empty lines within the block. This facilitates automated processing of the heading.

- **Title:** The title consists of a one-line comment containing the tool, library, or applications name followed by a short description. The name must be the same as the file name. This line will become the title of automatically generated reference entries and indexes.
- **Copyright:** The copyright consists of a single-line comment containing the appropriate copyright information.
- **Modification History:** The modification history consists of a comment block: in C, a multi-line comment. Each entry in the modification history consists of the version number, date of modification, initials of the programmer who made the change, and a complete description of the change. If the modification fixes an SPR, then the modification history must include the SPR number.

  The version number is a two-digit number and a letter (for example, 03c). The letter is incremented for internal changes, and the number is incremented for large changes, especially those that materially affect the module's external interface.

The following example shows a standard file heading from a C source file:

Example I-1 **Standard File Heading (C Version)**

```
/* fooLib.c - foo subroutine library */

/* Copyright 1984-1995 Wind River Systems, Inc. */

/*
modification history
--------------------
02a,15sep92,nfs  added defines MAX_FOOS and MIN_FATS.
01b,15feb86,dnw  added routines fooGet() and fooPut();
                 added check for invalid index in fooFind().
01a,10feb86,dnw  written.
*/
```

I.3 C Coding Conventions

These conventions are divided into the following categories:

- Module Layout
- Subroutine Layout
- Code Layout
- Naming Conventions
- Style
- Header File Layout
- Documentation Generation

I.3.1 C Module Layout

A *module* is any unit of code that resides in a single source file. The conventions in this section define the standard module heading that must come at the beginning of every source module following the standard file heading. The module heading consists of the blocks described below; the blocks should be separated by one or more blank lines.

After the modification history and before the first function or executable code of the module, the following sections are included in the following order, if appropriate:

- **General Module Documentation:** The module documentation is a C comment consisting of a complete description of the overall module purpose and function, especially the external interface. The description includes the heading *INCLUDE FILES:* followed by a list of relevant header files.
- **Includes:** The include block consists of a one-line C comment containing the word *includes* followed by one or more C pre-processor **#include** directives. This block groups all header files included in the module in one place.
- **Defines:** The defines block consists of a one-line C comment containing the word *defines* followed by one or more C pre-processor **#define** directives. This block groups all definitions made in the module in one place.
- **Typedefs:** The typedefs block consists of a one-line C comment containing the word *typedefs* followed by one or more C **typedef** statements, one per line. This block groups all type definitions made in the module in one place.
- **Globals:** The globals block consists of a one-line C comment containing the word *globals* followed by one or more C declarations, one per line. This block

groups together all declarations in the module that are intended to be visible outside the module.

- **Locals:** The locals block consists of a one-line C comment containing the word *locals* followed by one or more C declarations, one per line. This block groups together all declarations in the module that are intended not to be visible outside the module.

- **Forward Declarations:** The forward declarations block consists of a one-line C comment containing the words *forward declarations* followed by one or more ANSI C function prototypes, one per line. This block groups together all the function prototype definitions required in the module. Forward declarations must only apply to local functions; other types of functions belong in a header file.

The format of these blocks is shown in the following example (which also includes the file heading specified earlier).

Example I-2 **C File and Module Headings**

```
/* fooLib.c - foo subroutine library */

/* Copyright 1984-1995 Wind River Systems, Inc. */

/*
modification history
--------------------
02a,15sep92,nfs  added defines MAX_FOOS and MIN_FATS.
01b,15feb86,dnw  added routines fooGet() and fooPut();
                 added check for invalid index in fooFind().
01a,10feb86,dnw  written.
*/

/*
DESCRIPTION
This module is an example of the Wind River Systems C coding conventions.
...
INCLUDE FILES: fooLib.h
*/

/* includes */

#include "vxWorks.h"
#include "fooLib.h"

/* defines */

#define MAX_FOOS        112  /* max # of foo entries */
#define MIN_FATS        2     * min # of FAT copies */

/* typedefs */
```

```
typedef struct fooMsg       /* FOO_MSG */
    {
    VOIDFUNCPTR func;        /* pointer to function to invoke */
    int arg [FOO_MAX_ARGS];  /* args for function */
    } FOO_MSG;

/* globals */

char *    pGlobalFoo;        /* global foo table */

/* locals */

LOCAL int numFoosLost;       /* count of foos lost */

/* forward declarations */

LOCAL int     fooMat (list * aList, int fooBar, BOOL doFoo);
FOO_MSG       fooNext (void);
STATUS        fooPut (FOO_MSG inPar);
```

I.3.2 C Subroutine Layout

The following conventions define the standard layout for every subroutine.

Each subroutine is preceded by a C comment heading consisting of documentation that includes the following blocks. There should be no blank lines in the heading, but each block should be separated with a line containing a single asterisk (*) in the first column.

- **Banner:** This is the start of a C comment and consists of a slash character (/) followed by 75 asterisks (*) across the page.
- **Title:** One line containing the routine name followed by a short, one-line description. The routine name in the title must match the declared routine name. This line becomes the title of automatically generated reference entries and indexes.
- **Description:** A full description of what the routine does and how to use it.
- **Returns:** The word *RETURNS:* followed by a description of the possible result values of the subroutine. If there is no return value (as in the case of routines declared **void**), enter:

  ```
  RETURNS: N/A
  ```

  Mention only true returns in this section—not values copied to a buffer given as an argument.

- **Error Number:** The word *ERRNO:* followed by all possible **errno** values returned by the function. No description of the **errno** value is given, only the **errno** value and only in the form of a defined constant.[1]

The subroutine documentation heading is terminated by the C end-of-comment character (*/), which must appear on a single line, starting in column one.

The subroutine declaration immediately follows the subroutine heading.[2] The format of the subroutine and parameter declarations is shown in *I.3.3 C Declaration Formats*, p.568.

Example I-3 **Standard C Subroutine Layout:**

```
/********************************************************************
*
* fooGet - get an element from a foo
*
* This routine finds the element of a specified index in a specified
* foo.  The value of the element found is copied to <pValue>.
*
* RETURNS: OK, or ERROR if the element is not found.
*
* ERRNO:
*  S_fooLib_BLAH
*  S_fooLib_GRONK
*/

STATUS fooGet
    (
    FOO      foo,         /* foo in which to find element */
    int      index,       /* element to be found in foo */
    int *    pValue       /* where to put value */
    )
    {
    ...
    }
```

I.3.3 C Declaration Formats

Include only one declaration per line. Declarations are indented in accordance with *Indentation*, p.572, and are typed at the current indentation level.

The rest of this section describes the declaration formats for variables and subroutines.

1. A list containing the definitions of each **errno** is maintained and documented separately.
2. The declaration is used in the automatic generation of reference entries.

Variables

- For basic type variables, the type appears first on the line and is separated from the identifier by a tab. Complete the declaration with a meaningful one-line comment. For example:

```
unsigned    rootMemNBytes;   /* memory for TCB and root stack */
int         rootTaskId;      /* root task ID */
BOOL        roundRobinOn;    /* boolean for round-robin mode */
```

- The * and ** pointer declarators *belong* with the type. For example:

```
FOO_NODE *  pFooNode;        /* foo node pointer */
FOO_NODE ** ppFooNode;       /* pointer to the foo node pointer */
```

- Structures are formatted as follows: the keyword **struct** appears on the first line with the structure tag. The opening brace appears on the next line, followed by the elements of the structure. Each structure element is placed on a separate line with the appropriate indentation and comment. If necessary, the comments can extend over more than one line; see *Comments*, p.574, for details. The declaration is concluded by a line containing the closing brace, the type name, and the ending semicolon. Always define structures (and unions) with a **typedef** declaration, and always include the structure tag as well as the type name. Never use a structure (or union) definition to declare a variable directly. The following is an example of acceptable style:

```
typedef struct symtab   /* SYMTAB - symbol table */
    {
    OBJ_CORE    objCore;        /* object maintanance */
    HASH_ID     nameHashId;     /* hash table for names */
    SEMAPHORE   symMutex;       /* symbol table mutual exclusion sem */
    PART_ID     symPartId;      /* memory partition id for symbols */
    BOOL        sameNameOk;     /* symbol table name clash policy */
    int         nSymbols;       /* current number of symbols in table */
    } SYMTAB;
```

This format is used for other composite type declarations such as **union** and **enum**.

The exception to never using a structure definition to declare a variable directly is structure definitions that contain pointers to structures, which effectively declare another **typedef**. This exception allows structures to store pointers to related structures without requiring the inclusion of a header that defines the type.

For example, the following compiles without including the header that defines **struct fooInfo** (so long as the surrounding code never delves inside this structure):

CORRECT:
```
typedef struct tcbInfo
    {
    struct fooInfo *  pfooInfo;
    ...
    }  TCB_INFO;
```

By contrast, the following cannot compile without including a header file to define the type **FOO_INFO**:

INCORRECT:
```
typedef struct tcbInfo
    {
    FOO_INFO *  pfooInfo;
    ...
    }  TCB_INFO;
```

Subroutines

There are two formats for subroutine declarations, depending on whether the subroutine takes arguments.

- For subroutines that take arguments, the subroutine return type and name appear on the first line, the opening parenthesis on the next, followed by the arguments to the routine, each on a separate line. The declaration is concluded by a line containing the closing parenthesis. For example:

```
int lstFind
    (
    LIST *   pList,   /* list in which to search */
    NODE *   pNode    /* pointer to node to search for */
    )
```

- For subroutines that take no parameters, the word *void* in parentheses is required and appears on the same line as the subroutine return type and name. For example:

```
STATUS fppProbe (void)
```

I.3.4 C Code Layout

The maximum length for any line of code is 80 characters.

The rest of this section describes the conventions for the graphic layout of C code, and covers the following elements:

- vertical spacing
- horizontal spacing
- indentation
- comments

Vertical Spacing

- Use blank lines to make code more readable and to group logically related sections of code together. Put a blank line before and after comment lines.
- Do not put more than one declaration on a line. Each variable and function argument must be declared on a separate line. Do not use comma-separated lists to declare multiple identifiers.
- Do not put more than one statement on a line. The only exceptions are the **for** statement, where the initial, conditional, and loop statements can go on a single line:

  ```
  for (i = 0; i < count; i++)
  ```

  or the **switch** statement if the actions are short and nearly identical (see the **switch** statement format in *Indentation*, p.572).

  The **if** statement is not an exception: the executed statement always goes on a separate line from the conditional expression:

  ```
  if (i > count)
      i = count;
  ```

- Braces ({ and }) and **case** labels always have their own line.

Horizontal Spacing

- Put spaces around binary operators, after commas, and before an open parenthesis. Do not put spaces around structure members and pointer operators. Put spaces before open brackets of array subscripts; however, if a subscript is only one or two characters long, the space can be omitted. For example:

```
status = fooGet (foo, i + 3, &value);
foo.index
pFoo->index
fooArray [(max + min) / 2]
string[0]
```

- Line up continuation lines with the part of the preceding line they continue:

```
a = (b + c) *
    (d + e);

status = fooList (foo, a, b, c,
                  d, e);

if ((a == b) &&
    (c == d))
    ...
```

Indentation

- Indentation levels are every four characters (columns 1, 5, 9, 13, …).
- The module and subroutine headings and the subroutine declarations start in column one.
- Indent one indentation level after:
  - subroutine declarations
  - conditionals (see below)
  - looping constructs
  - switch statements
  - case labels
  - structure definitions in a **typedef**
- The **else** of a conditional has the same indentation as the corresponding **if**. Thus the form of the conditional is:

```
if ( condition )
    {
    statements
    }
else
    {
    statements
    }
```

The form of the conditional statement with an **else if** is:

```
if ( condition )
    {
    statements
    }
else if ( condition )
    {
    statements
    }
else
    {
    statements
    }
```

- The general form of the **switch** statement is:

```
switch ( input )
    {
    case 'a':
        ...
        break;
    case 'b':
        ...
        break;
    default:
        ...
        break;
    }
```

If the actions are very short and nearly identical in all cases, an alternate form of the switch statement is acceptable:

```
switch ( input )
    {
    case 'a': x = aVar; break;
    case 'b': x = bVar; break;
    case 'c': x = cVar; break;
    default: x = defaultVar; break;
    }
```

- Comments have the same indentation level as the section of code to which they refer (see *Comments*, p.574).
- Section braces ({ and }) have the same indentation as the code they enclose.

Comments

- Place comments within code so that they precede the section of code to which they refer and have the same level of indentation. Separate such comments from the code by a single blank line.
  - Begin single-line comments with the open-comment and end with the close-comment, as in the following:

    ```
    /* This is the correct format for a single-line comment */

    foo = MAX_FOO;
    ```

  - Begin and end multi-line comments with the open-comment and close-comment on separate lines, and precede each line of the comment with an asterisk (*), as in the following:

    ```
    /*
     * This is the correct format for a multiline comment
     * in a section of code.
     */

    foo = MIN_FOO;
    ```

- Compose multi-line comments in declarations and at the end of code statements with one or more one-line comments, opened and closed on the same line. For example:

```
int foo
    (
    int     a,     /* this is the correct format for a */
                   /* multiline comment in a declaration */
    BOOL    b      /* standard comment at the end of a line */
    )

    {
    day = night;   /* when necessary, a comment about a line */
                   /* of code can be done this way */
    }
```

I.3.5 C Naming Conventions

The following conventions define the standards for naming modules, routines, variables, constants, macros, types, and structure and union members. The purpose of these conventions is uniformity and readability of code.

- When creating names, remember that the code is written only once, but read many times. Assign names that are meaningful and readable; avoid obscure abbreviations.

- Names of routines, variables, and structure and union members are composed of upper- and lowercase characters and no underbars. Capitalize each "word" except the first:

  aVariableName

- Names of defined types (defined with **typedef**), and constants and macros (defined with **#define**), are all uppercase with underbars separating the words in the name:

  A_CONSTANT_VALUE

- Every module has a short prefix (two to five characters). The prefix is attached to the module name and all externally available routines, variables, constants, macros, and **typedefs**. (Names not available externally do not follow this convention.)

fooLib.c	module name
fooObjFind	subroutine name
fooCount	variable name
FOO_MAX_COUNT	constant
FOO_NODE	type

- Names of routines follow the *module-noun-verb* rule. Start the routine name with the module prefix, followed by the noun or object that the routine manipulates. Conclude the name with the verb or action the routine performs:

fooObjFind	foo - object - find
sysNvRamGet	system - NVRAM - get
taskSwitchHookAdd	task - switch hook - add

- Every header file defines a preprocessor symbol that prevents the file from being included more than once. This symbol is formed from the header file name by prefixing **__INC** and removing the dot (**.**). For example, if the header file is called **fooLib.h**, the *multiple inclusion guard symbol* is:

  __INCfooLibh

- Pointer variable names have the prefix *p* for each level of indirection. For example:

```
FOO_NODE *      pFooNode;
FOO_NODE **     ppFooNode;
FOO_NODE ***    pppFooNode;
```

I.3.6 C Style

The following conventions define additional standards of programming style:

- **Comments:** Insufficiently commented code is unacceptable.
- **Numeric Constants:** Use **#define** to define meaningful names for constants. Do not use numeric constants in code or declarations (except for obvious uses of small constants like 0 and 1).
- **Boolean Tests:** Do not test non-booleans as you test a boolean. For example, where **x** is an integer:

  CORRECT: `if (x == 0)`

  INCORRECT: `if (! x)`

  Similarly, do not test booleans as non-booleans. For example, where **libInstalled** is declared as **BOOL**:

  CORRECT: `if (libInstalled)`

  INCORRECT: `if (libInstalled == TRUE)`

- **Private Interfaces:** Private interfaces are functions and data that are internal to an application or library and do not form part of the intended external user interface. Place private interfaces in a header file residing in a directory named **private**. End the name of the header file with an uppercase *P* (for *private*). For example, the private function prototypes and data for the commonly used internal functions in the library **blahLib** would be placed in the file **private/private/blahLibP.h**.
- **Passing and Returning Structures:** Always pass and return pointers to structures. Never pass or return structures directly.
- **Return Status Values:** Routines that return status values should return either **OK** or **ERROR** (defined in **vxWorks.h**). The specific type of error is identified by setting **errno**. Routines that do not return any values should return **void**.
- **Use Defined Names:** Use the names defined in **vxWorks.h** wherever possible. In particular, note the following definitions:
  - Use **TRUE** and **FALSE** for boolean assignment.
  - Use **EOS** for end-of-string tests.
  - Use **NULL** for zero pointer tests.
  - Use **IMPORT** for **extern** variables.
  - Use **LOCAL** for **static** variables.
  - Use **FUNCPTR** or **VOIDFUNCPTR** for pointer-to-function types.

I.3.7 C Header File Layout

Header files, denoted by a **.h** extension, contain definitions of status codes, type definitions, function prototypes, and other declarations that are to be used (through **#include**) by one or more modules. In common with other files, header files must have a *standard file heading* at the top. The conventions in this section define the header file contents that follow the standard file heading.

Structural

The following structural conventions ensure that generic header files can be used in as wide a range of circumstances as possible, without running into problems associated with multiple inclusion or differences between ANSI C and C++.

- To ensure that a header file is not included more than once, the following must bracket all code in the header file. This follows the standard file heading, with the **#endif** appearing on the last line in the file.

  ```
  #ifndef __INCfooLibh
  #define __INCfooLibh
      ...
  #endif /* __INCfooLibh */
  ```

  See *I.3.5 C Naming Conventions*, p.574, for the convention for naming preprocessor symbols used to prevent multiple inclusion.

- To ensure C++ compatibility, header files that are compiled in both a C and C++ environment must use the following code as a nested bracket structure, subordinate to the statements defined above:

  ```
  #ifdef __cplusplus
  extern "C" {
  #endif /* __cplusplus */
      ...
  #ifdef __cplusplus
  }
  #endif /* __cplusplus */
  ```

Order of Declaration

The following order is recommended for declarations within a header file:

(1) Statements that include other header files.

(2) Simple defines of such items as error status codes and macro definitions.

(3) Type definitions.

(4) Function prototype declarations.

Example I-4 **Sample C Header File**

The following header file demonstrates the conventions described above:

```
/* bootLib.h - boot support subroutine library */

/* Copyright 1984-1993 Wind River Systems, Inc. */

/*
modification history
--------------------
01g,22sep92,rrr  added support for c++.
01f,04jul92,jcf  cleaned up.
01e,26may92,rrr  the tree shuffle.
01d,04oct91,rrr  passed through the ansification filter,
                 -changed VOID to void
                 -changed copyright notice
01c,05oct90,shl  added ANSI function prototypes;
                 added copyright notice.
01b,10aug90,dnw  added declaration of bootParamsErrorPrint().
01a,18jul90,dnw  written.
*/

#ifndef __INCbootLibh
#define __INCbootLibh
#ifdef __cplusplus
extern "C" {
#endif /* __cplusplus */

/*
 * BOOT_PARAMS is a structure containing all the fields of the
 * VxWorks boot line. The routines in bootLib convert this structure
 * to and from the boot line ASCII string.
 */

/* defines */

#define BOOT_DEV_LEN            20      /* max chars in device name */
#define BOOT_HOST_LEN           20      /* max chars in host name */
#define BOOT_ADDR_LEN           30      /* max chars in net addr */
#define BOOT_FILE_LEN           80      /* max chars in file name */
#define BOOT_USR_LEN            20      /* max chars in user name */
#define BOOT_PASSWORD_LEN       20      /* max chars in password */
#define BOOT_OTHER_LEN          80      /* max chars in "other" field */
#define BOOT_FIELD_LEN          80      /* max chars in boot field */

/* typedefs */

typedef struct bootParams              /* BOOT_PARAMS */
    {
    char bootDev [BOOT_DEV_LEN];        /* boot device code */
    char hostName [BOOT_HOST_LEN];      /* name of host */
    char targetName [BOOT_HOST_LEN];    /* name of target */
    char ead [BOOT_ADDR_LEN];           /* ethernet internet addr */
    char bad [BOOT_ADDR_LEN];           /* backplane internet addr */
    char had [BOOT_ADDR_LEN];           /* host internet addr */
    char gad [BOOT_ADDR_LEN];           /* gateway internet addr */
    char bootFile [BOOT_FILE_LEN];      /* name of boot file */
    char startupScript [BOOT_FILE_LEN]; /* name of startup script */
    char usr [BOOT_USR_LEN];            /* user name */
    char passwd [BOOT_PASSWORD_LEN];    /* password */
    char other [BOOT_OTHER_LEN];        /* avail to application */
    int  procNum;                       /* processor number */
    int  flags;                         /* configuration flags */
    } BOOT_PARAMS;

/* function declarations */

extern STATUS bootBpAnchorExtract (char * string, char ** pAnchorAdrs);
extern STATUS bootNetmaskExtract (char * string, int * pNetmask);
extern STATUS bootScanNum (char ** ppString, int * pValue, BOOL hex);
extern STATUS bootStructToString (char * paramString, BOOT_PARAMS *
                                  pBootParams);
extern char * bootStringToStruct (char * bootString, BOOT_PARAMS *
                                  pBootParams);
extern void   bootParamsErrorPrint (char * bootString, char * pError);
extern void   bootParamsPrompt (char * string);
extern void   bootParamsShow (char * paramString);

#ifdef __cplusplus
}
#endif /* __cplusplus */

#endif /* __INCbootLibh */
```

I.3.8 Documentation Format Conventions for C

This section specifies the text-formatting conventions for source-code derived documentation. The WRS tool **refgen** is used to generate reference entries (in HTML format) for every module automatically. All modules must be able to generate valid reference entries. This section is a summary of basic documentation format issues; for a more detailed discussion, see the *Tornado BSP Developer's Kit User's Guide: Documentation Guidelines*.

Layout

To work with **refgen**, the documentation in source modules must be laid out following a few simple principles. The file **sample.c** in *installDir*/**target/unsupported/tools/mangen** provides an example and more information.

Lines of text should fill out the full line length (assume about 75 characters); do not start every sentence on a new line.

Format Commands

Documentation in source modules can be formatted with UNIX **nroff**/**troff** formatting commands, including the standard **man** macros and several WRS extensions to the **man** macros. Some examples are described in the sections below. Such commands should be used sparingly.

Any macro (or "dot command") must appear on a line by itself, and the dot (`.`) must be the first character on the logical line (in the case of subroutines, this is column 3, because subroutine comment sections begin each line with an asterisk plus a space character).

Special Elements

- **Parameters:** When referring to a parameter in text, surround the name with the angle brackets, **<** and **>**. For example, if the routine ***getName*( )** had the following declaration:

  ```
  void getName
      (
      int     tid,    /* task ID */
      char *  pTname  /* task name */
      )
  ```

  You might write something like the following:

  ```
  This routine gets the name associated with a specified task ID and copies
  it to <pTname>.
  ```

- **Subroutines:** Include parentheses with all subroutine names, even those generally construed as shell commands. Do not put a space between the parentheses or after the name (unlike the WRS convention for code):

CORRECT:	`taskSpawn()`
INCORRECT:	`taskSpawn (), taskSpawn( ), taskSpawn`

Note that there is one major exception to this rule. In the subroutine title, do not include the parentheses in the name of the subroutine being defined:

CORRECT:

```
/*************************************************
*
* xxxFunc - do such and such
```

INCORRECT:

```
/*************************************************
*
* xxxFunc() - do such and such
```

Avoid using a library, driver, or routine name as the first word in a sentence, but if you must, do not capitalize it.

- **Terminal Keys:** Enter the names of terminal keys in all uppercase, as in **TAB** or **ESC**. Prefix the names of control characters with **CTRL+**; for example, **CTRL+C**.
- **References to Publications:** References to chapters of publications should take the form *Title*: *Chapter*. For example, you might say:

  For more information, see the *VxWorks Programmer's Guide: I/O System*.

  References to documentation volumes should be set off in italics. For general cases, use the **.I** macro. However, in SEE ALSO sections, use the **.pG** and **.tG** macros for the *VxWorks Programmer's Guide* and *Tornado User's Guide*, respectively.
- **Section-Number Cross-References:** Do not use the UNIX parentheses-plus-number scheme to cross-reference the documentation sections for libraries and routines:

  CORRECT: `sysLib, vxTas()`

  INCORRECT: `sysLib(1), vxTas(2)`

Table I-1 **Format of Special Elements**

Component	Input	Output (mangen + troff)
library in title	**sysLib.c**	sysLib
library in text	**sysLib**	(same)
subroutine in title	**sysMemTop**	sysMemTop()
subroutine in text	**sysMemTop()**	(same)
subroutine parameter	**<ptid>**	(same)

Table I-1 **Format of Special Elements**

Component	Input	Output (mangen + troff)
terminal key	`TAB, ESC, CTRL+C`	(same)
publication	`.I "Tornado User's Guide"`	*Tornado User's Guide*
VxWorks Programmer's Guide in **SEE ALSO**	`.pG "Configuration"`	*VxWorks Programmer's Guide: Configuration*
Tornado User's Guide in **SEE ALSO**	`.tG "Cross-Development"`	*Tornado User's Guide: Shell*
emphasis	`\f2must\fP`	*must*

Formatting Displays

- **Code:** Use the **.CS** and **.CE** macros for displays of code or terminal input/output. Introduce the display with the **.CS** macro; end the display with **.CE**. Indent such displays by four spaces from the left margin. For example:

```
* .CS
*     struct stat statStruct;
*     fd = open ("file", READ);
*     status = ioctl (fd, FIOFSTATGET, &statStruct);
* .CE
```

- **Board Diagrams:** Use the **.bS** and **.bE** macros to display board diagrams under the BOARD LAYOUT heading in the **target.nr** module for a BSP. Introduce the display with the **.bS** macro; end the display with **.bE**.

- **Tables:** Tables built with **tbl** are easy as long as you stick to basics, which suffice in almost all cases. Tables always start with the **.TS** macro and end with a **.TE**. The **.TS** should be followed immediately by a line of options terminated by a semicolon (**;**); then by one or more lines of column specification commands followed by a dot (**.**). For more details on table commands, refer to any UNIX documentation on **tbl**. The following is a basic example:

```
.TS
center; tab(|);
lf3 lf3
l l.
Command          | Op Code
_
INQUIRY          | (0x12)
```

```
REQUEST SENSE   | (0x03)
TEST UNIT READY | (0x00)
.TE
```

General stylistic considerations are as follows:

– Redefine the tab character using the **tab** option; keyboard tabs cannot be used by **tbl** tables. Typically the pipe character (|) is used.
– Center small tables on the page.
– Expand wide tables to the current line length.
– Make column headings bold.
– Separate column headings from the table body with a single line.
– Align columns visually.

Do not use **.CS**/**.CE** to build tables. This markup is reserved for code examples.

- **Lists:** List items are easily created using the standard **man** macro **.IP**. Do not use the **.CS**/**.CE** macros to build lists. The following is a basic example:

```
.IP "FIODISKFORMAT"
Formats the entire disk with appropriate hardware track and
sector marks.
.IP "FIODISKINIT"
Initializes a DOS file system on the disk volume.
```

Index

Numerics

NOTE: Index entries of the form "*see also* **bootLib**(1)" refer to the module's reference entry in the *VxWorks Reference Manual* or the equivalent entry in the *Tornado Online Manuals*.

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