WIND RIVER

VxWorks®

APPLICATION PROGRAMMER'S GUIDE

6.2

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9 Oct 05
Part #: DOC-15673-ZD-00

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1 Overview

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1.1 Introduction

This manual describes the VxWorks operating system, and how to use VxWorks facilities in the development of real-time applications and systems. It covers the following topics:

- real-time process (RTP) applications and process management
- multitasking facilities
- POSIX standard interfaces
- memory management
- I/O system
- local file systems
- error detection and reporting
- C++ development

NOTE: This book provides information about facilities available for real-time processes. For information about facilities available in the VxWorks kernel, see the the *VxWorks Kernel Programmer's Guide*.

1.2 Related Documentation Resources

The companion volume to this book, the *VxWorks Kernel Programmer's Guide*, provides material specific to kernel features and kernel-based development.

Detailed information about VxWorks libraries and routines is provided in the VxWorks API references. Information specific to target architectures is provided in the VxWorks BSP references and in the *VxWorks Architecture Supplement*.

For information about BSP and driver development, see the *VxWorks BSP Developer's Guide* and the *VxWorks Device Driver Guide*.

The VxWorks networking facilities are documented in the *Wind River Network Stack for VxWorks 6 Programmer's Guide* and the *VxWorks PPP Programmer's Guide.*

For information about migrating applications, BSPs, drivers, and projects from previous versions of VxWorks and the host development environment, see the *VxWorks Migration Guide* and the *Wind River Workbench Migration Guide*.

The Wind River IDE and command-line tools are documented in the Wind River compiler and GNU compiler guides, the Wind River Workbench user's guide, and the Wind River tools API and command line references.

1.3 VxWorks Configuration and Build

This document describes VxWorks features; it does not go into detail about the mechanisms by which VxWorks-based systems and applications are configured and built. The tools and procedures used for configuration and build are described in the Wind River Workbench documentation.

NOTE: In this book, as well as in the VxWorks API references, VxWorks components are identified by the names used in component description files, which is in the form of **INCLUDE_FOO**. Similarly, configuration parameters are identified by their configuration parameter names, such as **NUM_FOO_FILES**.

Component and parameter names can be used directly to identify components and configure VxWorks if you work with the command-line configuration facilities.

Wind River Workbench provides fuller descriptions of the components and their parameters in the GUI. But you can also use a simple search facility to locate a component based on its component name. Once you have located the component, you can access the component's parameters through the GUI.

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Applications and Processes

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2.1 Introduction

VxWorks real-time processes (RTPs) are in many respects similar to processes in other operating systems—such as UNIX and Linux—including extensive POSIX compliance. The ways in which they are created, execute applications, and terminate will be familiar to developers who understand the UNIX process model. The VxWorks process model is designed for use with real-time embedded systems and VxWorks processes:

- Occupy continuous blocks of virtual memory.
- Are started with a spawn model, in which the instantiation of the process is separate from the loading of the application.
- Load applications in their entirety; there is no demand paging.
- Maintain the VxWorks task scheduling model, in which all tasks are scheduled globally (processes themselves are not scheduled).
- Include traditional VxWorks APIs in addition to POSIX APIs.

All of these differences are designed to make VxWorks particularly suitable for hard real-time applications by ensuring determinism, as well as providing a common programming model for systems that run with an MMU and those that do not. As a result, there are differences between the VxWorks process model and that of server-style operating systems such as UNIX and Linux. The reasons for these differences are discussed as the relevant topic arises throughout this chapter.

VxWorks real-time processes provide the means for executing applications in user mode. Each process has its own address space, which contains the executable program, the program's data, stacks for each task, the heap, and resources associated with the management of the process itself (such as memory-allocation tracking).

Many processes may be present in memory at once, and each process may contain more than one task (sometimes known as a *thread* in other operating systems). Each VxWorks process has its own region of virtual memory; processes do not overlap in virtual memory. This flat virtual-memory map provides advantages in speed, in a programming model that accommodates systems with and without an MMU, and in debugging applications.

There is no limit to the number of processes in a system, or to the number of tasks in a process, other than the limit imposed by the amount of available memory.

Each real-time process (RTP) application can be created as a fully linked or partially linked (for use with shared libraries), relocatable executable with

cross-development tools on a host system. Applications are built as single executable files independent of the operating system, with the user code being linked to the required VxWorks application API libraries.

During development, processes can be spawned to execute applications from the VxWorks shell or various host tools. Processes can also be spawned programmatically, and systems can be configured to start processes automatically at boot time for deployed systems. For systems with multiple applications, not all need to be started at boot time. They can be started later by other applications, or interactively by users. Developers can also implement their own application startup managers.

The VxWorks operating system is configured and built independently of any applications that it might execute. Applications are built separately, and they can either be stored separately or bundled with VxWorks in an additional build step that combines the operating system and applications into a single system image (using the ROMFS file system). VxWorks need only be configured with the appropriate components for real-time process support and any other facilities required by the application (for example, message queues). This independence of operating system from applications allows for development of a variety of systems, using differing applications, that are based on a single operating system configuration. That is, a single variant of the operating system can be combined with different sets of applications to create different systems. The operating system does not need to be *aware* of what applications it will run before it is configured and built, as long as its configuration includes the components required to support the applications in question.

The isolation of applications in processes effectively prevents symbol name clashes during integration. As processes are completely linked, they never import functions from outside the process even when external functions have the same name. The name and symbol spaces of the kernel and processes are isolated.

Executable application files can be stored on disks, in RAM, flash, or ROM. They can be stored on the target or anywhere else that is accessible over a network connection. The executables are loaded from a file system; and any file system for which the kernel has support (ROMFS, NFS, ftp, and so on) can be used. The ROMFS file system technology is particularly useful for deployed systems. It allows developers to bundle application executables with the VxWorks image into a single file that the boot loader can load from ROM. Unlike other operating systems, no root file system—such as on NFS or a diskette—is required to hold application binaries, configuration files, and so on.

NOTE: The default configuration of VxWorks for hardware targets does not include support for running applications in real-time processes (RTPs). VxWorks must be re-configured and rebuilt to provide these process facilities. The default configuration of the VxWorks simulator does, however, include full support for running applications in processes.

The reason that the default configuration of VxWorks (for hardware targets) does not include process support, is that it facilitates migration of VxWorks 5.5 kernel-based applications to VxWorks 6.*x* by providing functionally the same basic set of kernel components, and nothing more.

VxWorks 6.*x* systems can be created with kernel-based applications and without any process-based applications, or with a combination of the two. Kernel applications, however, cannot be provided the same level of protection as those that run in processes. When applications run in kernel space, both the kernel and those applications are subject to any misbehavior on the part application code.

For more information about kernel-based applications, see the *VxWorks Kernel Programmer's Guide: Kernel*.

2.2 Configuring VxWorks For Real-time Processes

In order to run RTP applications on a hardware target, VxWorks must be configured with the **INCLUDE_RTP** component and rebuilt.

Note that if a system is configured with **INCLUDE_RTP** the MMU components required for memory protection are included by default. To create a system with processes, but without MMU support, the MMU components must be removed from the VxWorks configuration.

The default image provided for the VxWorks simulator includes all the necessary components.

Additional Components Options

The following components provide useful facilities for both development and deployed systems:

- **INCLUDE_ROMFS** for the ROMFS file system.

- **INCLUDE_RTP_APPL_USER**, **INCLUDE_RTP_APPL_INIT_STRING**, **INCLUDE_RTP_APPL_INIT_BOOTLINE**, and **INCLUDE_RTP_APPL_INIT_CMD_SHELL_SCRIPT** for various ways of automatically starting applications at boot time.
- **INCLUDE_SHARED_DATA** for shared data regions.
- **INCLUDE_SHL** for shared libraries.
- **INCLUDE_RTP_HOOKS** for the programmatic hook facility, which allows for registering kernel routines that are to be executed at various points in a process' life-cycle.
- **INCLUDE_POSIX_PTHREAD_SCHEDULER** and **INCLUDE_POSIX_CLOCK** for POSIX thread support. This replaces the native VxWorks scheduler with a scheduler handling user threads in a manner conformant with POSIX.1. VxWorks tasks and well as kernel POSIX threads are handled as usual. Note that the **INCLUDE_POSIX_PTHREAD_SCHEDULER** is compulsory when pthreads are used in processes.
- **INCLUDE_PROTECT_TASK_STACK** for user stack exception stack protection. This component enables stack protection for kernel tasks as well as for user task exception stacks for system calls into the kernel. For deployed systems this component may be omitted to save on memory usage. See *Task Stack*, p.85 for more information on stack protection.

The following components provide facilities used primarily in development systems, although they can be useful in deployed systems as well:

- The various **INCLUDE_SHELL**_*feature* components for the kernel shell, which, although not required for applications and processes, are needed for running applications from the command line, executing shell scripts, and on-target debugging.
- The **INCLUDE_WDB** component for using the host tools.
- Either the **INCLUDE_NET_SYM_TBL** or the **INCLUDE_STANDALONE_SYM_TBL** component, which specify whether symbols for the shell are loaded or built-in.
- The **INCLUDE_DISK_UTIL** and **INCLUDE_RTP_SHOW** components, which include useful shell routines.

For information about the kernel shell, symbol tables, and show routines, see the *VxWorks Kernel Programmer's Guide: Target Tools*. For information about the host shell, see the *VxWorks Command-Line Tools User's Guide*.

Component Bundles

The VxWorks configuration facilities provide component bundles to simplify the configuration process for commonly used sets of operating system facilities. The following component bundles are provided for process support:

- **BUNDLE_RTP_DEPLOY** is designed for deployed systems (final products), and is composed of **INCLUDE_RTP**, **INCLUDE_RTP_APPL**, **INCLUDE_RTP_HOOKS**, **INCLUDE_SHARED_DATA**, and the **BUNDLE_SHL** components.
- **BUNDLE_RTP_DEVELOP** is designed for the development environment, and is composed of **BUNDLE_RTP_DEPLOY**, **INCLUDE_RTP_SHELL_CMD**, **INCLUDE_RTP_SHOW**, **INCLUDE_SHARED_DATA_SHOW**, **INCLUDE_SHL_SHOW**, **INCLUDE_RTP_SHOW_SHELL_CMD**, **INCLUDE_SHL_SHELL_CMD**, components.

Configuration and Build

For information about configuring and building VxWorks, see the *Wind River Workbench User's Guide* and the *VxWorks Command-Line Tools User's Guide*.

Note that the VxWorks simulator includes all of the basic components required for processes by default.

2.3 Real-time Processes

A common definition of a process is "a program in execution," and VxWorks processes are no different in this respect. VxWorks processes, however, are called real-time processes precisely because they are designed to support the determinism required of real-time systems. They do so in various ways:

- Processes are not scheduled—tasks are scheduled globally throughout the system.
- Processes can be preempted in kernel mode as well as in user mode. Every task has both a user more and a kernel mode stack. (The VxWorks kernel is fully preemptive.)
- Process creation takes place in two phases—each with a separate task priority— which separates instantiation from loading the application. The

second task, therefore, bears the cost of instantiation itself, at its own task priority level. The calling task is not impacted, unless it is coded to wait.

- Processes load applications in their entirety; there is no demand paging.

The primary way in which VxWorks processes support determinism is that they themselves are simply not scheduled. Only tasks are scheduled in VxWorks systems, using a preemptive, priority-based algorithm. Based on the strong preemptibility of the VxWorks kernel, this ensures that at any given time, the highest priority task in the system that is ready to run will execute, regardless of whether the task is in the kernel or in any process in the system.

By way of contrast, the scheduling algorithm for non-real-time systems is based on time-sharing, as well as a dynamic determination of process priority that ensures that no process is denied use of the CPU for too long, and that no process monopolizes the CPU. Each Linux process is allocated its own time quantum, which it expends on its own tasks, regardless of the priorities of tasks in other processes. Thus, for example, a high priority task in process A may pend for a significant amount of time while processes B and C use up their time quantum on their own (lower priority) tasks. By way of analogy, it is something like spending small and equal amounts of time on each plate in a gourmet *prix fixe* meal in rotation—without regard to whether the hot ones get cold or the cold ones warm, and without regard to the gastronomic intentions of the chef's artistry.

VxWorks does provide an optional time-sharing capability—round-robin scheduling—but it does not interfere with priority-based preemption, and is therefore deterministic. Round-robin scheduling simply ensures that when there is more than one task with the highest priority ready to run at the same time, the CPU is shared between those tasks. No one of them, therefore, can usurp the processor until it is blocked. (For more information about VxWorks scheduling see *3.2.2 Task Scheduling*, p.80.)

The manner in which VxWorks processes are created also supports the determinism required of real-time systems. The creation of a VxWorks process takes place in two distinct phases, and the executable is loaded in its entirety when the process is created. In the first phase, the **rtpSpawn( )** call creates the process object in the system, allocates virtual and physical memory to it, and creates the initial process task (see *2.3.3 Processes and Tasks*, p.15). In the second phase, the initial process task loads the entire executable and starts the main routine.

This approach provides for system determinism in two ways:

- First, the work of process creation is divided between the **rtpSpawn( )** task and the initial process task—each of which has its own distinct task priority. This means that the activity of loading applications does not occur at the priority,

or with the CPU time, of the task requesting the creation of the new process. Therefore, the initial phase of starting a process is discrete and deterministic, regardless of the application that is going to run in it. And for the second phase, the developer can assign the task priority appropriate to the significance of the application, or to take into account necessarily indeterministic constraints on loading the application (for example, if the application is loaded from networked host system, or local disk). The application is loaded with the same task priority as the priority with which it will run. In a way, this model is analogous to asynchronous I/O, as the task that calls **rtpSpawn( )** just initiates starting the process and can concurrently perform other activities while the application is being loaded and started.

- Second, the entire application executable is loaded when the process is created, which means that the determinacy of its execution is not compromised by incremental loading during execution. This feature is obviously useful when systems are configured to start applications automatically at boot time—all executables are fully loaded and ready to execute when the system comes up.

Note that **rtpSpawn( )** has an option that provides for synchronizing for the successful loading and instantiation of the new process.

Note that the creation of VxWorks processes involves no copying or sharing of the parent processes page frames (copy-on-write), as is the case with some versions of UNIX and Linux. The flat virtual-memory model provided by VxWorks prohibits this approach. For information about the issue of inheritance of attributes from parent processes, see *2.3.4 Processes, Inheritance, and Resource Reclamation*, p.16.

2.3.1 Real-time Process Life-Cycle

The life-cycle of VxWorks real-time processes is largely consistent with the POSIX process model.

VxWorks processes can be started in a variety of ways:

- interactively from the kernel shell
- interactively from the host shell and debugger
- automatically at boot time, using a startup facility
- programmatically from applications or the kernel

VxWorks can run many processes at once, and any number of processes can run the same application executable. That is, many instances of an application can be run concurrently.

Each process can execute one or more tasks. When a process is created, the system spawns a single task to initiate execution of the application. The application may then spawn additional tasks to perform various functions.

The creation of a process includes several phases, as described in *2.3 Real-time Processes*, p.10. For information about what operations are possible on a process in each phase of its instantiation, see the API reference for **rtpLib**.

Processes are terminated under the following circumstances:

- When the last task in the process exits.
- If any task in the process calls **exit( )**, regardless of whether or not other tasks are running in the process.
- If the process' **main( )** routine returns.

  This is because **exit( )** is called implicitly when **main( )** returns. An application in which **main( )** spawns tasks can be written to avoid this behavior—and to allow its other tasks to continue operation—by including a **taskExit( )** call as the last statement in **main( )**. See *2.4 Developing VxWorks Applications*, p.18.
- If the **kill( )** routine is used to terminate the process.
- If **rtpDelete( )** is called on the process—from a program, a kernel module, the C interpreter of the shell, or from the host IDE. Or if the **rtp delete** command is used from the shell's command interpreter.
- If a process takes an exception during its execution.

  This default behavior can be changed for debugging purposes. When the error detection and reporting facilities are included in the system, and they are set to debug mode, processes are not terminated when an exception occurs.

Note that if a process fails while the shell is running, a message is printed to the shell console. Error messages can be recorded with the VxWorks error detection and reporting facilities (see *8. Error Detection and Reporting*).

For information about attribute inheritance and what happens to a process' resources when it terminates, see *2.3.4 Processes, Inheritance, and Resource Reclamation*, p.16.

2.3.2 Processes and Memory

Each process has its own address space, which contains the executable program, the program's data, stacks for each task, the heap, and resources associated with the management of the process itself (such as local heap management).

Many processes may be present in memory at once. Each VxWorks process has its own region of virtual memory; processes do not overlap in virtual memory. This flat virtual-memory map provides the following advantages:

- Speed—Context switching is fast.
- Ease of debugging.
- A flexible programming model that provides the same process-model orientation regardless of MMU support. VxWorks' application memory model allows for running the same applications with and without an MMU. Hard real-time determinism can be facilitated by using the same programming model, but disabling the MMU.

  Systems can be developed and debugged on targets with an MMU, and then shipped on hardware that does not have one, or has one that is not enabled for deployment. The advantages of being able to do so include facilitating debugging in development, lower cost of shipped units, as well as footprint and performance advantages of targets without an MMU (or with one that is not enabled).

Each process is protected from any other process that is running on the system, whenever the target system has an MMU, and MMU support has been configured into VxWorks. Operations involving the code, data, and memory of a process are accessible only to code executing in that process. It is possible, therefore, to run several instances of the same application in separate processes without any undesired side effects occurring between them.

As processes run a fully linked image without external references, a process cannot call a routine in another process, or a kernel routine that is not exported as a function call—whether or not the MMU is enabled. However, if the MMU is not enabled, a process can read and write memory external to its own address space, and could cause the system to malfunction.

While the address space of each process is invisible to tasks running in other processes, tasks can communicate across process boundaries through the use of various IPC mechanisms (including *public* semaphores, *public* message queues, and message channels) and shared data memory regions. See *3.3 Intertask and Interprocess Communications*, p.100 and *2.6 Creating and Managing Shared Data Regions*, p.59 for more information.

At startup time, the resources internally required for the process (such as the heap) are allocated on demand. The application's text is guaranteed to be write-protected, and the application's data readable and writable, as long as an MMU is present and the operating system is configured to manage it. While memory protection is provided by MMU-enforced partitions between processes, there is no mechanism to provide resource protection by limiting memory usage of processes to a specified amount.

For more information, see *5. Memory Management*.

2.3.3 Processes and Tasks

Each VxWorks process may contain more than one task. When a process is created, an initial task is spawned to begin execution of the application. The name of the process's initial task is based on the name of the executable file, with the following modifications:

- The letter **i** is prefixed.
- The first letter of the filename capitalized.
- The filename extension is removed.

For example, when **foobar.vxe** is run, the name of the initial task is **iFoobar**.

The initial task provides the execution context for the program's **main( )** routine, which it then calls. The application itself may then spawn additional tasks.

Task creation includes allocation of space for the task's stack from process memory. As needed, memory is automatically added to the process as tasks are created from the kernel free memory pool.

Heap management routines are available in user-level libraries for tasks in processes. These libraries provide the various ANSI APIs such as **malloc( )** and **free( )**. The kernel provides a pool of memory for each process in user space for these routines to manage.

Providing heap management in user space provides for speed and improved performance because the application does not incur the overhead of a system call for memory during its execution. However, if the heap is exhausted the system automatically allocates more memory for the process (by default), in which case a system call is made. Environment variables control whether or not the heap grows (see *5.3 Heap and Memory Partition Management*, p.208).

For more information, see *3. Multitasking*.

2.3.4 Processes, Inheritance, and Resource Reclamation

VxWorks has a process hierarchy made up of parent/child relationships. Any process spawned from the kernel (whether programmatically, from the shell or other development tool, or by an automated startup facility) is a child of the kernel. Any process spawned by another process is a child of that process. As in human societies, these relationships are critical with regard to what characteristics children inherit from their parents, and what happens when a parent or child dies.

VxWorks processes inherit certain attributes of their parent. The child process inherits the file descriptors of its parent, which means that they can access the same files (if they are open), signal masks, and environment variables.

By default, when a process is terminated, and its parent is not the kernel, it becomes a zombie process.[1] The parent process can then use **wait( )** or **waitpid( )** to get the exit status of the child process. After it has done so, the zombie entity is deleted automatically. The default behavior of zombie creation can be prevented by either of these two methods:

- By ignoring the **SIGCHLD** signal. That is, by setting the **SIGCHLD** signal handler to **SIG_IGN** with **sigaction( )**.
- By hooking a **SIGCHLD** handling with **SA_NOCLDSTOP | SA_NOCLDWAIT** **sa_flag** set with **sigaction( )**.

The **getppid( )** routine returns the parent process ID. If the parent is the kernel, or the parent is dead, it returns NULL.

While the signal mask is not actually a property of a process as such—it is a property of a task—the signal mask for the initial task in the process is inherited from the task that spawned it (that is, the task that called the **rtpSpawn( )** routine). If the kernel created the initial task, then the signal mask is zero, and all signals are unblocked.

When a process terminates, all resources owned by the process (objects, data, and so on) are returned to the system. The resources used internally for managing the process are released, as are all resources owned by the process. All information about that process is eliminated from the system (with the exception of any temporary zombie process information). Resource reclamation ensures that all

1. A zombie process is a "process that has terminated and that is deleted when its exit status has been reported to another process which is waiting for that process to terminate." (The Open Group Base Specifications Issue 6, IEEE Std 1003.1, 2004 Edition.)

resources that are not in use are immediately returned to the system and available for other uses.

Note, however, that there are exceptions to this general rule:

- Public objects—which may be referenced by tasks running in other processes that continue to run—must be explicitly deleted.
- Socket objects can persist for some time after a process is terminated. They are reclaimed only when they are closed, which is driven by the nature of the TCP/IP state machine. Some sockets must remain open until timeout is reached.
- File descriptors are reclaimed only when all references to them are closed. This can occur implicitly when all child processes—which inherit the descriptors from the parent process—terminate. It can also happen explicitly when all applications with references to the file descriptors close them.

For information about object ownership, and about public and private objects, see *3.3.1 Public and Private Objects*, p.100.

2.3.5 Processes and Environment Variables

By default, a process is created without environment variables. However, the creator of a process can pass an environment array to the application (for example, when a process is started from the shell's command interpreter, it always passes the **SHELL_INTERPRETER** variable). See the **rtpSpawn( )** API reference and *2.4.1 Application Structure*, p.18 for details.

In addition, if the creator is a kernel task, the contents of that task's environment array can be duplicated in the application's environment array using the **getenv( )** routine.

A task in a process (or in an application library) can create, reset, and remove environment variables in a process. The **getenv( )** routine can be used to get the environment variables, and the **setenv( )** and **unsetenv( )** routines to change or remove them. They environment array can also be manipulated directly.

In conformance with the POSIX standard, all tasks in a process share the same environment variables—unlike kernel tasks, which each have their own set of environment variables.

2.3.6 Processes and POSIX

The overall behavior of the application environment provided by the real-time process model is close to the POSIX 1003.1 standard, while maintaining the embedded and real-time characteristics of the VxWorks operating system. The key areas of deviation from the standard are that VxWorks does not provide the following:

- an overlapping virtual memory model
- process creation with **fork( )** and **exec( )**
- memory-mapped files
- file ownership and file permissions

For information about POSIX conformance, see *4. POSIX Standard Interfaces*.

2.4 Developing VxWorks Applications

VxWorks RTP applications are created as a fully linked, relocatable executables. They are built independently of the VxWorks operating system, using cross-development tools on the host system. When an application is built, user code is linked to the required VxWorks application API libraries, and an ELF executable is produced. By convention, VxWorks RTP executables are named with a **.vxe** file-name extension. The extension draws on the **vx** in VxWorks and the **e** in executable to indicate the nature of the file.

A VxWorks application can be loaded from any file system for which the kernel has support (NFS, ftp, and so on). In addition, applications can be bundled into a single image with the operating system (see *2.8 Bundling Applications with a VxWorks System using ROMFS*, p.71). Executable application files can be stored on disks, in RAM, flash, or ROM.

2.4.1 Application Structure

VxWorks applications have a simple structural requirement that is common to C programs on other operating systems—they must include a **main( )** routine. The **main( )** routine can be used with the conventional **argc** and **argv** arguments, as well as two additional optional arguments, **envp** and **auxp**:

```
int main
```

```
(
int argc,      /* number of arguments */
char * argv[], /* null-terminated array of argument strings */
char * envp[], /* null-terminated array of environment variable strings */
void * auxp    /* implementation specific auxiliary vector */
);
```

The **envp** and **auxp** arguments are usually not required by the application code.

The **envp** argument is used for passing VxWorks environment variables to the application. These can be set by a user and are typically inherited from the calling environment. Note that the **getenv( )** routine can be used to get the environment variables programmatically, and the **setenv( )** and **unsetenv( )** routines to change or remove them. (See *2.3.5 Processes and Environment Variables*, p.17.)

Environment variables are general properties of the running system, such as the default path—unlike **argv** arguments, which are passed to a particular invocation of the application, and are unique to that application. The system uses the **auxp** vector to pass system information to the new process, including page size, cache alignment size and so on.

The **argv[0]** argument is typically the relative path to the executable.

2.4.2 VxWorks Header Files

RTP applications often make use of VxWorks operating system facilities or utility libraries. This usually requires that the source code 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. VxWorks provides all header files specified by the ANSI X3.159-1989 standard.

VxWorks system header files for RTP applications are in the directory *installDir*/**vxworks-6.***x*/**target/usr/h** and its subdirectories (different directories are used for kernel applications).

CAUTION: Do not reference header files that are for kernel code (which are in and below *installDir*/**vxworks-6.***x*/**target/h**) in application code.

POSIX Header Files

Traditionally, VxWorks has provided many header files that are described by POSIX.1, although their content was only partially that described by POSIX.1. For user-mode applications the POSIX header files are more strictly compliant with the

POSIX.1 description, in both in their content and in their location. See *4.4 POSIX Header Files*, p.156 for more information.

VxWorks Header File: vxWorks.h

It is often useful to include header file **vxWorks.h** in all application modules in order to take advantage of architecture-specific VxWorks facilities. Many other VxWorks header files require these definitions. Include **vxWorks.h** with the following line:

```
#include <vxWorks.h>
```

Other VxWorks Header Files

Applications 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 API reference 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. Those that are compiler-independent or more VxWorks-specific are provided in *installDir*/**vxworks-6.***x*/**target/usr/h** while a few that are compiler-dependent (for example **stddef.h** and **stdarg.h**) are provided by the compiler installation. Each toolchain knows how to find its own internal headers; no special compile flags are needed.

ANSI C++ Header Files

Each compiler has its own C++ libraries and C++ headers (such as **iostream** and **new**). The C++ headers are located in the compiler installation directory rather than in *installDir*/**vxworks-6.***x*/**target/usr/h**. No special flags are required to enable the compilers to find these headers. For more information about C++ development, see *9. C++ Development*.

NOTE: In releases prior to VxWorks 5.5 Wind River recommended the use of the flag **-nostdinc**. This flag *should not* be used with the current release since it prevents the compilers from finding headers such as **stddef.h**.

The -I Compiler Flag

By default, the compiler searches for header files first in the directory of the source code and then in its internal subdirectories. In general, *installDir*/**vxworks-6.***x*/**target/usr/h** should always be searched before the compilers' other internal subdirectories; to ensure this, always use the following flag for compiling under VxWorks:

```
-I %WIND_BASE%/target/usr/h %WIND_BASE%/target/usr/h/wrn/coreip
```

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 one exception is the basic VxWorks header file **vxWorks.h**, which all other header files assume is already included.)

Generally, explicit inclusion of prerequisite header files can pose a problem: a header file could get included more than once and generate fatal compilation errors (because the C preprocessor regards duplicate definitions as potential sources of conflict). However, 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 can include just those header files it needs directly, without regard to interdependencies or ordering, and no conflicts will arise.

VxWorks Private Header Files

Some elements of VxWorks are internal details that may change and so should not be referenced in your application. The only supported uses of VxWorks facilities are through the public definitions in the header file, and through the public APIs. Your adherence ensures that your application code is not affected by internal changes in the implementation of a VxWorks facility.

Some header files mark internal details using **HIDDEN** comments:

```
/* HIDDEN */
...
/* END HIDDEN */
```

Internal details are also hidden with *private* header files that are stored in the directory *installDir*/**vxworks-6.***x*/**target/usr/h/private**. The naming conventions for these files parallel those in *installDir*/**vxworks-6.***x*/**target/usr/h** with the library name followed by **P.h**. For example, the private header file for **semLib** is *installDir*/**vxworks-6.***x*/**target/usr/h/private/semLibP.h**.

2.4.3 Applications, Processes, and Tasks

A process is an instance of an application in execution. A process must be spawned in order to initiate execution of an application; when the application exits, the process terminates.

VxWorks can run one or more applications simultaneously. Each application can spawn multiple tasks, as well as other processes. Application tasks are scheduled by the kernel, independently of the process within which they execute—processes themselves are not scheduled. In one sense, processes can be viewed as containers for tasks.

Processes, which provide the execution environment for applications, are started with **rtpSpawn( )**. The initial task for any application is created automatically in the create phase of the **rtpSpawn( )** call. This initial task provides the context within which **main( )** is called.

By default, a process is terminated when the **main( )** returns, because the C compiler automatically inserts an **exit( )** call at the end of **main( )**. This is undesirable behavior if **main( )** spawns other tasks, because terminating the process deletes all the tasks that were running in it. To prevent this from happening, any application that uses **main( )** to spawn tasks can call **taskExit( )** instead of **return( )** as the last statement in the **main( )** routine. When **main( )** includes **taskExit( )** as its last call, the process' initial task can exit without the kernel automatically terminating the process.

A process can explicitly be terminated when a task does either of the following:

- Calls **exit( )** to terminate the process in which it is are running, regardless of whether or not other tasks are running in the process.
- Calls the **kill( )** routine to terminate the specified process (using the process ID).

Terminating processes—either programmatically or by interactive user command—can be used as a means to update or replace application code. Once the process is stopped, the application code can be replaced, and the process started again using the new executable.

If the application is multi-threaded (has multiple tasks), the developer must ensure that the **main( )** routine task starts all the other tasks.

In developing systems in which multiple applications will run, developers should consider:

- the priorities of tasks running in all the different processes
- any task synchronization requirements *between* processes as well as *within* processes

For information about task priorities and synchronization, see *3.2 Tasks and Multitasking*, p.76 and *3.3 Intertask and Interprocess Communications*, p.100.

2.4.4 Applications and VxWorks Kernel Component Requirements

VxWorks is a highly configurable operating system. Because RTP applications are built independently of the operating system, the build process cannot determine if the instance of VxWorks on which the application will eventually run has been configured with all of the components that the application requires (for example, networking and file systems).

It is, therefore, important for application code to check for errors indicating that kernel facilities are not available (that is, check the return values of API calls) and to respond appropriately. If an API requires a facility that is not configured into the kernel, an **errno** value of **ENOSYS** is returned when the API is called.

The **syscallPresent( )** routine can also be used to determine whether or not a particular system call is present in the system.

2.4.5 Building Applications

The VxWorks cross-development environment provides simple mechanisms for building applications, including a useful set of default makefile rules. Both the IDE and command line can be used to build applications.

For command line use, the VxWorks Development Shell or **wrenv** utility program can be used to open a command shell with the appropriate environment variables set. See the *VxWorks Command-Line Tools User's Guide*.

An application can then be compiled for VxWorks by creating a simple makefile and executing a **make** command in the directory that contains the application C file. Makefile macros allow for compiling the same source code for different architectures, with different compilers, and so on. For example, assuming that **c:\vxApp\myVxApp.c** has been created, a makefile with the following macro assignments and include statement could be used to generate the executable:

```
EXE = myVxApp.vxe
OBJS =  myVxApp.o
include $(WIND_USR)/make/rules.rtp
```

When **make** is run, the executable is created in *installDir***vxworks-6.***x****target\usr\root***cpuTool***bin**. As the defaults in this regard are PowerPC and the Wind River (Diab) compiler, the path and filename would be as follows:

c:\myInstallDir\vxworks-6.*x***\target\usr\root\PPC32diab\bin\myVxApp.vxe**

Macro assignments can be used at the command line to identify other architectures and compilers. For example, the command used to build the application with the GNU compiler for Pentium 2 would be as follows:

```
make CPU=PENTIUM2 TOOL=gnu
```

Note that applications that make use of share libraries or plug-ins must be built as dynamic executables. See *Building Shared Libraries and Dynamic Applications*, p.36 for information about dynamic executables and additional **make** macros.

For information about build options, see the *VxWorks Architecture Supplement* for the target architecture in question. For information about using makefiles to build applications, see the *Wind River Command Line User's Guide*.

2.4.6 C++ Applications

For information about developing C++ applications, see *9. C++ Development*.

2.4.7 Processes and Hook Routines

For information about hook routines, see the VxWorks API reference for **rtpHookLib** and *3.2.4 Tasking Extensions*, p.92.

2.4.8 Application APIs, System Calls, and Library Routines

VxWorks provides an extensive set of APIs for developing RTP applications. As with other operating systems, these APIs include both system calls and library routines.

System calls provide access to kernel facilities that are otherwise inaccessible in user space, such as APIs that involve interaction with the hardware, I/O, and the processor itself. Some library routines include system calls, and others execute entirely in user space.

Note that a few APIs operate on the process rather than the task level—for example, **kill( )** and **exit( )**.

System Calls

Because kernel mode and user mode have different instruction sets and MMU settings, RTP applications—which run in user mode—cannot directly access kernel routines and data structures (as long as the MMU is on). System calls provide the means by which applications request that the kernel perform a service on behalf of the application, which usually involves operations on kernel or hardware resources.

System calls are transparent to the user, but operate as follows: For each system call, an architecture-specific trap operation is performed to change the CPU privilege level from user mode to kernel mode. Upon completion of the operation requested by the trap, the kernel returns from the trap, restoring the CPU to user mode. Because they involve a trap to the kernel, system calls have higher overhead than library routines that execute entirely in user mode.

Note that if VxWorks is configured without a component that provides a system call required by an application, **ENOSYS** is returned as an **errno** by the corresponding user-mode library API.

Also note that if a system call has trapped to the kernel and is waiting on a system resource when as signal is received, the system call may be aborted. In this case the errno **EINTR** may be returned to the caller of the API.

System calls are identified as such in the VxWorks API references.

The set of system calls provided by VxWorks can be extended by kernel developers. They can add their own facilities to the operating system, and make them available to processes by registering new system calls with the VxWorks

system call infrastructure. For more information, see the *VxWorks Kernel Programmer's Guide: Kernel*.

VxWorks Libraries

VxWorks distributions include libraries of routines that provide APIs for RTP applications. Some of these routines execute entirely in the process in user mode. Others are wrapper routines that make one or more system calls, or that add additional functionality to one or more system calls. For example, **printf( )** is a wrapper that calls the system call **write( )**. The **printf( )** routine performs a lot of formatting and so on, but ultimately must call **write( )** to output the string to a file descriptor.

Library routines that do not include system calls execute in entirely user mode, and are therefore more efficient than system calls, which include the overhead of a trap to the kernel.

The standard C and C++ libraries for VxWorks applications are provided by Dinkumware, Ltd.

Note that the user-mode libraries provided for RTP applications are completely separate from kernel libraries.

For information about creating custom user-mode libraries for applications, see *2.5 Developing Application Libraries*, p.27.

API Documentation

For detailed information about the routines available for use in applications, see the VxWorks application API references and Dinkumware library references.

2.4.9 POSIX

For information about POSIX APIs available with VxWorks, and a comparison of native VxWorks and POSIX APIs, see *4. POSIX Standard Interfaces*.

2.5 Developing Application Libraries

Developers can create their own custom libraries to support their RTP applications. These libraries can be developed for either static or dynamic (run-time) linking. See 2.5.4 Developing Shared Libraries, p.31 for a discussion of the differences between static and shared libraries.

As with applications, libraries should check for errors indicating that kernel facilities are not available (see 2.4.4 Applications and VxWorks Kernel Component Requirements, p.23).

The subsections 2.5.1 Library Initialization, p.27 and 2.5.2 Library Termination, p.29 provide information relevant to both static and shared libraries.

2.5.1 Library Initialization

An application library requires an initialization routine only if its operation requires that resources be created (such as semaphores, or a data area) before its routines are called.

If an initialization routine is required for the library, its prototype should follow this convention:

```
void fooLibInit (void);
```

The routine takes no arguments and returns nothing. It can be useful to use the same naming convention used for VxWorks libraries; *name***LibInit( )**, where *name* is the basename of the feature. For example, **fooLibInit( )** would be the initialization routine for **fooLib**.

The code that calls the initialization of application libraries is generated by the compiler. The **_WRS_CONSTRUCTOR** compiler macro must be used to identify the library's initialization routine (or routines), as well as the order in which they should be called. The macro takes two arguments, the name of the routine and a rank number. The routine itself makes up the body of the macro:

```
_WRS_CONSTRUCTOR (fooLibInit, rankNumInteger)
    {
      /* body of the routine */
    }
```

The following example is of a routine that creates a mutex semaphore used to protect a scarce resource, which may be used in a transparent manner by various features of the application.

```
_WRS_CONSTRUCTOR (scarceResourceInit , 101)
    {
    /*
     * Note: a FIFO mutex is preferable to a priority-based mutex
     * since task priority should not play a role in accessing the scarce
     * resource.
     */

    if ((scarceResourceMutex = semMCreate (SEM_DELETE_SAFE | SEM_Q_FIFO |
                                           SEM_USER)) == NULL)
        EDR_USR_FATAL_INJECT (FALSE,
                    "Cannot enable task protection on scarce resource\n");
    }
```

(For information about using the error detection and reporting macro **EDR_USR_FATAL_INJECT**, see *8.7 Using Error Reporting APIs in Application Code*, p.300.)

The rank number is used by the compiler to order the initialization routines. The rank number is referred to somewhat misleadingly as a *priority* number by the toolchain. Rank numbers from 100 to 65,535 can be used—numbers below 100 are reserved for VxWorks libraries. Using a rank number below 100 does not have detrimental impact on the kernel, but may disturb or even prevent the initialization of the application environment (which involves creating resources such as the heap, semphores, and so on).

Initialization routines are called in numerical order (from lowest to highest). When assigning a rank number, consider whether or not the library in question is dependent on any other application libraries that should be called before it. If so, make sure that its number is greater.

If initialization routines are assigned the same rank number, the order in which they are run is indeterminate within that rank (that is, indeterminate relative to each other).

C++ Library Initialization

Application libraries written in C++ may require initialization of static constructors for any global objects the library might use, in addition to the library initialization required for libraries written in C (described in *2.5.1 Library Initialization*, p.27).

By default, static constructors are called last, after the library's initialization routine. In addition, there is no guarantee that the library's static constructors will be called before any static constructors in the associated application's code. (Functionally, they both have the default rank of *last*, and there is no defined ordering within a rank.)

If you require that the initialization of static constructors be ordered, explicitly rank them by using the **_WRS_CONSTRUCTOR** macro. However, a well-written C++ library should not need a specific initialization routine if the objects and methods defined by the library are properly designed (using lazy initialization).

Handling Initialization Failures

Libraries should be designed to respond gracefully to initialization failures. In such cases, they should do the following:

- Check whether the **ENOSYS** errno has been set, and respond appropriately. For system calls, this errno indicates that the required support component has not been included in the kernel.
- Release all the resources that have been created or obtained by the initialization routine.
- Use the **EDR_USR_FATAL_INJECT** macro to report the error. If the system has been configured with the error detection and reporting facility, the error is recorded in the error log (and the system otherwise responds to the error depending on how the facility has been configured). If the system has not been configured with the error detection and reporting facility, it attempts to print the message to a host console by way of a serial line. It is best to use the macro for this purpose without tracing. For example:

```
if (mutex = semMCreate (SEM_Q_PRIORITY | SEM_INVERSION_SAFE)) == NULL)
        {
        EDR_USR_FATAL_INJECT (FALSE, "myLib: cannot create mutex. Abort.");
        }
```

For more information, see *8.7 Using Error Reporting APIs in Application Code*, p.300.

2.5.2 Library Termination

When the last task in a process exits, or the application's **main( )** routine returns, or any task in the process explicitly calls the POSIX **exit( )** routine, the process will be terminated. When a process terminates, the operating system performs the

default cleanup actions (see 2.3.1 Real-time Process Life-Cycle, p.12 for information about process termination).

These default actions include: all existing destructors are called in the reverse order of the related constructors, all registered cleanup routines are called in the reverse order of their registration (see Using atexit() for Termination Routines, p.30), any remaining process tasks are deleted, the process' memory pages are returned to the general pool, and any objects created by the process' tasks in the kernel are deleted (if they are owned by the terminated process).

Additional cleanup work can be stipulated by using **atexit( )** or **taskDeleteHookAdd( )**, and if pthreads are used, **pthread_cleanup_push( )** can be employed.

Using atexit() for Termination Routines

While there is no library *termination* routine facility comparable to that for initialization routines (particularly with regard to ranking), a library can register cleanup routines to be executed using the POSIX **atexit( )** routine. These routines are executed in reverse order of their registration when a process is being terminated.

Using **atexit( )** is useful for cleanup activities that are not handled automatically by the operating system, such as shutting down a device. The call to **atexit( )** can be made at anytime during the life of the process, although it is preferably done by the library's initialization routine.

Cleanup routines registered with **atexit( )** are called when **exit( )** is called. Note that if a process' task directly calls the POSIX **_exit( )** routine, none of the cleanup routines registered with **atexit( )** will be executed.

2.5.3 Developing Static Libraries

The VxWorks development environment provides simple mechanisms for building libraries, including a useful set of default makefile rules. Both the IDE and command line can be used to build libraries.

At the command line, a application library can be compiled for VxWorks by creating a simple makefile and executing a **make** command in the directory that contains the library's C file. Makefile macros allow for compiling the same source code for different architectures, with different compilers, and so on.

For example, to create a static archive called **libfoobar.a** from various **foo** and **bar** modules, a makefile might look like this:

```
# This file contains make rules for building the foobar library
LIB_BASE_NAME = foobar
OBJS =          foo1.o foo2.o \
                bar1.o bar2.o
include $(WIND_USR)/make/rules.library
```

The makefile includes the default rules defined in **rules.library**. By default, static libraries are created in **installDir/vxworks-6.***x***/target/usr/lib/***arch***/***CPU***/common**.

The makefile defaults are for the PowerPC architecture and the Wind River Compiler (Diab). Variable assignments can be used at the command line to identify other architectures and compilers. For example, the command used to build the application with the GNU compiler for Pentium2 would be as follows:

```
make CPU=PENTIUM2 TOOL=gnu
```

For more information about using the VxWorks command-line build environment, see the *VxWorks Command-Line Tools User's Guide: Building Applications and Libraries*.

Also see *2.5.4 Developing Shared Libraries*, p.31, and particularly *Using the VxWorks CLI Build Environment*, p.36, which includes information about creating makefiles to build both static and shared versions of libraries.

For information about using the IDE, see the *Wind River Workbench User's Guide*.

2.5.4 Developing Shared Libraries

Shared libraries are made up of routines and data that can be used by applications, just like static (archive) libraries. However, when an application is linked to a shared library, the linker does not copy object code from the library into the executable—they are not statically linked. Instead it copies information about the name of the shared library (its *shared object name*) and its run-time location (if the appropriate compiler option is used).

Conceptually, shared libraries do the same job as static libraries. The key differences in their utility are that:

- Statically-linked applications link only those elements of a static library that they need. The entire library does not necessarily become part of the system. If multiple applications in a system use the same library elements, it means that there is replication of library code in the system.

- Dynamically-linked applications require the presence of the entire shared library in the system, even if they only use a small set of its features. If multiple applications in a system need the shared library, however, they share a single copy. The library code is not duplicated.

Applications that make use of shared libraries must be built as dynamic executables, which includes a dynamic linker that carries out the binding of the shared library and application at run time.

Once loaded into memory by the dynamic linker, shared libraries are held in sections of memory (shared data areas) that are accessible to all applications. Each application that uses the shared library gets its own copy of the private data, which is stored in its own memory space. When the last application that references a shared library exits, the library is removed from memory.

Plug-ins (also referred to as dynamically linked libraries, or DLLs) are another class of shared object similar to shared libraries. An application can load or unload a plug-in using a special set of routines. Plug-ins allow for dynamic modification of an application at run time. They can also be used to modify the functionality of a deployed application by loading replacement plug-ins rather than replacing the entire application. (See *Using Plug-Ins*, p.51.)

Dynamic Linking

The dynamic linking feature in VxWorks is based on equivalent functionality in UNIX and related operating systems. It uses features of the UNIX-standard ELF binary executable file format, and it uses many features of the ELF ABI standards, although it is not completely ABI-compliant for technical reasons. The source code for the dynamic linker comes from NetBSD, with VxWorks-specific modifications. It provides **dlopen( )** for plug-ins, and other standard features.

An application that is built as a dynamic executable is statically linked with a *dynamic linker* library that contains code to locate, read and edit shared objects at run-time (unlike UNIX, in which the dynamic linker is itself a shared library). The dynamic linker contains a constructor function that schedules its initialization at a very early point in the execution of process (during its instantiation phase). It reads a list of shared libraries and other information about the executable file and uses that information to make a list of shared libraries that it will load. As it reads each shared library, it looks for more of this dynamic information, so that eventually it has loaded all of the code and data that is required by the program and its libraries. The dynamic linker makes special arrangements to share code between processes, placing shared code in a shared memory region and using special kernel locks to make sure that the shared memory region is only initialized once. The dynamic

linker allocates its memory resources from shared data regions and additional pages of memory allocated on demand—and not from process memory—so that the use of process memory is predictable.

Shared objects are compiled in a special way, into position-independent code (PIC). This type of code is designed so that it requires relatively few changes to accommodate different load addresses. A table of indirections called a global offset table (GOT) is used to access all global functions and data. Each process that uses a given shared object has a private copy of the library's GOT, and that private GOT contains pointers to shared code and data, and to private data. When PIC needs to use the value of a variable, it fetches the pointer to that variable from the GOT and de-references it. This means that when code from a shared object is shared across processes, the same code can fetch different copies of the analogous variable. The dynamic linker is responsible for initializing and maintaining the GOT.

Because VxWorks uses a flat (that is, not overlapped) virtual memory space, the NetBSD version of the dynamic linker was modified so that the code and data segments of a shared library can have different relative addresses at run time. In standard PIC, the code can locate its GOT by computing the offset from the code's load address; overlapped memory allows each private copy of the GOT to have the same virtual address. With VxWorks PIC, an RTP (process) variable is used instead to locate a private table of GOTs; each resident shared object reserves a fixed offset in this GOT table, with which a program can recover the GOT address for a given shared object.

Advantages and Disadvantages of Shared Libraries

Shared libraries can provide advantages of footprint reduction, flexibility, and efficiency:

- The storage requirements of a system can be reduced because the applications that rely on a shared library are smaller than if they were each linked with a static library. Only one set of the required library routines is needed, and they are provided by the run-time library file itself. The extent to which shared libraries make efficient use of mass storage and memory depends primarily on how many applications are using how much of a shared library, and if the applications are running at the same time.
- Plug-ins (DLLs) provide flexibility in allowing for dynamic configuration of applications.
- Shared libraries are efficient because their code requires fewer relocations than standard code when loaded into RAM. Moreover, lazy binding allows for linking only those functions that are required.

At the same time, shared libraries use PIC code, which is slightly larger than standard code, and PIC accesses to data are usually somewhat slower than non-PIC accesses because of the extra indirection through the GOT. This has more impact on some architectures than on others. Usually the difference is on the order of a fraction of a percent, but if a time-sensitive code path in a shared library contains many references to global functions, global data or constant data, there may be a measurable performance penalty.

If deferred binding is also used, it introduces non-deterministic behavior.

The startup cost of shared libraries makes up the largest efficiency loss (as is the case on UNIX). It is also greater because of more complex memory setup and more I/O (file accesses) than for static executables.

Shared libraries are therefore most useful when:

- Many programs require a few libraries.
- Many programs that use libraries run at the same time.
- Libraries are discrete functional units with little unused code.
- Library code represents a substantial amount of total code.

Conversely, it is not advisable to use shared libraries when only one application runs at a time, or when applications make use of only a small portion of the routines provided by the library.

Additional Considerations

There are a number of other considerations that may affect whether to use shared libraries:

- Assembly code that refers to global functions or data must be converted by hand into PIC in order to port it to a shared library.
- In shared libraries, the relocation process only affects the data segment. Read-only data identified with the **const** C keyword are therefore gathered with the data segment and not with the text segment to allow a relocation per executable. This means that read-only data used in shared libraries are not protected against erroneous write operations at run-time.
- Code that has not been compiled as PIC will not work in a shared library. Code that has been compiled as PIC does not work in an executable program, even if the executable program is dynamic. The dynamic linker does not edit any PIC prologues in the executable program therefore PIC does not work there.

- All constructors in a shared library are executed together, hence a constructor with high priority in one shared library may be executed after a constructor with low priority in a shared library that was loaded later than the first one. All shared library constructors are executed at the priority level of the dynamic linker's constructor from the point of view of the executable program. (The constructor for the dynamic linker has a priority of 6.)
- Shared objects are not cached (they do not *linger*) if no currently executing program is using them. There is, therefore, extra processor overhead if a shared library is loaded and unloaded frequently.
- There is a limit on the number of concurrent shared libraries, which is 1024. This limit is imposed by the fact that the GOT table has a fixed size, so that indexing can be used to look up GOTs (which makes it fast).

⚠ **CAUTION:** There is no support for so-called *far PIC* on PowerPC. Some shared libraries require the global offset table to be larger than 16,384 entries; since this is greater than the span of a 16-bit displacement, specialized code must be used to support such libraries.

Configuring VxWorks for Shared Libraries

While shared libraries can only be used with applications in user mode (not in the kernel), they do require kernel support for managing their use by different processes.

Shared library support is not provided by VxWorks by default. The operating system must be configured with the **INCLUDE_SHL** main component.

Doing so automatically includes these components as well:

- **INCLUDE_RTP**, the main component for real-time process support
- **INCLUDE_SHARED_DATA** for storing shared library code
- **INCLUDE_RTP_HOOKS** for shared library initialization
- and various **INCLUDE_SC**_*XYZ*, the relevant system call components

It can also be useful to include support for relevant show routines with these components:

- **INCLUDE_RTP_SHOW**
- **INCLUDE_SHL_SHOW**
- **INCLUDE_SHARED_DATA_SHOW**

Note that if you use the **INCLUDE_SHOW_ROUTINES** component, all of the above are automatically added.

Configuration can be simplified through the use of component bundles. Both **BUNDLE_RTP_DEVELOP** or **BUNDLE_RTP_DEPLOY** provide support for shared libraries (see *Component Bundles*, p.10).

Building Shared Libraries and Dynamic Applications

There are three alternative approaches to building shared libraries and the dynamic applications that make use of them:

- Use Wind River Workbench. All of the build-related elements are created automatically as part of creating and associating shared library and application projects. For information in this regard, see the *Wind River Workbench User's Guide: Shared Library Projects*.
- Use the **make** build rules and macros provided with the VxWorks installation to create the appropriate makefiles, and execute the build from the command line. See *Using the VxWorks CLI Build Environment*, p.36 and the *VxWorks Command-Line Tools User's Guide: Building Applications and Libraries*.
- Write makefiles and rules from scratch, or make use of a custom or proprietary build environment. See *Using a Custom Build Environment*, p.42, which includes information about the compiler flags used for shared libraries and dynamic applications.

Using the VxWorks CLI Build Environment

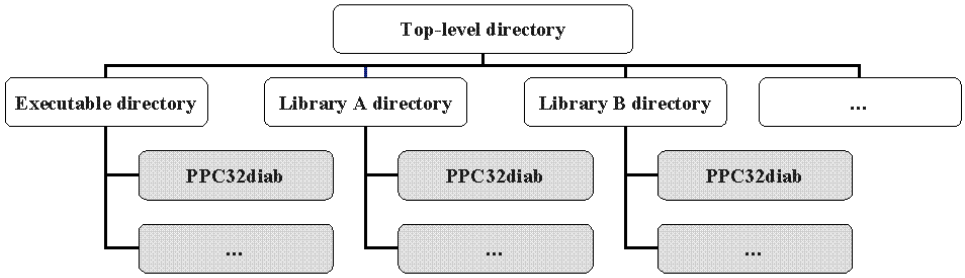
Using the command-line interface (CLI) build environment provided with the VxWorks installation allows you to take advantage of a set of default makefile rules to build dynamic executables and shared libraries.

It can be useful to set up a project with a top-level directory with subdirectories for the application and for each shared library. The makefiles would be:

- A top-level makefile that identifies the application and library subdirectories to build.
- A makefile for each shared library.
- A makefile for each application.

The directory structure might look like the one in Figure 2-1. The grey boxes indicate directories created automatically by the default build rules.

Figure 2-1 **Example of CLI Build Directory Structure**



If you do not use a top-level makefile for the whole project, and you build libraries and applications separately, you must of course build libraries first.

Top-Level Makefile

The top level makefile requires only two elements. For example:

```
SUBDIRS = libA libB app
include $(WIND_USR)/make/rules.rtp
```

The **SUBDIRS** variable indicates what subdirectories to build. In this case, there are two library subdirectories (**libA** and **libB**) and an application subdirectory (**app**) identified.

The include statement references **rules.rtp**, which is the make fragment holding build rules for application (**.vxe**) files.

The **$(WIND_USR)** element is an environment variable pointing to the user-side of the target tree: *installDir*/**vxworks-6.***x*/**target/usr**.

Library Makefile

Only four elements are required for a library makefile. For example:

```
LIB_BASE_NAME = MyFoo
OBJS = foo1.o foo2.o foo3.o
EXTRA_INCLUDE += -I/home/moimoi/proj/h
include $(WIND_USR)/make/rules.library
```

The **LIB_BASE_NAME** variable specifies the library's *basename*. It takes a *stripped* version of the library name; that is, without the **lib** prefix and without the filename extension. The **LIB_BASE_NAME** variable is required for generating the shared object name (soname) information, which is necessary for identifying the run-time

location of the shared library. See *Shared Object Names, Library Versions, and Run-time Locations*, p.47.

The **OBJS** variable identifies the object files that make up the library.

The **EXTRA_INCLUDE** variable appends additional search paths for the include files (using the **+=** operator).

The include statement references **rules.library**, which is the make fragment holding build rules for libraries.

The **$(WIND_USR)** element is an environment variable pointing to the user-side of the target tree: *installDir*/**vxworks-6.***x*/**target/usr**.

Additional makefile macros and conditional statements can be used to build either shared or static libraries, to specify a location other than the default in which to create the library, and so on. A more useful makefile would look like this:

```
SL_INSTALL_DIR = /home/moimoi/proj/ppc32/lib
ifeq ($(EXE_FORMAT),dynamic)
LIB_FORMAT = shared
endif
ifeq ($(LIB_FORMAT),shared)
LOCAL_CLEAN += $(OBJ_DIR)/*.sho $(OBJ_DIR)/libMyFoo.so
else
LOCAL_CLEAN += $(OBJ_DIR)/*.o $(OBJ_DIR)/libMyFoo.a
endif
LIB_BASE_NAME = MyFoo
LIBNAME = lib$(LIB_BASE_NAME)
SL_VERSION = 2
OBJS = module1.o module2.o
OBJ_DIR = $(CPU)$(TOOL)
EXTRA_INCLUDE += -I/home/moimoi/proj/h
include $(WIND_USR)/make/rules.library
LIBDIR = $(OBJ_DIR)
```

The **SL_INSTALL_DIR** variable specifies a non-default location for the library file. It is often useful to keep project work outside of the installation directory. Note that if you are generating code for different processor architectures, you could use the **$(CPU)** variable to define the architecture-specific subdirectory (which would then use the Wind River naming conventions—**PPC32** instead of **ppc32**, as in this case).

The **LIB_FORMAT** variable specifies whether the library must be generated as a static library (the default if not specified) or a shared library. It can be set to static, shared, or both. See *Library Build Commands*, p.39.

The **LOCAL_CLEAN** variable specifies what must be deleted when non-default directories are used.

The **OBJ_DIR** variable specifies a non-default directory in which the object modules are generated.

The **LIBNAME** variable specifies a non-default directory for the static library.

The **SL_VERSION** variable is used to create a version number for a shared library. By default, the shared library version number is one (*libName*.**so.1**), so the variable is not needed unless you want to build an alternate version of the shared library. For more information about shared library versions, see *Shared Object Names, Library Versions, and Run-time Locations*, p.47.

The **LIBDIR** variable prevents the creation of an unused directory in *installDir*/**vxworks-6.***x*/**target/usr/lib** when set to **$(OBJ_DIR)**, as it is in this example. This variable must be the last one used; that is, it must be listed after the inclusion of **rules.library** in order to take precedence.

Library Build Output

By default, a library is created as a static archive file (*libName*.**a**) in *installDir*/**target/usr/lib/***arch*/*cpu*/**common**. For example, *installDir*/**target/usr/lib/ppc/PPC32/common**.

When a library is built as a shared library:

- The reference file (*libName*.**so**) is created by default in the same default directory as a static library file. The reference file is used by the linker when a dynamic application is built.
- The runtime version of the shared library (*libName*.**so.***n*) is created by default in the same default directory as the application executable.

  That is, all the runtime executables are created in the same binary directory by default: *installDir*/**target/usr/root/***cpuTool*/**bin**. For example, *installDir*/**target/usr/root/PPC32diab/bin**.

As noted in *Library Makefile*, p.37, the **SL_INSTALL_DIR** makefile variable can be used to specify a non-default location for the library file.

NOTE: The rather cumbersome usage of **LIBNAME**, **OBJ_DIR** and **LIBDIR** is required by the library rules. The three must be specified if one does not want to clutter the distribution's *installDir*/**vxworks-6.***x*/**target/usr/lib/***arch*/*cpu*/**common** directory with unnecessary directories and user application-specific files.

Library Build Commands

The first conditional statement in the example above allows for building both a shared library and dynamic application using the top-level makefile. For example:

```
make EXE_FORMAT=dynamic
```

builds the dynamic executable and related shared libraries for the PPC32 architecture with the Wind River Compiler (the default architecture and compiler).

The following command is similar, but uses the GNU compiler to build for the Pentium architecture:

```
make CPU=PPC32 TOOL=gnu EXE_FORMAT=dynamic
```

Static libraries are created by default, so the **EXE_FORMAT** variable need not be used to create them.

You can also build libraries by executing **make** in the directory containing the library makefile. The **LIB_FORMAT** variable allows you to create static, shared, or both sets of libraries. For example:

```
make LIB_FORMAT=static
make LIB_FORMAT=shared
make LIB_FORMAT=both
```

Static libraries are created by default, so that option is superfluous in this context.

Application Makefile

Only four elements are required for an application makefile when the application is a dynamic executable that uses a shared library. For example:

```
EXE = myVxApp.vxe
OBJS = myVxApp.o
ADDED_LIBS += -L../lib/$(CPU)$(TOOL) -lMyFoo
include $(WIND_USR)/make/rules.rtp
```

The **EXE** variable defines the name of the application executable.

The **OBJS** variable identifies the constituent object modules. If more than one is used, they are listed in a space-separated string. For example:

```
OBJS = bar1.o bar2.0 bar3.0
```

The **ADDED_LIBS** variable appends the search paths and *stripped* names of any custom libraries that the application requires (with the **+=** operator). This option can be used for creating either static or dynamic applications. See *Compiler Flag For Shared Objects and Dynamic Applications*, p.44 for a discussion of the **-l** flag.

The include statement and **$(WIND_USR)** element are described in *Top-Level Makefile*, p.37.

Additional makefile macros can (and often should) be used to specify a different location for the application executable, the runtime location of the shared libraries upon which it depends, conditional compilation of either a dynamic or static application, and so on. A more useful makefile would look like this:

```
EXE = myVxApp.vxe
```

```
OBJS = myVxApp.o
VXE_DIR = $(CPU)$(TOOL)/bin
LIB_DIR         = ../lib/$(CPU)$(TOOL)
ADDED_LIBS += -L $(LIB_DIR) -lMyFoo
ifeq ($(EXE_FORMAT),dynamic)
ADDED_DYN_EXE_FLAGS += -Wl,-rpath /romfs/lib
else
ADDED_LIB_DEPS += $(LIB_DIR)/libMyFoo.a
endif
include $(WIND_USR)/make/rules.rtp
```

The **VXE_DIR** variable identifies an alternative to the default directory in which the application executable is created. It is often useful to keep project work outside of the installation tree.

The **LIB_DIR** variable is simply a local **make** variable that can be used conveniently to identify where a library is located (if it is not in the default location) in the **ADDED_LIBS** and **ADDED_LIB_DEPS** lines without repeating the literal path information.

The **ADDED_DYN_EXE_FLAGS** variable is used to pass additional compiler flags specific to the generation of dynamic executables. It is used here with the **-Wl,-rpath** flag to specify the run-time location of any shared libraries upon which the application depends. In this example, the location is in a **lib** subdirectory of the ROMFS file system on the VxWorks target:

```
ADDED_DYN_EXE_FLAGS    += -Wl,-rpath /romfs/lib
```

In this next example, the location is on the host system:

```
# ADDED_DYN_EXE_FLAGS    += -Wl,-rpath c:/myProj/lib/SIMPENTIUMdiab
```

For information about the **-Wl,-rpath** flag, see *Compiler Flag For Shared Objects and Dynamic Applications*, p.44. Also see *Shared Object Names, Library Versions, and Run-time Locations*, p.47.

Note that some types of connections between the target and host require modifiers to the pathname (NFS is transparent; FTP requires **hostname:** before the path if it is not on the same system from which VxWorks was booted; the VxWorks simulator requires a **host:** prefix; and so on).

The **ADDED_LIB_DEPS** specifies the dependencies between the application and the application's static libraries (with the **+=** operator). For static linkage, this variable forces a rebuild of the application if the static library has been changed since the last build.

Application Build Output

By default, the executable is created in *installDir*/**target/usr/root/***cpuTool*/**bin**, as are the run-time shared object files (libraries and plug-ins). For example, *installDir*/**target/usr/root/PPC32diab/bin**.

As noted in *Application Makefile*, p.40, the **VXE_DIR** variable can be used to identify an alternative output directory.

Application Build Commands

In the example provided in *Application Makefile*, p.40, the conditional **ifeq**/**else**/**endif** statement allows for generating either a static executable or a dynamic executable, depending on the value given the **EXE_FORMAT** variable when **make** is executed at the command line. The **EXE_FORMAT** variable can take one of two values, **dynamic** or **static**. For example:

```
make EXE_FORMAT=dynamic
```

As a static build is the default, setting **EXE_FORMAT** to **static** is not necessary.

Using a Custom Build Environment

If you do not use Wind River Workbench or the CLI VxWorks build environment to create shared libraries and dynamic executables, follow the guidelines provided in this section (including the compiler flags listed in *Compiler Flag For Shared Objects and Dynamic Applications*, p.44).

To create a dynamically linked program or shared object, you must run the static linker (**dld** or **ld**) with specific flags. These flags cause the linker to mark the output as dynamically linked, and to include various data structures for later dynamic linking.

Shared objects are compiled as position-independent code (PIC). Note that all code that you compile for a shared object must be PIC. Do not use PIC options to compile modules that will be statically linked into an executable program.

A shared library must be built before any dynamic application that makes use of it, in two steps:

1. Generate the PIC object modules that are to be assembled into a shared object file. The modules are created with the **.sho** filename extension.
2. Generate the shared object (with the **.so** filename extension) based on the PIC object modules.

The dynamic application can then be built, in two more steps:

1. Generate the object modules that will be assembled into an executable file. The application's object modules are created with a **.o** filename extension.
2. Generate the executable file based on the object modules. By convention, the application is created with the **.vxe** filename extension.

Generating PIC Object Modules

The following examples illustrate compiler commands used to generate a library's PIC modules. The compiler flags are the same as those used by the default makefile system.

Using the Wind River Compiler:

```
dcc -tPPCEH:rtp -Xansi -XO -I$(WIND_BASE)/target/usr/h -I/home/moimoi/proj/h
-DCPU=PPC32 -DTOOL_FAMILY=diab -DTOOL=diab -Xpic -Xswitch-table-off -c foo1.c
-o PPC32diab/foo1.sho
```

Using the GNU Compiler:

```
ccppc -mhard-float -mstrict-align -mregnames -ansi -mrtp -O2
-fstrength-reduce -fno-builtin -I$(WIND_BASE)target/usr/h
-I/home/moimoi/proj/h -DCPU=PPC32 -DTOOL_FAMILY=gnu -DTOOL=gnu -fpic -c
foo1.c -o PPC32gnu/foo1.sho
```

⚠ **CAUTION:** The combination of PIC modules generated by the Wind River Compiler and the GNU compiler is not supported and is not expected to work. Doing so may lead to unpredictable results.

Generating the Shared Library

The following examples illustrate compiler commands used to generate a library from PIC modules. The compiler flags are the same as those used by the default makefile system.

Using the Wind River Compiler:

```
dplus -tPPCEH:rtp -Xansi -XO -DCPU=PPC32 -DTOOL_FAMILY=diab -DTOOL=diab -Xpic
-Xswitch-table-off -Wl, -Xshared -Wl, -Xdynamic -soname=libMyFoo.so.1
-L$(WIND_BASE)/target/usr/lib/ppc/PPC32/common/PIC -lstlstd
PPC32diab/foo1.sho PPC32diab/foo2.sho -o libMyFoo.so
```

Using the GNU Compiler:

```
c++ppc -mhard-float -mstrict-align -mregnames -ansi -mrtp -O2
-fstrength-reduce -fno-builtin -DCPU=PPC32 -DTOOL_FAMILY=gnu -DTOOL=gnu -fpic
-shared -Wl,-soname,libMyFoo.so.1
-L$(WIND_BASE)/target/usr/lib/ppc/PPC32/common/PIC -lstdc++ PPC32gnu/foo1.sho
PPC32gnu/foo2.sho -o libMyFoo.so
```

Generating the Application's Object Modules

The following examples illustrate compiler commands used to generate an application's object modules. The compiler flags are the same as those used by the default makefile system.

Using the Wind River Compiler:

```
dcc -tPPCEH:rtp -Xansi -XO -I$(WIND_BASE)/target/usr/h -I/home/moimoi/proj/h
-DCPU=PPC32 -DTOOL_FAMILY=diab -DTOOL=diab -c main.c -o PPC32diab/main.o
```

Using the GNU Compiler:

```
ccppc -mhard-float -mstrict-align -mregnames -ansi -mrtp -O2
-fstrength-reduce -fno-builtin -I$(WIND_BASE)/target/usr/h
-I/home/moimoi/proj/h -DCPU=PPC32 -DTOOL_FAMILY=gnu -DTOOL=gnu -c main.c -o
PPC32gnu/main.o
```

Generating the Application Executable

The following examples illustrate compiler commands used to generate the application executable. The compiler flags are the same as those used by the default makefile system.

Using the Wind River Compiler:

```
dplus -tPPCEH:rtp -Xansi -XO -DCPU=PPC32 -DTOOL_FAMILY=diab -DTOOL=diab
PPC32diab/main.o PPC32diab/secondary.o -Xdynamic -L
$(WIND_BASE)/target/usr/lib/ppc/PPC32/common/ -L../lib/PPC32diab -lMyFoo
-lstlstd -Wl,-rpath /romfs/lib -o myVxApp.vxe
```

Using the GNU Compiler:

```
c++ppc -mhard-float -mstrict-align -mregnames -ansi -mrtp -O2
-fstrength-reduce -fno-builtin -DCPU=PPC32 -DTOOL_FAMILY=gnu -DTOOL=gnu -mrtp
PPC32gnu/main.o PPC32gnu/secondary.o -non-static -L
$(WIND_BASE)/target/usr/lib/ppc/PPC32/common -Wl,--start-group
-L../lib/PPC32gnu -lMyFoo -lstdc++ -Wl,--end-group -Wl,-rpath /romfs/lib -o
tmPthreadLib.vxe
```

Compiler Flag For Shared Objects and Dynamic Applications

The most important compiler flags used in generating shared objects (shared libraries and plug-ins) and dynamic applications are described below. Note that no specific flags are required for generating the application modules (the **.o** files), but

that special flags are required for generating an application executable (the **.vxe** file).

Flags for Shared Objects

To generate position-independent code (PIC), suitable for use in a shared library, use:

- **-Xpic** with the Wind River Compiler
- **-fpic** with the GNU Compiler

To link shared library PIC modules, use:

- **-Xshared** with the Wind River Compiler
- **-shared** with the GNU Compiler

To name a shared object (and optionally provide a version number), use:

- **-soname=** *sharedLibraryName* with the Wind River Compiler
- **-Wl,-soname,***sharedLibraryName* with the GNU Compiler

  Note that **gcc** does not recognize **-soname** so it must be passed to **ld** with **-Wl**.

The **-soname** flag specifies a *shared object name* for a shared library. This information is used both for locating shared libraries at run-time, as well as for creating different versions of shared libraries. See *Defining Shared Object Names and Shared Library Versions*, p.49

To force the object to use its own definitions for global functions and data even if some other shared object, or the dynamic executable, would otherwise override those definitions, use:

- **-Bsymbolic** with either compiler

  Note that the compilers do not recognize **-Bsymbolic**, so it must be passed to their linker with **-Wl**.

Normally when the dynamic linker looks for a definition for a function or some data, it chooses the first one that it sees, even if some later module has its own definition.

Flags for Application Executables

To allow an application to dynamically link with a shared library, use:

- **-Xdynamic** with the Wind River Compiler
- **-non-static** with the GNU Compiler

To identify the runtime path to shared libraries, use the following when building the application's dynamic executable:

- **-Wl,-rpath** *sharedLibDirPath* with either compiler

Provide a semicolon-separated list of directory names (the *run path*), which the dynamic linker uses as one of the means to locate shared libraries at runtime. See *Shared Object Names, Library Versions, and Run-time Locations*, p.47 for more information in this regard. The runtime dynamic linker can only make use of this information if the shared library is created with a shared object name (see the **-soname** flag description in *Flags for Shared Objects*, p.45).

The paths provided with the **-Wl,-rpath** linker flag must, of course, be accessible to the VxWorks target system. If the paths reference files on the host's file system, make sure that they are identified in a way that is appropriate for the host-target connection (NFS is transparent; FTP requires **hostname:** before the path if it is not on the same system from which VxWorks was booted; the VxWorks simulator requires a **host:** prefix; and so on).

For example, the following example identifies a **lib** subdirectory in the ROMFS file system in VxWorks, the **c:\proj\lib** on a Windows host system, and **/home/moimoi/proj** on an NFS file system as the locations for shared libraries:

```
-Wl,-rpath /romfs/lib;c:/proj/lib;/home/moimoi/proj
```

When using Wind River Workbench to create a dynamic executable, the linker option for a dynamic executable must be selected. The **-Wl,-rpath** option can be used to identify shared library locations, if necessary.

To indicate which shared libraries will be used by the dynamic application, use:

- **-l** with either compiler

  The **-l** flag takes a *stripped* version of the library name. By convention, libraries referred to by the **-l** flag are named **lib***name***.so** or **lib***name***.a**. Both the **lib** part of the name and the filename extension (**.so** or **.a**) are omitted when specified with **-l**. For example, both **libMyFoo.so** and **libMyFoo.a** could be identified with **-l MyFoo**. This facility is particularly useful for conditional compilation of either static or dynamic applications (see *Application Makefile*, p.40).

To have the dynamic linker to look up and bind functions only when the function is first called, use:

- -**Xbind-lazy** with either compiler

By default, the dynamic linker computes the addresses of all functions and data to which a shared object refers at the time that it loads the shared object. The dynamic linker can save some work when computing function addresses by delaying the

computation until a function is called for the first time. If a function is never called, the dynamic linker does not need to compute its address. This feature can improve performance for large libraries when an application uses only a subset of the functions in the library. However, it can cause non-real-time latencies, so it is not enabled by default.

Note that you can also select or disable lazy function binding using environment variables when you start an application. If the variable **LD_BIND_NOW** is non-null, the dynamic linker uses immediate binding. If the variable **LD_BIND_LAZY** is non-null, then the dynamic linker uses lazy binding.

Shared Object Names, Library Versions, and Run-time Locations

Shared libraries can be created with shared object names. These names can be used to identify different versions of shared libraries. They can also be used in conjunction with a variety of mechanisms to identify the runtime locations of shared libraries, so that the application's dynamic linker can find them.

A shared object name is defined when the library is built, and is incorporated into the executable file. It is independent of the library's run-time filename, but is often the same. A shared object name is often referred to as an *soname* (after the **-soname** compiler flag), and is effectively the run-time name of the shared library.

When a shared library is built with a shared object name, the name is stored in an ELF **SONAME** record. When a dynamic application is linked against that shared library, the soname information is recorded in an ELF **NEEDED** record for use at run-time by the dynamic linker.

Locating Shared Libraries at Run-time

If a shared library is created without soname information, the application's dynamic linker only looks for the run-time shared library file in same directory as the one in which the application executable is located.

By default, the VxWorks makefile system creates both the application executable and run-time shared library files in the same directory (*Application Makefile*, p.40), which facilitates running the application during the development process. For a deployed system, shared libraries created without version information will work only if they are stored in the same directory as the application that requires them (for example, if they are both stored in the same ROMFS directory). However, if the dynamic library files are stored somewhere else on the host or target system, as will often be the case, the application's dynamic linker will not be able to find them.

If a shared library is created with shared object name information, the dynamic linker can use environment variables, configuration files, compiled location information, and a default location to find the shared libraries required by its applications. The linker checks the directories provided by the following mechanisms, in this order:

1. The environment variable **LD_LIBRARY_PATH**, which can be set to a semicolon-separated list of directories. (See below for more information.)
2. The configuration file **ld.so.conf**. By default the dynamic linker looks for this file in the same directory as the one in which the application executable resides. The location can also be specified with the **LD_SO_CONF** environment variable. The **ld.so.conf** file simply lists paths, one per line with the pound sign (#) at the left margin for comment lines.
3. The run paths identified at build time with the **–rpath** option.

   See *Compiler Flag For Shared Objects and Dynamic Applications*, p.44 and the discussion of the **ADDED_DYN_EXE_FLAGS** variable in *Application Makefile*, p.40.
4. The same directory as the application file itself.

In addition, the **LD_PRELOAD** environment variable can be used to identify a set of libraries to load at startup time, before loading any other shared libraries. The variable can be set to a semicolon-separated list of library files. For example:

```
/romfs/lib/libMyFoo.so.1;c:/proj/lib/libMyBar.so.1;/home/moimoi/proj/libMoreStuff.so.1
```

The **LD_LIBRARY_PATH** environment variable can be used when the application is started. Using the shell's command interpreter, for example, the syntax would be as follows:

```
rtp exec -e "LD_LIBRARY_PATH=libPath1;libPath2" exePathAndName arg1 arg2...
```

Note in particular that there are no spaces within the quote-enclosed string, but that there is a comma separating the paths in the quoted string; and that there is one space between the string and the executable argument to **rtp exec**.

If, for example, the application and shared libraries were stored in ROMFS on the target in **app** and **lib** subdirectories, the command would look quite tidy:

```
rtp exec -e "LD_LIBRARY_PATH=/romfs/lib" /romfs/app/myVxApp.vxe one two three
```

In this next example, the command (which would be entered all on one line, of course), identifies the location of **libc.so.1** as well as a custom shared library on the host system:

```
rtp exec -e
"LD_LIBRARY_PATH=host:c:/myInstallDir/vxworks-6.1/target/usr/root/SIMPENTIUMdiab/bin;
host:c:/wrwb_demo/RtpAppShrdLib/lib/SIMPENTIUMdiab"
host:c:/wrwb_demo/RtpAppShrdLib/app/SIMPENTIUM/bin/myVxApp.vxe one two three
```

Note that some types of connections between the target and host require modifiers to the pathname (NFS is transparent; FTP requires **hostname:** before the path if it is not on the same system from which VxWorks was booted; the VxWorks simulator requires a **host:** prefix; and so on).

Also note that even on Windows hosts you must use forward slashes (or double backslashes) as path delimiters, This is the case even when the executable is stored on the host system.

Using Different Versions of Shared Libraries

In addition to being used by the dynamic linker to locate shared libraries at run-time, shared object names (sonames) can be used create different versions of shared libraries for use by different applications.

For example, if you need to modify **libMyFoo** to support new applications, but in ways that would make it incompatible with old ones, you can merely change the version number and link the new programs against the new version. If the original version of the run-time shared library was **libMyFoo.so.1**, then you would build the new version with the soname **libMyFoo.so.2** and link the new applications against that one (which would then add this soname to the ELF **NEEDED** list). You could then, for example, install **libMyFoo.so.1**, **libMyFoo.so.2**, and both the old and new applications in a common ROMFS directory on the target, and they would all behave properly.

Defining Shared Object Names and Shared Library Versions

Shared object name and version information can be defined with the following:

- The **SHARED_LIB_VERSION** build macro for Wind River Workbench.
- The **LIB_BASE_NAME** and **SL_VERSION** make macros for the default build system (see *Library Makefile*, p.37).
- The compiler's **-soname** flag (see *Compiler Flag For Shared Objects and Dynamic Applications*, p.44).

By default, the VxWorks CLI build environment create version one instances of dynamic shared libraries (that is, *libName***.so.1**). With Wind River Workbench, the user must set the **SHAREDLIB_VERSION** build macro explicitly.

VxWorks Run-time C Library libc.so

The VxWorks distribution provides a run-time shared library that is similar to the UNIX C run-time library. The VxWorks shared library **libc.so** includes all of the user-side libraries except for the following:

- **aioPxLib** (see *6.6 Asynchronous Input/Output*, p.241)
- **memEdrLib** (see *5.5 Memory Error Detection*, p.212)
- message channel libraries (see *3.3.8 Message Channels*, p.127)
- networking libraries (see the *Wind River Network Stack for VxWorks 6 Programmer's Guide*)

The **libc.so** shared library provides all of the basic facilities that an executable might need. It is the shared library equivalent of **libc.a**. All dynamic executables require **libc.so.1** at run time.

Note that the default shared library is intended to facilitate development, but may not be suitable for production systems because of its size.

When generating a dynamic executable, the GNU and Wind River toolchains automatically use the corresponding build-time shared object, **libc.so**, which is located in *installDir*/**vxworks-6.***x*/**target/usr/lib/***arch*/*cpu*/**common** (where *arch* is a the architecture such as **ppc**, **pentium**, or **mips)**. If required, another location can be referred to by using the linker's **-L** option.

The run-time version of the library is **libc.so.1**, which is located in the directory *installDir*/**vxworks-6.***x*/**target/usr/root/***cpuTool*/**bin**, where *cpu* is the name of the target CPU (such as PPC32, or PENTIUM4) and *Tool* is the name of a toolchain—including modifiers indicating the endianness and the floating point attributes applied when generating the code (for example **diab**, **sfdiable**, **gnu**, or **gnule**). For example:

installDir/**vxworks-6.***x*/**target/usr/root/SIMPENTIUMdiab/bin/libc.so.1**

For a development environment, various mechanisms can be used for providing the dynamic linker with information about the location of the **libc.so.1** file.

For deployed systems, the **libc.so.1** file can be copied manually to whatever location is appropriate. The most convenient way to make the dynamic linker aware of the location of **libc.so.1** is to store the file in the same location as the dynamic application, or to use the **-Wl,-rpath** compiler flag when the application is built. See *Locating Shared Libraries at Run-time*, p.47 for more information.

Using Plug-Ins

A plug-in is a shared object that can be loaded by an application at run-time to modify or add functionality. It is functionally equivalent to a dynamically linked library (DLL) in other operating systems. A plug-in is built in exactly the same way as a shared library, except that it does not need a shared object name.

Applications that use plug-ins must include the **dlfcn.h** header file (as in the example provided below). They must also be compiled as dynamic executables, even if they do not use shared libraries. Static executables cannot load plug-ins because they do not have a dynamic symbol table.

The location of the plug-in is coded into the application itself. The application makes API calls to the dynamic linker to load the plug-in and to access its functions and data. The **libdl** library, which provides the APIs for these calls, is automatically linked into a dynamic executable.

As an example, assume that you have a networking application and you want to be able to add support for new datagram protocols. You can put the code for datagram protocols into plug-ins, and you can load them on demand, using a separate configuration protocol. In the application, you might write the following:

```
#include <dlfcn.h>
[...]

typedef void *PROTO;
const char plugin_path[] = "/romfs/plug-ins";

PROTO attach(const char *name)
{
    void *handle;
    char *path;
    size_t n;

    n = sizeof plugin_path + 1 + strlen(name) + 3;
    if ((path = malloc(n)) == -1) {
        fprintf(stderr, "can't allocate memory: %s",
            strerror(errno));
        return NULL;

    sprintf(path, "%s/%s.so", plugin_path, name);

    if ((handle = dlopen(path, RTLD_NOW)) == NULL)
        fprintf(stderr, "%s: %s", path, dlerror());

    free(path);

    return handle;
}

void detach(PROTO handle)
```

```
{
    dlclose(handle);
}

[...]

int
send_packet(PROTO handle, struct in_addr addr, const char *data, size_t len)
{
    int (*proto_send_packet)(struct in_addr, const char *, size_t);

    if ((proto_send_packet = dlsym(handle, "send_packet")) == NULL) {
        fprintf(stderr, "send_packet: %s", dlerror());
        return -1;
    }

    return (*proto_send_packet)(addr, data, len);
}
```

Assume you implement a new protocol named *reliable*. You would compile the code as PIC, then link it using the **-Xdynamic -Xshared** flags (with the Wind River compiler) into a shared object named **reliable.so** (the comparable GNU flags would be **-non-static** and **-shared**). You install **reliable.so** as **/romfs/plug-ins/reliable.so** on the target.

When a configuration request packet arrives on a socket, the application would take the name of the protocol (**reliable**) and call **attach( )** with it. The **attach( )** routine uses **dlopen( )** to load the shared object named **/romfs/plug-ins/reliable.so**. Subsequently, when a packet must be sent to a particular address using the new protocol, the application would call **send_packet( )** with the return value from **attach( )**, the packet address, and data parameters. The **send_packet( )** routine looks up the protocol-specific **send_packet( )** routine inside the plug-in and calls it with the address and data parameters. To unload a protocol module, the application calls **detach( )**.

If a plug-in must make calls into the application, it may be necessary to link the application with the **-E** flag (with either the Wind River Compiler or the GNU compiler) to force the dynamic linker to register all the necessary symbols for the plug-ins before they are loaded. Otherwise, the plug-in may not have access to all the symbols to which it should link. The only case in which you would not need to use the **-E** flag is when the process' shared libraries require all of the same symbols as the plug-in.

Dynamic Linking Routines for Plug-Ins

The routines used with plug-ins are:

void *dlopen(const char ***path*, int** *mode***)**
Load the shared object from the given pathname.

void *dlsym(void *_handle_, const char *_name_)
Look up the function or data identified by *name* in the shared object that is described by *handle*, and return its address.

int dlclose(void *_handle_)
Remove a reference to the shared object that is described by *handle*. If this is the last reference, **dlclose( )** unloads the shared object.

char *dlerror(void)
Return the error string after an error in **dlopen( )**, **dlclose( )** or **dlsym( )**.

For more information, see the **libdl** API references.

Using readelf to Examine Dynamic ELF Files

The **readelf** tool can be used to extract dynamic records from an executable or a shared object, such as a shared object name and path.

Use the version that is appropriate for the target architecture; for example, use **readelfppc** on a PowerPC file. The various versions of the tool are provided in *installDir*/**gnu/3.3.2-vxworks6***x*/*hostType*/**bin**.

The **-d** flag causes **readelf** to list dynamic records by tag type, such as:

NEEDED
A required shared library. There is one **NEEDED** record for every library that a given dynamic ELF file depends on. The **NEEDED** record instructs the dynamic linker to load the given library at run time, in order to include definitions that are needed by the given ELF file. Both dynamic executable programs and shared objects may use **NEEDED** records. The dynamic linker loads shared libraries in the order in which it encounters **NEEDED** records. (It is useful to know that the dynamic linker executes the constructors in each shared library in reverse order of loading.)

SONAME
The shared object name.

RPATH
The run path.

Getting Runtime Information About Shared Libraries

This section illustrates how to get information about shared libraries from the shell, using command interpreter commands.

The two commands below starts the **tmPthreadLib.vxe** application in the background, so that the shell is available for other commands:

```
[vxWorks *]# tmPthreadLib.vxe 2 &
Launching process 'tmPthreadLib.vxe' ...
Process 'tmPthreadLib.vxe' (process Id = 0x8109a0) launched.
Attachment number for process 'tmPthreadLib.vxe' is %1.


[vxWorks *]# rtp exec -e "LD_LIBRARY_PATH=/romfs/lib" tmPthreadLib.vxe 2 &
Launching process 'tmPthreadLib.vxe' ...
Process 'tmPthreadLib.vxe' (process Id = 0x807c90) launched.
Attachment number for process 'tmPthreadLib.vxe' is %1.
```

The **rtp** command can then be used to display information about processes. In this case it shows information about the process started with the first of the two commands above.

```
[vxWorks *]# rtp

       NAME              ID          STATE      ENTRY ADDR  OPTIONS   TASK CNT
------------------- ---------- --------------- ---------- ---------- --------
./tmPthreadLib.vxe     0x8109a0 STATE_NORMAL 0x10002360        0x1        1
```

The **shl** command displays information about shared libraries. The **REF CNT** column provides information about the number of clients per library. The **<** symbol to the left of the shared library name indicates that the full path is not displayed. In this case, **libc.so.1** is not in the same place as **threadLibTest.so.1**; it is in the same directory as the executable.

```
[vxWorks *]# shl

      SHL NAME            ID     TEXT ADDR  TEXT SIZE  DATA SIZE  REF CNT
------------------- ---------- ---------- ---------- ---------- -------
< threadLibTest.so.1    0x30000 0x10031000     0x979c     0x6334       1
./libc.so.1             0x40000 0x10043000    0x5fe24    0x2550c       1
```

Note that the **shl info** command will provide the full path.

The **sd** command provides information about shared data regions. In this case the regions are used by the two shared libraries (one region for each shared library and one for the GOT).

```
[vxWorks *]# sd

    NAME         ID     VIRT ADDR      PHYS ADDR         SIZE    CLIENT CNT
------------ ---------- ---------- ------------------ ---------- ----------
/dl-text-s >   0x95e158 0x10031000          0x183b000     0xa000          1
/dl-text-s >   0x95e428 0x10042000          0x18e4000     0x1000          1
/dl-text-s >   0x95e1d0 0x10043000          0x184c000    0x60000          1
```

You can get information about a specific shared data region with the **sd info** command. In this case, information is displayed about the region with ID 0x95e158.

Note that in the **dl-text-segments.** part of the full name is the convention for shared data. The forward slash indicates that it is public. And this shared data region holds the shared library **libPthreadLibTest.so.1**.

```
[vxWorks *]# sd info 0x95e158

    NAME         ID     VIRT ADDR      PHYS ADDR         SIZE    CLIENT CNT
------------ ---------- ---------- ------------------ ---------- ----------
/dl-text-s >   0x95e158 0x10031000          0x183b000     0xa000          1

Full Name:          /dl-text-segments./libPthreadLibTest.so.1

Default MMU Attributes (0x87f):

      ACCESS                  CACHE
     ----------------------- ---------
     RWX / RWX  DEFAULT  --

Clients:

      NAME         ID          ACCESS                   CACHE
     ------------ ----------  ----------------------- ----------
     ./tmPthrea >   0x80a4f0  R-X / R-X   CB-/--/-  --
```

In this next example, the application is started in *stopped* mode. The job number is **1**.

```
[vxWorks *]# rtp exec -s tmPthreadLib.vxe 2 &
Launching process 'tmPthreadLib.vxe' ...
Process 'tmPthreadLib.vxe' (process Id = 0x808510) launched.
Attachment number for process 'tmPthreadLib.vxe' is %1.
```

Here, the job number is used (with the ampersand sign) to switch to the process address space, as indicated by the prompt. A breakpoint is set on **main( )** with **bp**, and execution is continued with **rtpc**.

```
[vxWorks *]# %1
[tmPthreadLib]# bp &main

[tmPthreadLib]# rtpc
Break at 0x10002500: main               Task: 0x813088 (tInitTask)
```

Then a new breakpoint is set, all breakpoints listed, and execution continued.

```
[tmPthreadLib]# bp &tmPthreadTest1

[tmPthreadLib]# bp
 #        Breakpoint Address       Ctx    Ctx Id   Cnt  Stops  N     Hard
--- ---------------------------- ----- ---------- --- ------- - ------------
  2 0x10038e34: tmPthreadTest1     RTP    0x808510   0   task  y
  1 0x10002500: main               RTP    0x808510   0   task  y

[tmPthreadLib]# rtpc
Break at 0x10038e34: tmPthreadTest1      Task: 0x813088 (tInitTask)
```

The **l** alias for **mem list** provides disassembly from address 0x10038e34, and one instruction is executed using the **s** alias for **task step**.

```
[tmPthreadLib]# l 0x10038e34
                        tmPthreadTest1:
0x10038e34  9421fff0    stwu        r1,-16(r1)
0x10038e38  93c1000c    stw         r30,12(r1)
0x10038e3c  3fc01004    lis         r30,0x1004 # 4100
0x10038e40  83de2000    lwz         r30,8192(r30)
0x10038e44  7c0802a6    mfspr       r0,LR
0x10038e48  83de002c    lwz         r30,44(r30)
0x10038e4c  90010014    stw         r0,20(r1)
0x10038e50  38600001    li          r3,0x1 # 1
0x10038e54  4bfff38d    bl          0x100381e0 # 0x100381e0
0x10038e58  2c030000    cmpi        crf0,0,r3,0x0 # 0

[tmPthreadLib]# s
r0          = 0x10003524   sp          = 0x1001def0   r2          = 0x10013790
r3          = 0x00b560fa   r4          = 0x00000000   r5          = 0x00000000
r6          = 0x00000000   r7          = 0x00000000   r8          = 0x00000000
r9          = 0x00000000   r10         = 0x00000000   r11         = 0x00000000
r12         = 0x10038e34   r13         = 0x10014924   r14         = 0x00000000
r15         = 0x00000000   r16         = 0x00000000   r17         = 0x00000000
r18         = 0x00000000   r19         = 0x00000000   r20         = 0x00000000
r21         = 0x00000000   r22         = 0x1000cd50   r23         = 0x1000cc50
r24         = 0x43300000   r25         = 0x00b55c0b   r26         = 0x000008b0
r27         = 0x00000000   r28         = 0x00000000   r29         = 0x00000000
r30         = 0x00b560fa   r31         = 0x000004ef   msr         = 0x0000f032
lr          = 0x1000352c   ctr         = 0x10038e34   pc          = 0x10038e38
cr          = 0x42000280   xer         = 0x00000000   pgTblPtr    = 0x006b3000
scSrTblPtr = 0x0180b2e4   srTblPtr    = 0x0180b2a4
0x10038e38  93c1000c    stw         r30,12(r1)
```

Debugging Shared Libraries

Failures related to the inability of the application to locate **libc.so.1** or some other run-time share library would manifest themselves from the shell as follows:

```
[vxWorks *]# tmPthreadLib.vxe 2 &
Launching process 'tmPthreadLib.vxe' ...
```

```
Process 'tmPthreadLib.vxe' (process Id = 0x811000) launched.
Attachment number for process 'tmPthreadLib.vxe' is %1.
Shared object "libc.so.1" not found
```

When a shared library cannot be found, make sure that its location has been correctly identified or that it resides in the same location as the executable (*Locating Shared Libraries at Run-time*, p.47). If the shared libraries are not stored on the target, also make sure that they are accessible from the target.

If an application is started with the incorrect assignment of **argv[0]**, or no assignment at all, the behavior of any associated shared libraries can be impaired. The dynamic linker uses **argv[0]** to uniquely identify the executable, and if it is incorrectly defined, the linker may not be able to match the executable correctly with shared libraries. For example, if an application is started more than once without **argv[0]** being specified, a shared library may be reloaded each time; or if the paths are missing for executables with the same filename but different locations, the wrong shared library may be loaded for one or more of the executables.

Note that shared library symbols are not visible if an application is started in *stopped* mode. Until execution of **_start( )** (the entry point of an application provided by the compiler) calls the dynamic linker, shared library symbols are not yet registered. (For information about symbol registration, see *2.7.3 Applications and Symbol Registration*, p.70.)

Working With Shared Libraries From a Windows Host

Loading shared libraries from a Windows host system with ftp (the default method) can be excessively slow. As an alternative, shared libraries can be included in the VxWorks system image with the ROMFS file system, or NFS can be used to provide the target system with access to shared libraries on the host.

While ROMFS is useful for deployed systems, using it for development means long edit-compile-debug cycles, as you need to rebuild the system image and reboot the target whenever you want to use modified code. During development, therefore, it is better to maintain shared libraries on the host file system and have the target load them from the network. The NFS file system provides for much faster loading than ftp or the Target Server File System.

To make use of NFS, you can either install an NFS server on Windows or make use of remote access to a UNIX machine that runs an NFS server. If you have remote access, you can use the UNIX machine to boot your target and export its file system. In this case you need to set up your Workspace with a VxWorks File

System Project on the remote UNIX machine's file system, which in turn exports it to the target.

If you choose to install an NFS server, you can use the one that Microsoft provides free of charge as part of its Windows Services for UNIX (SFU) package. It can be downloaded from **http://www.microsoft.com/**. The full SFU 3.5 package is a 223MB self-extracting executable to download, but if you only install the NFS Server, it only takes about 20MB on your hard disk.

To install the Microsoft NFS server, run the SFU **setup.exe** and select **NFS Server** only. The setup program prompts you to install **NFS User Synchronization** as well, which you should do. The corresponding Windows services are installed and started automatically.

To configure the Windows NFS server for use with a VxWorks target:

1. In Windows Explorer, select your Workspace and use the context menu to select **Share...**
2. Select the **NFS Sharing** tab.
3. Enter **Share this folder**, Share name = **Workspace**
4. Enable **Allow anonymous access**. This provides the VxWorks target with read-only access to the share without having to set up user mappings or access permissions.

Before you can use NFS to load shared libraries, VxWorks also must be reconfigured with NFS facilities.

Adding the **INCLUDE_NFS_MOUNT_ALL** component provides all the necessary features. (Using Wind River Workbench, the **VxWorks Image Configuration Editor** can be used to add the component from the following node: **Network Components > Network Applications > NFS Components > NFS mount all**.) Make sure the target the target connection is disconnected before you rebuild your kernel image.

When you reboot the target it automatically mounts all NFS shares exported by the host. To verify that VxWorks can access your NFS mount, use the **devs** and **ls "/Workspace"** commands from the kernel shell.

2.6 Creating and Managing Shared Data Regions

Shared data regions provide a means for RTP applications to share a common area of memory with each other. Processes otherwise provide for full separation and protection of all processes from one another.

The shared data region facility provides no inherent facility for mutual exclusion. Applications must use standard mutual exclusion mechanisms—such as public semaphores—to ensure controlled access to a shared data region resources (see *3.3 Intertask and Interprocess Communications*, p.100).

For systems without an MMU enabled, shared data regions simply provide a standard programming model and separation of data for the applications, but without the protection provided by an MMU.

A shared data region is a single block of contiguous virtual memory. Any type of memory can be shared, such as RAM, memory-mapped I/O, flash, or VME.

Multiple shared data regions can be created with different characteristics and different users.

Common uses of a shared data region would include video data from buffers.

The **sdLib** shared data region library provides the facilities for the following activities:

- Creating a shared data region.
- Opening the region.
- Mapping the region to a process' memory context so that it can be accessed.
- Changing the protection attributes of a region that has been mapped.
- Un-mapping the region when a process no longer needs to access it.
- Deleting the region when no processes are attached to it.

Operations on shared data regions are not restricted to applications—kernel tasks may also perform these operations.

Shared data regions use memory resources from both the kernel's and the application's memory space. The kernel's heap is used to allocate the shared data object. The physical memory for the shared data region is allocated from the global physical page pool.

When a shared data region is created, it must be named. The name is global to the system, and provides the means by which applications identify regions to be shared.

Shared data regions can be created in systems with and without MMU support.

Also see *3.3.2 Shared Data Structures*, p.102.

2.6.1 Configuring VxWorks for Shared Data Regions

For applications to be able to use shared data region facilities, the **INCLUDE_SHARED_DATA** component must be included in VxWorks.

2.6.2 Creating Shared Data Regions

Shared data regions are created with **sdCreate( )**. They can be created by an application, or from a kernel task such as the shell. The region is automatically mapped into the creator's memory context. The **sdOpen( )** routine also creates and maps a region—if the region name used in the call does not exist in the system.

WARNING: If the shell is used to create shared data regions, the optional physical address parameter should not be used with architectures for which the **PHYS_ADDRESS** type is 64 bits. The shell passes the physical address parameter as 32 bits regardless. If it should actually be 64 bits, the arguments will not be aligned with the proper registers and unpredictable behavior will result. See the *VxWorks Architecture Supplement* for the processor in question for more information.

The creation routines take parameters that define the name of the region, its size and physical address, MMU attributes, and two options that govern the regions persistence and availability to other processes.

The MMU attribute options define access permissions and the cache option for the process' page manager:

- read-only
- read/write
- read/execute
- read/write/execute
- cache write-through, cache copy-back, or cache off

By default, the creator process always gets read and write permissions for the region, regardless of the permissions set with the creation call, which affect all client processes. The creator, can however, change its own permissions with **sdProtect( )**. See *Changing Shared Data Region Protection Attributes*, p.61.

The **SD_LINGER** creation option provides for the persistence of the region after all processes have unmapped from it—the default behavior is for it to cease to exist, all of its resources being reclaimed by the system. The second option, **SD_PRIVATE**, restricts the accessibility of the region to the process that created it. This can be useful, for example, for restricting memory-mapped I/O to a single application.

2.6.3 Accessing Shared Data Regions

A shared data region is automatically opened and mapped to the process that created it, regardless of whether the **sdCreate( )** or **sdOpen( )** routine was used.

A client process must use the region's name with **sdOpen( )** to access the region. The region name can be hard-coded into the client process' application, or transmitted to the client using IPC mechanisms.

Mutual exclusion mechanisms should be used to ensure that only one application can access the same shared data region at a time. The **sdLib** library does not provide any mechanisms for doing so automatically. For more information about mutual exclusion, see *3.3 Intertask and Interprocess Communications*, p.100.

Changing Shared Data Region Protection Attributes

The MMU attributes of a shared data region can be changed with **sdProtect( )**. The change can only be to a sub-set of the attributes defined when the region was created. For example, if a region was created with only read and write permissions, these can only be changed to read-only and no access, and not expanded to other permissions. In addition, the changes are made only for the caller's process; they do not affect the permissions of other processes.

A set of macros is provided with the library for common sets of MMU attribute combinations.

2.6.4 Deleting Shared Data Regions

Shared data regions can be deleted explicitly and automatically. However, deletion of regions is restricted by various conditions, including how the region was created, and if any processes are attached to it.

If a shared data region was created without the **SD_LINGER** option, the region is deleted if:

- Only one process is mapped to the region, and its application calls **sdUnmap( )**.

- Only one process is mapped to the region, and the process exits.

If a shared data region is created with the **SD_LINGER** option, it is never deleted implicitly. The region is only deleted if **sdDelete( )** is called on it after all clients have unmapped it.

2.7 Executing Applications

Because a process is an instance of a program in execution, starting and terminating an application involves creating and deleting a process. An RTP application can be started and terminated interactively, programmatically, and automatically with various facilities that act on processes.

An application can be started by:

- a user from the shell or debugger with **rtpSp** (for the shell C interpreter) or **rtp exec** (for the shell command interpreter)
- other applications or from the kernel with **rtpSpawn( )**
- one of the startup facilities that runs applications automatically at boot time

An application can be stopped by the same means as those that terminate processes—a process is an instance of an application in execution after all. See *2.3.1 Real-time Process Life-Cycle*, p.12 for information about all the ways in which processes can be terminated.

Application executables can be stored in the VxWorks ROMFS file system on the target system, on the host development system, or on any other file system accessible to the target system (another workstation on a network, for example).

Various combinations of startup mechanisms and storage locations can be used for developing systems and for deployed products. For example, storing application executables on the host system and using the kernel shell to run them is ideal for the early phases of development because of the ease of application re-compilation and of starting applications. Final products, on the other hand, can be configured and built so that applications are bundled with the operating system, and started automatically when the system boots, all independently of humans, hosts, and hard drives.

2.7.1 Running Applications Interactively

Running applications interactively is obviously most desirable for the development environment, but it can also be used to run special applications on deployed systems that are otherwise not run as part of normal system operation (for diagnostic purposes, for example). In the latter case, it might be advantageous to store auxiliary applications in ROMFS; see *2.8 Bundling Applications with a VxWorks System using ROMFS*, p.71.

Starting Applications

From the shell, applications can be started with shell command variants of the **rtpSpawn( )** routine.

Using the traditional C interpreter, the **rtpSp** command is used as follows:

```
rtpSp "host:c:/myInstallDir/vxworks-6.1/target/usr/root/PPC32diab/bin/myVxApp.vxe first
second third"
```

In this example, a process is started to run the application **myVxApp.vxe**, which is stored on the host system in **c:\myInstallDir\vxworks-6.***x***\target\usr\root\PPC32diab\bin**. The application takes command-line arguments, and in this case they are first, second, and third. Additional arguments can also be used to specify the initial task priority, stack size, and other **rtpSpawn( )** options.

Note that some types of connections between the target and host require modifiers to the pathname (NFS is transparent; FTP requires **hostname:** before the path if it is not on the same system from which VxWorks was booted; the VxWorks simulator requires a **host:** prefix; and so on).

Using the shell's command interpreter, the application can be started in two different ways, either directly specifying the path and name of the executable file and the arguments (like with a UNIX shell):

```
host:c:/myInstallDir/vxworks-6.1/target/usr/root/PPC32diab/bin/myVxApp.vxe first second third
```

Or, the application can be started with the **rtp exec** command:

```
rtp exec host:c:/myInstallDir/vxworks-6.1/target/usr/root/PPC32diab/bin/myVxApp.vxe first
second third
```

Note that you must use forward-slashes as path delimiters with the shell, even for files on Windows hosts. The shell does not work with back-slash delimiters.

Regardless of how the process is spawned, the application runs in exactly the same manner.

Note that you can switch from the C interpreter to the command interpreter with the **cmd** command; and from the command interpreter to the C interpreter with the **C** command. The command interpreter **rtp exec** command has options that provide more control over the execution of an application.

Stopping Applications

An application can be stopped by terminating the process in which it is running.

Using the shell's command interpreter, a process can be killed with the full **rtp delete** command, or with either of the command shell aliases **kill** and **rtpd**. It can also be killed with **CTRL+C** if it is running in the foreground (that is, it has not been started using an ampersand after the **rtp exec** command and the name of the executable—which is similar to UNIX shell command syntax for running applications in the background).

With the shell's C interpreter, a process can be terminated with **kill( )** or **rtpDelete( )**.

For a description of all the ways in which a process can be terminated, see *2.3.1 Real-time Process Life-Cycle*, p.12.

And, of course, rebooting the system terminates all processes that are not configured to restart at boot time.

2.7.2 Running Applications Automatically

Running applications automatically—without user intervention—is required for many deployed systems. VxWorks applications can be started automatically in a variety of ways. In addition, application executables can be stored either on a host system—which can be useful during development even when a startup facility is in use—or they can be stored on the target itself.

The VxWorks application startup facility is designed to serve the needs of both the development environment and deployed systems.

For the development environment, the startup facility can be used interactively to specify a variety of applications to be started at boot time. The operating system does not need to be rebuilt to run different sets of applications, or to run the same applications with different arguments or process-spawn parameters (such as the priority of the initial task). That is, as long as VxWorks has been configured with the appropriate startup components, and with the components required by the applications themselves, the operating system can be completely independent and

ignorant of the applications that it will run until the moment it boots and starts them. One might call this a blind-date scenario.

For deployed systems, VxWorks can be configured and built with statically defined sets of applications to run at boot time (including their arguments and process-spawn parameters). The applications can also be built into the system image using the ROMFS file system. And this scenario might be characterized as most matrimonial.

In this section, use of the startup facility is illustrated with applications that reside on the host system. For information about using ROMFS to bundle applications with the operating system, and for examples illustrating how applications in the ROMFS file system are identified for the startup facility, see *2.8 Bundling Applications with a VxWorks System using ROMFS*, p.71.

Startup Facility Options

Various means can be used to identify applications to be started, as well as to provide their arguments and process-spawn parameters for the initial application task. Applications can be identified and started automatically at boot time using any of the following:

- a boot loader parameter
- a VxWorks shell script
- an application startup configuration parameter
- custom startup routines written by the user

The components that support this functionality are, respectively:

- **INCLUDE_RTP_APPL_BOOTLINE**
- **INCLUDE_RTP_APPL_INIT_CMD_SHELL_SCRIPT** (for the command interpreter; the C interpreter can also be used with other components)
- **INCLUDE_RTP_APPL_INIT_STRING**
- **INCLUDE_RTP_APPL_USER**

The boot loader parameter and the shell script methods can be used both interactively (without modifying the operating system) and statically. Therefore, they are equally useful for application development, and for deployed systems.

The startup configuration parameter and custom startup methods require that the operating system be re-configured and rebuilt if the developer wants to change the set of applications, application arguments, or process-spawn parameters.

There are no speed or initialization-order differences between the various means of automatic application startup. All of the startup facility components provide much the same performance.

Application Startup String Syntax

A common string syntax is used with both the boot loader parameter and the startup facility configuration parameter for identifying applications. The basic syntax is as follows:

#progPathName^arg1^arg2^arg3#progPathName...

This syntax involves only two special characters:

#

A pound sign identifies what immediately follows as the path and name of an application executable.

^

A caret delimits individual arguments (if any) to the application. A caret is not required after the final argument.

The carets are not required—spaces can be used instead—with the startup configuration parameter, but carets must be used with the boot loader parameter.

The following examples illustrate basic syntax usage:

`#c:/apps/myVxApp.vxe`
Starts **c:\apps\myVxApp.vxe**

`#c:/apps/myVxApp.vxe^one^two^three`
Starts **c:\apps\myVxApp.vxe** with the arguments **one**, **two**, **three**.

`#c:/apps/myOtherVxApp.vxe`
Starts **c:\apps\myOtherVxApp.vxe** without any arguments.

`#c:/apps/myVxApp.vxe^one^two^three#c:/apps/myOtherVxApp.vxe`
Starts both applications, the first one with its three arguments.

The startup facility also allows for specification of **rtpSpawn( )** routine parameters with additional syntax elements:

%p=*value*
Sets the priority of the initial task of the process. Priorities can be in the range of 0-255.

%s=*value*
Sets the stack size for the initial task of the process (an integer parameter).

%o=*value*
Sets the process options parameter.

%t=*value*
Sets task options for the initial task of the process.

When using the boot loader parameter, the option values must be either decimal or hexadecimal numbers. When using the startup facility configuration parameter, the code is preprocessed before compilation, so symbolic constants may be used as well (for example, **VX_FP_TASK**).

The following string, for example, specifies starting **c:\apps\myVxApp.vxe** with the arguments **one**, **two**, **three**, and an initial task priority of 125; and also starting **c:\apps\myOtherVxApp.vxe** with the options value 0x10 (which is to stop the process before running in user mode):

```
#c:/apps/myVxApp.vxe p=125^one^two^three#c:/apps/myOtherVxApp.vxe %o=0x10
```

If the **rtpSpawn( )** options are not set, the following defaults apply: the initial task priority is 220; the initial task stack size is 64 Kb; the options value is zero; and the initial task option is **VX_FP_TASK**.

The maximum size of the string used in the assignment is 160 bytes, inclusive of names, parameters, and delimiters. No spaces can be used in the assignment, so application files should not be put in host directories for which the path includes spaces.

Specifying Applications with a Boot Loader Parameter

The VxWorks boot loader includes a parameter—the **s** parameter—that can be used to identify applications that should be started automatically at boot time, as well as to identify shell scripts to be executed.[2] (For information about the boot loader, see the *VxWorks Kernel Programmer's Guide: Kernel*.)

2. In versions of VxWorks 5.*x*, the boot loader **s** parameter was used solely to specify a shell script.

Applications can be specified both interactively and statically with the **s** parameter. In either case, the parameter is set to the path and name of one or more executables and their arguments (if any), as well as to the applications' process-spawn parameters (optionally). The special syntax described above is used to describe the applications (see *Application Startup String Syntax*, p.66).

This functionality is provided with the **INCLUDE_RTP_APPL_BOOTLINE** component.

Note that the boot loader **s** parameter serves a dual purpose: to dispatch script file names to the shell, and to dispatch application startup strings to the startup facility. Script files used with the **s** parameter can only contain C interpreter commands; they cannot include startup facility syntax (also see *Specifying Applications with a VxWorks Shell Script*, p.69).

If the boot parameter is used to identify a startup script to be run at boot time as well as applications, it must be listed before any applications. For example, to run the startup script file **myScript** and **myVxApp.vxe** (with three arguments), the following sequence would be required:

```
myScript#c:/apps/myVxApp.vxe^one^two^three
```

The assignment in the boot console window would look like this:

```
startup script (s)    : myScript#c:/apps/myVxApp.vxe^one^two^three
```

The interactively-defined boot-loader parameters are saved in the target's boot media, so that the application is started automatically with each reboot.

For the VxWorks simulator, the boot parameter assignments are saved in a special file on the host system, in the same directory as the image that was booted, for example, *installDir*/**vxworks-6.***x*/**target/proj/simpc_diab/default/nvram.vxWorks0**. The number appended to the file name is processor ID number—the default for the first instance of the simulator is zero.

For a hardware target, applications can be identified statically. Using the host IDE, the **DEFAULT_BOOT_LINE** parameter of the **INCLUDE_RTP_APPL_BOOTLINE** component can be set to an identification string using the same syntax as the interactive method. Of course, the operating system must be rebuilt thereafter.

Specifying Applications with a VxWorks Shell Script

Applications can be started automatically with a VxWorks shell script. Different methods must be used, however, depending on whether the shell script uses command interpreter or C interpreter commands.

If the shell script is written for the command interpreter, applications can be identified statically with the host IDE. The **RTP_APPL_CMD_SCRIPT_FILE** parameter of the **INCLUDE_RTP_APPL_INIT_CMD_SHELL_SCRIPT** component can be set to the location of the shell script file.

A startup shell script for the command interpreter might, for example, contain the following line:

```
rtp exec c:/apps/myVxApp.vxe first second third
```

Note that for Windows hosts you must use either forward-slashes or double back-slashes instead of single back-slashes as path delimiters with the shell.

If a shell script is written for the C interpreter, it can be identified interactively using the boot loader **s** parameter— in a manner similar to applications—using a sub-set of the same string syntax. A shell script for the C interpreter can also be identified statically with the **DEFAULT_BOOT_LINE** parameter of the **INCLUDE_RTP_APPL_BOOTLINE** component in the host IDE. (See *Specifying Applications with a Boot Loader Parameter*, p.67 and *Application Startup String Syntax*, p.66.)

The operating system must be configured with the kernel shell and the C interpreter components for use with C interpreter shell scripts (see the *VxWorks Kernel Programmer's Guide: Target Tools*).

A startup shell script file for the C interpreter could contain the following line:

```
rtpSp "c:/apps/myVxApp.vxe first second third"
```

With the shell script file **c:\scripts\myVxScript**, the boot loader **s** parameter would be set interactively at the boot console as follows:

```
startup script (s)    : c:/scripts/myVxScript
```

Note that shell scripts can be stored in ROMFS for use in deployed systems (see *2.8 Bundling Applications with a VxWorks System using ROMFS*, p.71).

Specifying Applications with a Startup Configuration Parameter

Applications can be specified with the **RTP_APPL_INIT_STRING** parameter of the **INCLUDE_RTP_APPL_INIT_STRING** component in the host IDE.

The identification string must use the syntax described in *Application Startup String Syntax*, p.66. And the operating system must be rebuilt thereafter.

Starting Applications with Custom Startup Routines

The VxWorks application startup facility can be used in conjunction with custom routines written by developers. In order to use this method, VxWorks must be configured with the **INCLUDE_RTP_APPL_USER** component.

Developers then add custom code to the **usrRtpAppInit( )** routine in *installDir*/**vxworks-6.***x*/**target/src/config/usrRtpAppInit.c**.

2.7.3 Applications and Symbol Registration

Symbol registration is the process of storing symbols in a symbol table that is associated with a given process. Symbol registration depends on how an application is started:

- When an application is started from the shell, symbols are registered automatically, as is most convenient for a development environment.
- When an application is started programmatically—that is, with a call to **rtpSpawn( )**—symbols are not registered by default. This saves on memory at startup time, which is useful for deployed systems.

The registration policy for a shared library is, by default, the same as the one for the application that loads the shared library.

The default symbol-registration policy for a given method of starting an application can be overridden, whether the application is started interactively or programmatically.

The shell's command interpreter provides the **rtp exec** options **–g** for global symbols, **-a** for all symbols (global and local), and **–z** for zero symbols. For example:

```
rtp exec -a /folk/pad/tmp/myVxApp/ppc/myVxApp.vxe one two three &
```

The **rtp symbols override** command has the options **–g** for global symbols, **-a** for all symbols (global and local), and **–c** to cancel the policy override.

The **rtpSpawn( )** options parameter **RTP_GLOBAL_SYMBOLS** (0x01) and **RTP_ALL_SYMBOLS** (0x03) can be used to load global symbols, or global and local symbols (respectively).

The shell's C interpreter command **rtpSp( )** provides the same options with the **rtpSpOptions** variable.

Symbols can also be registered and unregistered interactively from the shell, which is useful for applications that have been started without symbol registration. For example:

```
rtp symbols add –a –s 0x10000 –f /romfs/bin/myApp.vxe
rtp symbols remove –l –s 0x10000
rtp symbols help
```

Note that symbols should not be stripped from executable files (**.vxe** files) because they are relocatable. And while symbols may be stripped from run-time shared library files (**.so** files), it makes debugging them more difficult.

2.8 Bundling Applications with a VxWorks System using ROMFS

The ROMFS facility provides the ability to bundle RTP applications—or any other files for that matter—with the operating system. No other file system is required to store applications; and no storage media is required beyond that used for the system image itself.

RTP applications do not need to be built in any special way for use with ROMFS. As always, they are built independently of the operating system and ROMFS itself. When they are added to a ROMFS directory on the host system and VxWorks is rebuilt, however, a single system image is that includes both the VxWorks and the application executables is created. ROMFS can be used to bundle applications in either a system image loaded by the boot loader, or in a self-loading image (for information about VxWorks image types, see the *VxWorks Kernel Programmer's Guide: Kernel*).

When the system boots, the ROMFS file system and the application executables are loaded with the kernel. Applications and operating system can therefore be deployed as a single unit. And coupled with an automated startup facility (see

2.7 Executing Applications, p.62), ROMFS provides the ability to create fully autonomous, multi-process systems.

This section provides information about using ROMFS to store process-based applications with the VxWorks operating system in a single system image. For general information about ROMFS, see 7.7 Read-Only Memory File System: ROMFS, p.284.

2.8.1 Configuring VxWorks with ROMFS

VxWorks must be configured with the **INCLUDE_ROMFS** component to provide ROMFS facilities.

2.8.2 Building a System With ROMFS and Applications

Configuring VxWorks with ROMFS and applications involves several simple steps. A ROMFS directory must be created in the BSP directory on the host system, application files must be copied into the directory, and then VxWorks must be rebuilt. For example:

```
cd c:\myInstallDir\vxworks-6.1\target\proj\wrSbc8260_diab
mkdir romfs
copy c:\myInstallDir\vxworks-6.1\target\usr\root\PPC32diab\bin\myVxApp.vxe romfs
make TOOL=diab
```

The contents of the **romfs** directory are automatically built into a ROMFS file system and combined with the VxWorks image.

The ROMFS directory does not need to be created in the VxWorks project directory. It can also be created in any location on (or accessible from) the host system, and the **make ROMFS_DIR** macro used to identify where it is in the build command. For example:

```
make TOOL=diab ROMFS_DIR="c:\allMyVxAppExes"
```

Note that any files located in the **romfs** directory are included in the system image, regardless of whether or not they are application executables.

2.8.3 Accessing Files in ROMFS

At run time, the ROMFS file system is accessed as **/romfs**. The content of the ROMFS directory can be browsed using the traditional **ls** and **cd** shell commands,

and accessed programmatically with standard file system routines, such as **open( )** and **read( )**.

For example, if the directory *installDir*/**vxworks-6.***x*/**target/proj/wrSbc8260_diab/romfs** has been created on the host, **myVxApp.vxe** copied to it, and the system rebuilt and booted, then using **ls** from the shell looks like this:

```
[vxWorks]# ls /romfs
/romfs/.
/romfs/..
/romfs/myVxApp.vxe
```

And **myVxApp.vxe** can also be accessed at run time as **/romfs/myVxApp.vxe** by any other applications running on the target, or by kernel modules (kernel-based applications).

2.8.4 Using ROMFS to Start Applications Automatically

ROMFS can be used with any of the application startup mechanisms simply by referencing the local copy of the application executables. See *2.7.2 Running Applications Automatically*, p.64 for information about the various ways in which applications can be run automatically when VxWorks boots.

3 Multitasking

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3.1 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.

Tasks are the basic unit of scheduling in VxWorks. All tasks, whether in the kernel or in processes, are subject to the same scheduler. VxWorks processes are not themselves scheduled.

Intertask communication facilities allow tasks to synchronize and communicate in order to coordinate their activity. In VxWorks, the intertask communication facilities include semaphores, message queues, message channels, pipes, network-transparent sockets, and signals.

For interprocess communication, VxWorks semaphores and message queues, pipes, and events (as well as POSIX semaphores and events) can be created as

public objects to provide accessibility across memory boundaries (between the kernel and processes, and between different processes). In additions, message channels provide a socket-based inter-process communications mechanism.

VxWorks provides watchdog timers, but they can only be used in the kernel (see *VxWorks Kernel Programmer's Guide: Multitasking*. However, process-based applications can use POSIX timers (see *4.6 POSIX Clocks and Timers*, p.159).

This chapter discusses the tasking, intertask communication, and interprocess communication facilities that are at the heart of the VxWorks run-time environment.

For information about VxWorks and POSIX, see *4. POSIX Standard Interfaces*.

NOTE: This chapter provides information about facilities available for real-time processes. For information about facilities available in the VxWorks kernel, see the corresponding chapter in the *VxWorks Kernel Programmer's Guide*.

3.2 Tasks and Multitasking

VxWorks tasks are the basic unit of code execution in the operating stem itself, as well as in applications that it executes in processes. In other operating systems the term *thread* is used similarly.

Multitasking provides the fundamental mechanism for an application to control and react to multiple, discrete real-world events. The VxWorks real-time kernel 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 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 tasks' virtual memory context (if process support is included)
- the CPU registers and (optionally) coprocessor registers

- stacks for dynamic variables and function calls
- I/O assignments for standard input, output, and error
- a delay timer
- a time-slice timer
- kernel control structures
- signal handlers
- task variables
- error status (errno)
- debugging and performance monitoring values

Note that in conformance with the POSIX standard, all tasks in a process share the same environment variables (unlike kernel tasks, which each have their own set of environment variables).

For more information about virtual memory contexts, see the *VxWorks Kernel Programmer's Guide: Memory Management*.

NOTE: The POSIX standard includes the concept of a thread, which is similar to a task, but with some additional features. For details, see *4.9 POSIX Threads*, p.163.

3.2.1 Task State Transition

The kernel maintains the current state of each task in the system. A task changes from one state to another as a 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.

Table 3-1 describes the *state symbols* that you see when working with development tools. Example 3-1 shows output from the **i( )** and **taskShow( )** shell commands containing task state information.

Table 3-1 **Task State Symbols**

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

The **STOP** state is used by the debugger facilities when a breakpoint is hit. It is also used by the error detection and reporting facilities when an error condition occurs (see *8. Error Detection and Reporting*).

Example 3-1 **Task States in Shell Command Output**

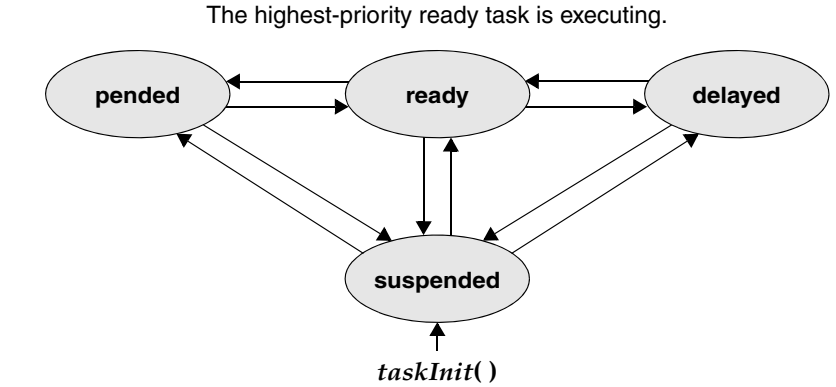
```
-> taskShow

  NAME        ENTRY       TID    PRI   STATUS      PC       SP     ERRNO  DELAY
---------- ------------ -------- --- ---------- -------- -------- ------- -----
tShell0    shellTask    455720   1 READY        214118   5db390       0     0
value = 0 = 0x0
-> i

  NAME        ENTRY       TID    PRI   STATUS      PC       SP     ERRNO  DELAY
---------- ------------ -------- --- ---------- -------- -------- ------- -----
tExcTask   excTask      437460   0 PEND         209fac   484e40       0     0
tJobTask   jobTask      437910   0 PEND         20c6dc   487dd0       0     0
tLogTask   logTask      437c80   0 PEND         209fac   48a190  3d0001     0
tShell0    shellTask    455720   1 READY        214118   5db390       0     0
tWdbTask   wdbTask      517a98   3 PEND         20c6dc   5c7560       0     0
tNetTask   netTask      43db90  50 PEND         20c6dc   48d920       0     0
value = 0 = 0x0
->
```

Figure 3-1 illustrates task state transitions. The routines listed are examples of ones that would cause the associated transition. For example, a task that called **taskDelay( )** would move from the ready state to the delayed state.

Figure 3-1 **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( )

3.2.2 Task Scheduling

Multitasking requires a scheduling algorithm to allocate the CPU to ready tasks. The default algorithm is priority-based preemptive scheduling. You can also select to use round-robin scheduling for your applications (see *Round-Robin Scheduling*, p.82). Both algorithms rely on the task's priority.

See *2.11 Kernel Schedulers*, p.149 for information about implementing custom schedulers, and about using a POSIX threads scheduler for processes (RTPs).

The kernel has 256 priority levels, numbered 0 through 255. Priority 0 is the highest and priority 255 is the lowest.

All application tasks should be in the priority range from 100 to 255.

Tasks are assigned a priority when created. You can also change a task's priority level while it is executing by calling **taskPrioritySet( )**. The ability to change task priorities dynamically allows applications to track precedence changes in the real world.

The routines that control task scheduling are listed in Table 3-2.

Table 3-2 **Task Scheduler Control Routines**

Routine	Description
taskPrioritySet( )	Changes the priority of a task.
taskRtpLock( )	Disables task context switching within a process. Prevents any other task in the process from preempting the calling task.
taskRtpUnLock( )	Enables task context switching within a process.

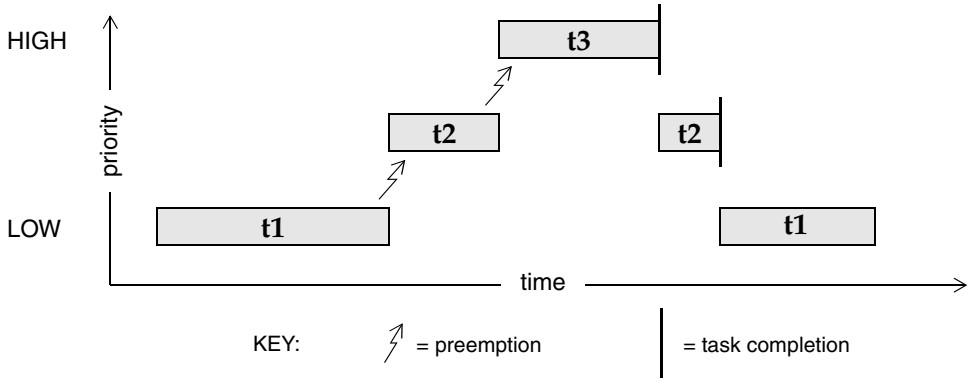
POSIX also provides a scheduling interface. For more information, see *4.10 POSIX Scheduling*, p.170.

Preemptive Priority Scheduling

A *preemptive* priority-based scheduler *preempts* the CPU when a task has a higher priority than the current task running. Thus, the kernel ensures that the CPU is always allocated to the highest priority task that is ready to run. This means that if a task—with a higher priority than that of 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. For example, in Figure 3-2, 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.

The disadvantage of this scheduling algorithm is that, when multiple tasks of equal priority must share the processor, if a single task is never blocked, it can usurp the processor. Thus, other equal-priority tasks are never given a chance to run. Round-robin scheduling solves this problem.

Figure 3-2 **Priority Preemption**



Round-Robin Scheduling

A round-robin scheduling algorithm attempts to share the CPU fairly among all ready tasks of the *same priority*. Round-robin scheduling uses *time slicing* to achieve fair allocation of the CPU to all tasks with the same priority. Each task, in a group of tasks with the same priority, executes for a defined interval or *time slice*.

It may be useful to use round-robin scheduling in systems that execute the same application in more than one process. In this case, multiple tasks would be executing the same code, and it is possible that a task might not relinquish the CPU to a task of the same priority running in another process (running the same binary). Note that round-robin scheduling is global, and controls all tasks in the system (kernel and processes); it is not possible to implement round-robin scheduling for selected processes.

Round-robin scheduling is enabled by calling **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. Thus, the tasks rotate, each executing for an equal interval of time. No task gets a second slice of time before all other tasks in the priority group have been allowed to run.

In most systems, it is not necessary to enable round-robin scheduling, the exception being when multiple copies of the same code are to be run, such as in a user interface task.

If round-robin scheduling is enabled, and preemption is enabled for the executing task, the system tick handler increments the task's time-slice count. When the specified time-slice interval is completed, the system tick handler clears the counter and the task is placed at the tail of the list of tasks at its priority level. New tasks joining a given priority group are placed at the tail of the group with their run-time counter initialized to zero.

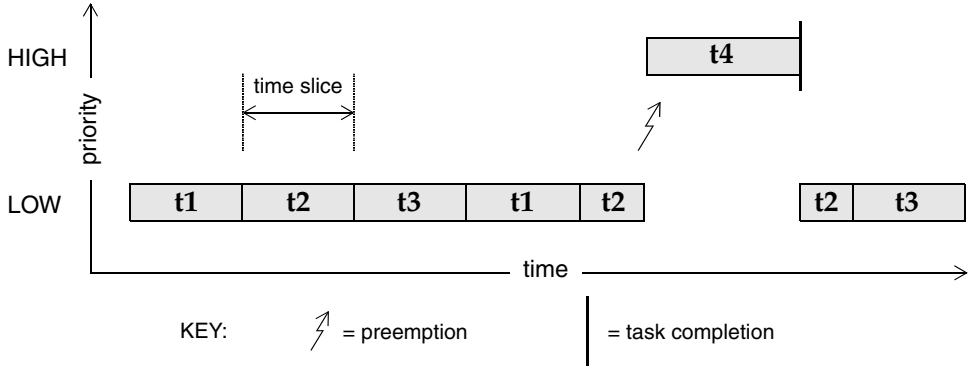
Enabling round-robin scheduling does not affect the performance of task context switches, nor is additional memory allocated.

If a task blocks or is preempted by a higher priority task during its interval, its time-slice count is saved and then restored when the task becomes eligible for execution. In the case of preemption, the task will resume execution once the higher priority task completes, assuming that no other task of a higher priority is ready to run. In the case where the task blocks, it is placed at the tail of the list of tasks at its priority level. If preemption is disabled during round-robin scheduling, the time-slice count of the executing task is not incremented.

Time-slice counts are accrued by the task that is executing when a system tick occurs, regardless of whether or not the task has executed for the entire tick interval. Due to preemption by higher priority tasks or ISRs stealing CPU time from the task, it is possible for a task to effectively execute for either more or less total CPU time than its allotted time slice.

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



Preemption Locks

The scheduler can be explicitly disabled and enabled on a per-task basis—within a process—with the routines **taskRtpLock ( )** and **taskRtpUnLock ( )**. When a task disables the scheduler by calling **taskRtpLock( )**, no priority-based preemption can take place by other tasks running in the same process while that task is running. Using a semaphore is, however, preferable to **taskRtpLock( )** as a means of mutual exclusion, because preemption lock-outs add preemptive latency to the process.

If the task that has disabled the scheduler with **taskRtpLock( )** 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.

If mutual exclusion between tasks in different processes is required, use a public semaphore. For information about global objects, see *3.3.1 Public and Private Objects*, p.100.

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 *3.3.3 Mutual Exclusion*, p.103.

3.2.3 Task Control

The following sections give an overview of the basic VxWorks task routines, which are found in the VxWorks library **taskLib**. These routines provide the means for task creation and control, as well as for retrieving information about tasks. See the VxWorks API reference for **taskLib** for further information.

For interactive use, you can control VxWorks tasks with the host tools or the kernel shell; see the *Wind River Workbench User's Guide*, the *VxWorks Command-Line Tools User's Guide*, and *VxWorks Kernel Programmer's Guide: Target Tools*.

Task Creation and Activation

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

The arguments to **taskSpawn( )** are the new task's name (an ASCII string), the task's priority, an *options* word, the stack size, the 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.

Table 3-3 **Task Creation Routines**

Call	Description
taskSpawn( )	Spawns (creates and activates) a new task.
taskCreate( )	Creates, but not activates a new task.
taskOpen( )	Open a task (or optionally create one, if it does not exist).
taskActivate( )	Activates an initialized task.

The **taskOpen( )** routine provides a POSIX-like API for creating a task (with optional activation) or obtaining a *handle* on existing task. It also provides for creating a task as either a public or private object (see *Task Names and IDs*, p.86). The **taskOpen( )** routine is the most general purpose task-creation routine.

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

Task Stack

It can be difficult to know exactly how much stack space to allocate without reverse-engineering the configuration of the system. To help avoid a stack overflow, and task stack corruption, you can take the following approach: when initially allocating the stack, make it much larger than anticipated (for example, from 20KB to up to 100KB), depending upon the type of application; then periodically monitor the stack with **checkStack( )**, and if it is safe to make it smaller, do so.

If the **INCLUDE_RTP** component (which provides process support) is included in the system, all user tasks have overflow and underflow guard zones on the execution stack. Tasks in processes do not have guard zone on the exception stack by default. Kernel tasks also have no guard zones on the execution nor the exception stack by default, nor if **INCLUDE_RTP** is configured. The component **INCLUDE_PROTECT_TASK_STACK** must be configured to add overflow (no underflow) protection for user task exception stacks and to enable overflow and underflow protection for kernel task execution stacks. Note that kernel tasks have no guard zones on the exception stack.

The protection provided by this component is, however, available only for tasks that are created without the **VX_NO_STACK_PROTECT** task option. If tasks are created with this option, no guard zones are created for their execution and exception stacks.

Developers can also design and test their systems with the assistance of the **INCLUDE_PROTECT_TASK_STACK** component. This component provides the guard zone protection of stacks in the kernel, both for kernel task execution stacks and for user task exception stacks. When this component is used, kernel tasks have underflow and overflow protection on the execution stack (no protection on the exception stacks for kernel tasks) and overflow protection (only) on the user task exception stacks. Production systems can be shipped without the component to save memory.

For more information about stack-protection facilities, see *VxWorks Kernel Programmer's Guide: Memory Management*.

Task Names and IDs

When a task is spawned, you can specify an ASCII string of any length to be the task name, and a task ID is returned.

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.

The following rules and guidelines should be followed when naming tasks:

- The names of public tasks must be unique and must begin with a forward slash; for example **/tMyTask**. Note that public tasks are *visible* throughout the entire system—in the kernel and any processes.
- The names of private tasks should be unique. VxWorks does not require that private task names be unique, but it is preferable to use unique names to avoid

confusing the user. (Note that private tasks are *visible* only within the entity in which they were created—either the kernel or a process.)

To use the host 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 any kernel task name started from the target with the letter **t**, and any task name started from the host with the letter **u**. In addition, the name of the initial task of a real-time process is the executable file name (less the extension) prefixed with the letter **i**.

Creating a task as a public object allows other tasks from outside of its process to send signals or events to it (with the **taskKill( )** or the **eventSend( )** routine, respectively).

For more information, see *3.3.1 Public and Private Objects*, p.100.

You do not have to explicitly name 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 is incremented by one for each unnamed task that is spawned.

The **taskLib** routines listed in Table 3-4 manage task IDs and names.

Table 3-4 **Task Name and ID Routines**

Call	Description
taskName( )	Gets the task name associated with a task ID (restricted to the context—process or kernel—in which it is called).
taskNameGet( )	Gets the task name associated with a task ID anywhere in the entire system (kernel and any processes).
taskNameToId( )	Looks up the task ID associated with a task name.
taskIdSelf( )	Gets the calling task's ID.
taskIdVerify( )	Verifies the existence of a specified task.

Note that for use within a process, it is preferable to use **taskName( )** rather than **taskNameGet( )** from a process, as the former does not incur the overhead of a system call.

Task Options

When a task is spawned, you can pass in one or more option parameters, which are listed in Table 3-5. The result is determined by performing a logical OR operation on the specified options.

Table 3-5 **Task Options**

Name	Description
VX_ALTIVEC_TASK	Execute with Altivec coprocessor support.
VX_DSP_TASK	Execute with DSP coprocessor support.
VX_FP_TASK	Executes with the floating-point coprocessor.
VX_NO_STACK_FILL	Does not fill the stack with 0xee (for debugging)
VX_NO_STACK_PROTECT	Create without stack overflow or underflow guard zones.
VX_PRIVATE_ENV	Executes a task with a private environment.
VX_TASK_NOACTIVATE	Used with **taskOpen( )** so that the task is not activated.

You must include the **VX_FP_TASK** option when creating a task that:

- Performs floating-point operations.
- Calls any function that returns a floating-point value.
- Calls any function that takes a floating-point value as an argument.

For example:

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

Some routines perform floating-point operations internally. The VxWorks documentation for each of these routines clearly states the need to use the **VX_FP_TASK** option.

Task Information

The routines listed in Table 3-6 get information about a task by taking a snapshot of a task's context when the routine is called. Because the task state is dynamic, the

information may not be current unless the task is known to be dormant (that is, suspended).

Table 3-6 **Task Information Routines**

Call	Description
taskInfoGet( )	Gets information about a task.
taskPriorityGet( )	Examines the priority of a task.
taskIsSuspended( )	Checks whether a task is suspended.
taskIsReady( )	Checks whether a task is ready to run.
taskIsPended( )	Checks whether a task is pended.

Note that the task-local storage (TLS) facility and the routines provided by **tlsLib** can be used to maintain information on a task basis.

Also note that each task has a VxWorks events register, which receives events sent from other tasks, ISRs, semaphores, or message queues. See *3.3.7 VxWorks Events*, p.121 for more information about this register, and the routines used to interact with it.

Task Deletion and Deletion Safety

Tasks can be dynamically deleted from the system. VxWorks includes the routines listed in Table 3-7 to delete tasks and to protect tasks from unexpected deletion.

Table 3-7 **Task-Deletion Routines**

Call	Description
exit( )	Terminates the specified process (and therefore all tasks in it) and frees the process' memory resources.
taskExit( )	Terminates the calling task (in a process) and frees the stack and any other memory resources, including the task control block.[a]
taskDelete( )	Terminates a specified task and frees memory (task stacks and task control blocks only).[a] The calling task may terminate itself with this routine.

Table 3-7 **Task-Deletion Routines** (cont'd)

Call	Description
taskSafe( )	Protects the calling task from deletion by any other task in the same process. A task in a different process can still delete that task by terminating the process itself with **kill( )**.
taskUnsafe( )	Undoes a **taskSafe( )**, which makes calling task available for deletion.

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

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

A process implicitly calls **exit( )**, thus terminating all tasks within it, if the process' **main( )** routine returns. For more information see *2.4.3 Applications, Processes, and Tasks*, p.22.

Tasks implicitly call **taskExit( )** if the entry routine specified during task creation returns.

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.

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*. Only the calling task is protected. 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 code */
.
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.108.

Task Execution Control

The routines listed in Table 3-8 provide direct control over a task's execution.

Table 3-8 **Task Execution Control Routines**

Call	Description
taskSuspend( )	Suspends a task.
taskResume( )	Resumes a task.
taskRestart( )	Restarts a task.
taskDelay( )	Delays a task; delay units are ticks, resolution in ticks.
nanosleep( )	Delays a task; delay units are nanoseconds, resolution in ticks.

Tasks may require restarting during execution in response to some catastrophic error. The restart mechanism, **taskRestart( )**, recreates a task with the original creation arguments.

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 *4.6 POSIX Clocks and Timers*, p.159.

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.

NOTE: ANSI and POSIX APIs are similar.

System clock resolution is typically 60Hz (60 times per second). This is a relatively long time for one clock tick, and would be even at 100Hz or 120Hz. Thus, since periodic delaying is effectively *polling*, you may want to consider using event-driven techniques as an alternative.

3.2.4 Tasking Extensions

To allow additional task-related facilities to be added to the system, VxWorks provides hook routines that 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 3-9; for more information, see the VxWorks API reference for **taskHookLib**.

Table 3-9 **Task Create, Switch, and Delete Hooks**

Call	Description
taskCreateHookAdd( )	Adds a routine to be called at every task create.
taskCreateHookDelete( )	Deletes a previously added task create routine.
taskDeleteHookAdd( )	Adds a routine to be called at every task delete.
taskDeleteHookDelete( )	Deletes a previously added task delete routine.

Task create hook routines execute in the context of the creator task.

Task create hooks need to consider the ownership of any kernel objects (such as watchdog timers, semaphores, and so on) created in the hook routine. Since create hook routines execute in the context of the creator task, new kernel objects will be owned by the creator task's process. It may be necessary to assign the ownership of these objects to the new task's process. This will prevent unexpected object reclamation from occurring if and when the process of the creator task terminates.

When the creator task is a kernel task, the kernel will own any kernel objects that are created. Thus there is no concern about unexpected object reclamation for this case.

User-installed switch hooks are called within the kernel context and therefore do not have access to all VxWorks facilities. Table 3-10 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 3-10 **Routines 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( )**
taskLib	**taskIdVerify( )**, **taskIdDefault( )**, **taskIsReady( )**, **taskIsSuspended( )**, **taskTcb( )**
vxLib	**vxTas( )**

NOTE: For information about POSIX extensions, see *4. POSIX Standard Interfaces*.

3.2.5 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.

A Separate errno Value for Each Task

In processes, there is no single global **errno** variable. Instead, standard application accesses to **errno** directly manipulate the per-task **errno** field in the TCB (assuming, of course, that **errno.h** has been included).

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.

Assignment of Error Status Values

VxWorks **errno** values encode the module that issues the error, in the most significant two bytes, and uses 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 VxWorks API reference on **errnoLib** for more information about defining and decoding **errno** values with this convention.

3.2.6 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 (see *8. Error Detection and Reporting*).

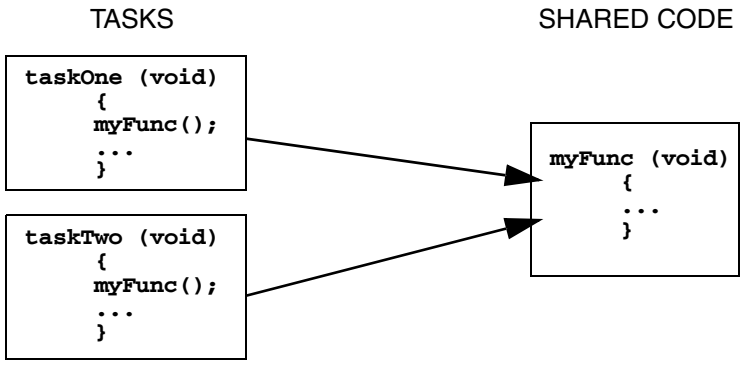
Tasks can also attach their own handlers for certain hardware exceptions through the *signal* facility. If a task has supplied a signal handler for an exception, the default exception handling described above is not performed. A user-defined signal handler is useful for recovering from catastrophic events. Typically, **setjmp( )** is called to define the point in the program where control will be restored, and **longjmp( )** is called in the signal handler to restore that context. Note that **longjmp( )** restores the state of the task's signal mask.

Signals are also used for signaling software exceptions as well as hardware exceptions. They are described in more detail in *3.3.10 Signals*, p.143 and in the VxWorks API reference for **sigLib**.

3.2.7 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 especially easy. Shared code makes a system more efficient and easier to maintain; see Figure 3-4.

Figure 3-4 **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, you should assume that any routine *someName***( )** is not reentrant if there is a corresponding routine named *someName*_**r( )** — the latter is provided as a reentrant version of the routine. For example, because **ldiv( )** has a corresponding routine **ldiv_r( )**, you can assume that **ldiv( )** is not reentrant.

The majority of VxWorks routines use the following reentrancy techniques:

- dynamic stack variables
- global and static variables guarded by semaphores

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

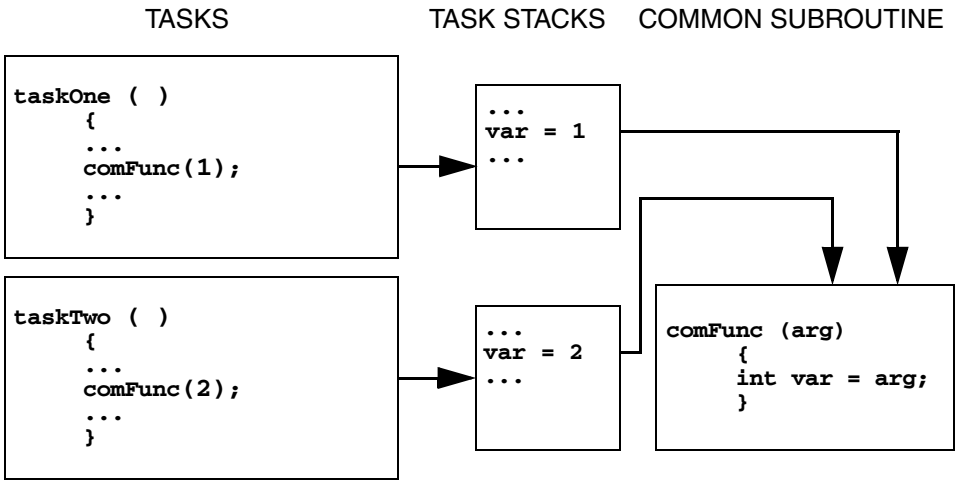
NOTE: Initialization routines should be callable multiple times, even if logically they should only be called once. As a rule, routines should avoid **static** variables that keep state information. Initialization routines are an exception; using a **static** variable that returns the success or failure of the original initialization routine call is appropriate.

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 3-5.

Figure 3-5 **Stack Variables and Shared Code**



Guarded Global and Static Variables

Some libraries encapsulate access to common data. 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 mutex semaphore facility provided by **semMLib** and described in *Mutual-Exclusion Semaphores*, p.108.

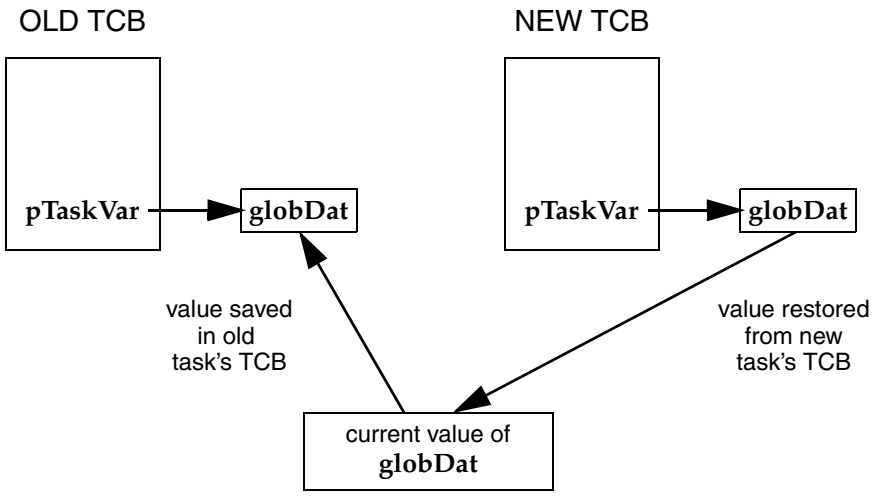
Task Variables

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 3-6. This facility is provided by the routines **taskVarAdd( )**, **taskVarDelete( )**, **taskVarSet( )**, and **taskVarGet( )**, which are described in the VxWorks API reference for **taskVarLib**.

Figure 3-6 **Task Variables and Context Switches**



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.

Multiple Tasks with the Same Main Routine

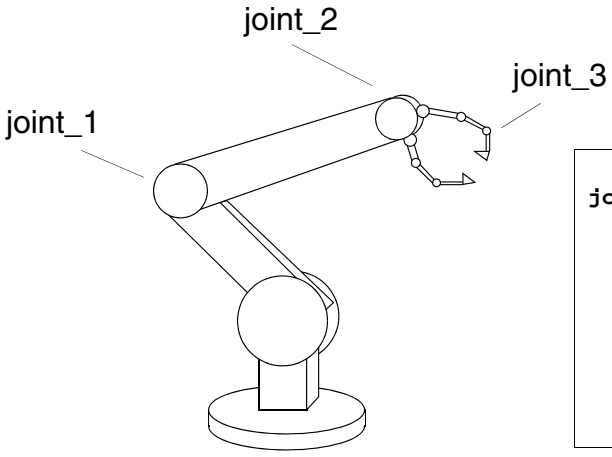
With VxWorks, it is possible to spawn several tasks with the same main routine. Each spawn creates a new task with its own stack and context. Each spawn can also pass the main routine different parameters to the new task. In this case, the same rules of reentrancy described in *Task Variables*, p.97 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 3-7, 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.

Figure 3-7 **Multiple Tasks Utilizing Same Code**




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

3.3 Intertask and Interprocess Communications

The complement to the multitasking routines described in *3.2 Tasks and Multitasking*, p.76 is the intertask communication facilities. These facilities permit independent tasks to coordinate their actions.

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

- *Shared memory*, for simple sharing of data.
- *Semaphores*, for basic mutual exclusion and synchronization.
- *Mutexes* and *condition variables* for mutual exclusion and synchronization using POSIX interfaces.
- *Message queues* and *pipes*, for intertask message passing within a CPU.
- *VxWorks events*, for communication and synchronization.
- *Message channels*, for socket-based interprocess communication.
- *Sockets* and *remote procedure calls*, for network-transparent intertask communication.
- *Signals*, for exception handling, interprocess communication, and process management.

In addition, the VxMP component provides for intertask communication between multiple CPUs that share memory. See the *VxWorks Kernel Programmer's Guide*.

3.3.1 Public and Private Objects

Kernel objects such as semaphores and message queues can be created as either private or public objects. This provides control over the scope of their accessibility—which can be limited to a virtual memory context by defining them as private, or extended to the entire system (the kernel and any processes) by defining them as public. There is no difference in performance between a public and a private object.

An object can only be defined as public or private when it is created—the designation cannot be changed thereafter. Public objects must be named when they are created, and the name must begin with a forward slash; for example, **/foo**. Private objects do not need to be named.

For information about naming tasks in addition to that provided in this section, see *Task Names and IDs*, p.86.

Creating and Naming Public and Private Objects

Public objects are always named, and the name must begin with a forward-slash. Private objects can be named or unnamed. If they are named, the name must not begin with a forward-slash.

Only one public object of a given class and name can be created. That is, there can be only one public semaphore with the name **/foo**. But there may be a public semaphore named **/foo** and a public message queue named **/foo**. Obviously, more distinctive naming is preferable (such as **/fooSem** and **/fooMQ**).

The system allows creation of only one private object of a given class and name in any given memory context; that is, in any given process or in the kernel. For example:

- If process A has created a private semaphore named **bar**, it cannot create a second semaphore named **bar**.
- However, process B could create a private semaphore named **bar**, as long as it did not already own one with that same name.

Note that private tasks are an exception to this rule—duplicate names are permitted for private tasks; see *Task Names and IDs*, p.86.

To create a named object, the appropriate *xyz***Open( )** API must be used, such as **semOpen( )**. When the routine specifies a name that starts with a forward slash, the object will be public.

To delete public objects, the *xyz***Delete( )** API cannot be used (it can only be used with private objects). Instead, the *xyz***Close( )** and *xyz***Unlink( )** APIs must be used in accordance with the POSIX standard. That is, they must be unlinked from the name space, and then the last close operation will delete the object (for example, using the **semUnlink( )** and **semClose( )** APIs for a public semaphore). Alternatively, all close operations can be performed first, and then the unlink operation, after which the object is deleted. Note that if an object is created with the **OM_DELETE_ON_LAST_CLOSE** flag, it is be deleted with the last close operation, regardless of whether or not it was unlinked.

Object Ownership and Resource Reclamation

All objects are owned by the process to which the creator task belongs, or by the kernel if the creator task is a kernel task. When ownership must be changed, for example on a process creation hook, the **objOwnerSet( )** can be used. However, its use is restricted—the new owner must be a process or the kernel.

All objects that are owned by a process are automatically destroyed when the process dies.

All objects that are children of another object are automatically destroyed when the parent object is destroyed.

Processes can share public objects through an object lookup-by-name capability (with the *xyz***Open( )** set of routines). Sharing objects between processes can only be done by name.

When a process terminates, all the private objects that it owns are deleted, regardless of whether or not they are named. All references to public objects in the process are closed (an *xyz***Close( )** operation is performed). Therefore, any public object is deleted during resource reclamation, regardless of which process created them, if there are no more outstanding *xyz***Open( )** calls against it (that is, no other process or the kernel has a reference to it), and the object was already unlinked or was created with the **OM_DELETE_ON_LAST_CLOSE** option. The exception to this rule is tasks, which are always reclaimed when its creator process dies.

When the creator process of a public object dies, but the object survives because it hasn't been unlinked or because another process has a reference to it, ownership of the object is assigned to the kernel.

The **objHandleShow( )** show routine can be used to display information about ownership relations between objects in a process.

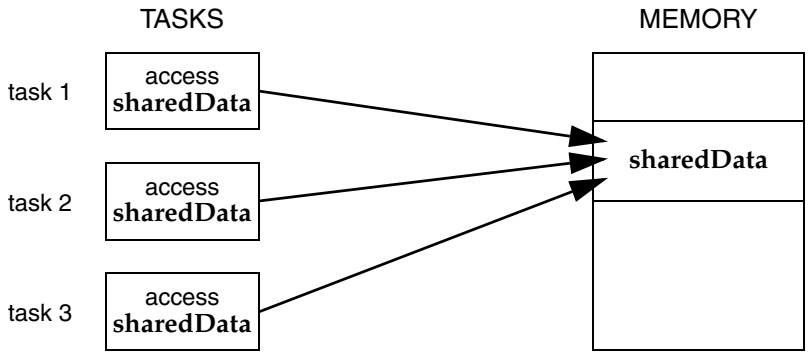
3.3.2 Shared Data Structures

The most obvious way for tasks executing in the same memory space (either a process or the kernel) to communicate is by accessing shared data structures. Because all the tasks in a single process or in the kernel exist in a single linear address space, sharing data structures between tasks is trivial; see Figure 3-8.

Global variables, linear buffers, ring buffers, linked lists, and pointers can be referenced directly by code running in different contexts.

For information about using shared data regions to communicate between processes, see *2.6 Creating and Managing Shared Data Regions*, p.59.

Figure 3-8 **Shared Data Structures**



3.3.3 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.

For information about POSIX mutexes, see *4.12 POSIX Mutexes and Condition Variables*, p.186.

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 of code 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, be sure to keep the duration short. Semaphores provide a better mechanism; see *3.3.4 Semaphores*, p.104.

WARNING: The critical region code should not block. If it does, preemption could be re-enabled.

3.3.4 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, as described below:

- 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 *3.3.3 Mutual Exclusion*, p.103.
- For *synchronization*, semaphores coordinate a task's execution with external events.

There are three types of VxWorks 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 semaphores can be created as private objects, which are accessible only within the memory space in which they were created (kernel or process); or as public objects, which accessible throughout the system. For more information, see *3.3.1 Public and Private Objects*, p.100.

VxWorks provides not only the semaphores designed expressly for VxWorks, but also POSIX semaphores, designed for portability. An alternate semaphore library provides the POSIX-compatible semaphore interface; see *4.11 POSIX Semaphores*, p.179.

The semaphores described here are for use on a single CPU. The optional product VxMP provides semaphores that can be used across processors; see *VxWorks Kernel Programmer's Guide: Shared Memory Objects*.

Semaphore Control

Instead of defining a full set of semaphore control routines for each type of semaphore, the VxWorks semaphores provide a single uniform interface for semaphore control. Only the creation routines are specific to the semaphore type. Table 3-11 lists the semaphore control routines.

Table 3-11 **Semaphore Control Routines**

Call	Description
semBCreate( )	Allocates and initializes a binary semaphore.
semMCreate( )	Allocates and initializes a mutual-exclusion semaphore.
semCCreate( )	Allocates and initializes a counting semaphore.
semDelete( )	Terminates and frees a semaphore.
semTake( )	Takes a semaphore.
semGive( )	Gives a semaphore.
semFlush( )	Unblocks 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**).

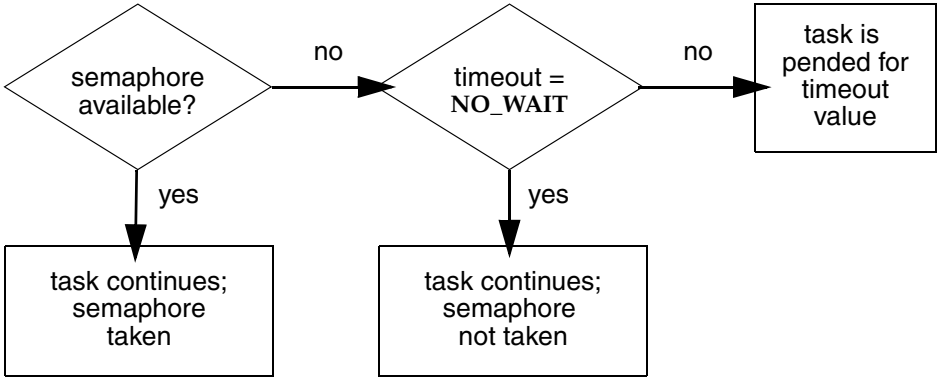
WARNING: The **semDelete( )** call terminates a semaphore and deallocates all associated memory. Take care when deleting semaphores, particularly those used for mutual exclusion, to avoid deleting a semaphore that another task still requires. Do not delete a semaphore unless the same task first succeeds 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.108 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.

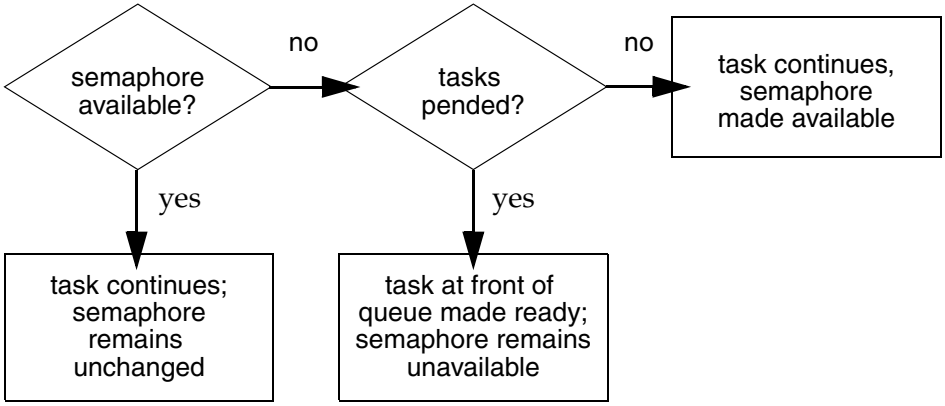
A binary semaphore can be viewed as a flag that is available (full) or unavailable (empty). When a task takes a binary semaphore, with **semTake( )**, the outcome depends on whether the semaphore is available (full) or unavailable (empty) at the time of the call; see Figure 3-9. If the semaphore is available (full), the semaphore 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.

Figure 3-9 **Taking a 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 3-10. 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).

Figure 3-10 **Giving a Semaphore**



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. 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.

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.
- The **semFlush( )** operation is illegal.

Note that mutex semaphores can be created as *user-level* objects. These are faster than *kernel-level* semaphores as long as they are uncontested, which means that:

- The mutex semaphore is available during a **semTake( )** operation.
- There is no task waiting for the semaphore during a **semGive( )** operation.

The uncontested case should be the most common given the intended use of a mutex semaphore. In the case when a mutex semaphore is contested, it will be slower than a kernel-level semaphore because a system call needs to be made.

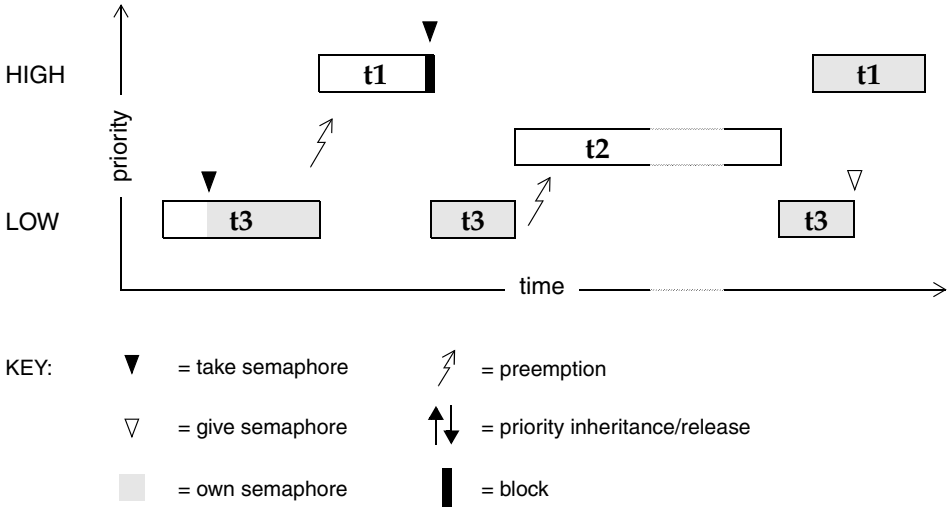
By, default, using the **semMCreate()** routine in a process creates a user-level mutex semaphore. However, a kernel-level semaphore can be created when

semMCreate() is used with the **SEM_KERNEL** option. The **semOpen()** routine can only be used in a process to create kernel-level semaphores.

Priority Inversion

Figure 3-11 illustrates a situation called priority inversion.

Figure 3-11 **Priority Inversion**

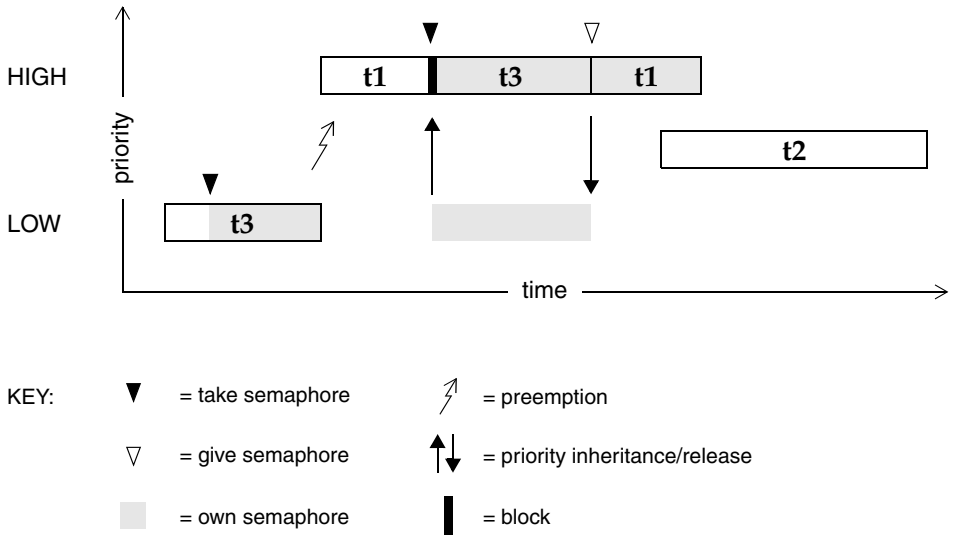


Priority inversion arises when a higher-priority task is forced to wait an indefinite period of time for a lower-priority task to complete. Consider the scenario in Figure 3-11: **t1**, **t2**, and **t3** are tasks of high, medium, and low priority, respectively. **t3** has acquired some resource by 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.

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 holds 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 have contributed to the

tasks elevated priority are released. 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 3-12 **Priority Inheritance**



In Figure 3-12, 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 holds 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 holds 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 3-2 **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 3-12 shows an example time sequence of tasks taking and giving a counting semaphore that was initialized to a count of 3.

Table 3-12 **Counting Semaphore Example**

Semaphore Call	Count after Call	Resulting Behavior
semCCreate( )	3	Semaphore initialized with an 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 VxWorks semaphore interface includes three special options. These options are not available for the POSIX-compatible semaphores described in *4.11 POSIX Semaphores*, p.179.

Timeouts

As an alternative to blocking until a semaphore becomes available, semaphore take operations can be restricted to a specified period of time. If the semaphore is not taken within that period, the take operation fails.

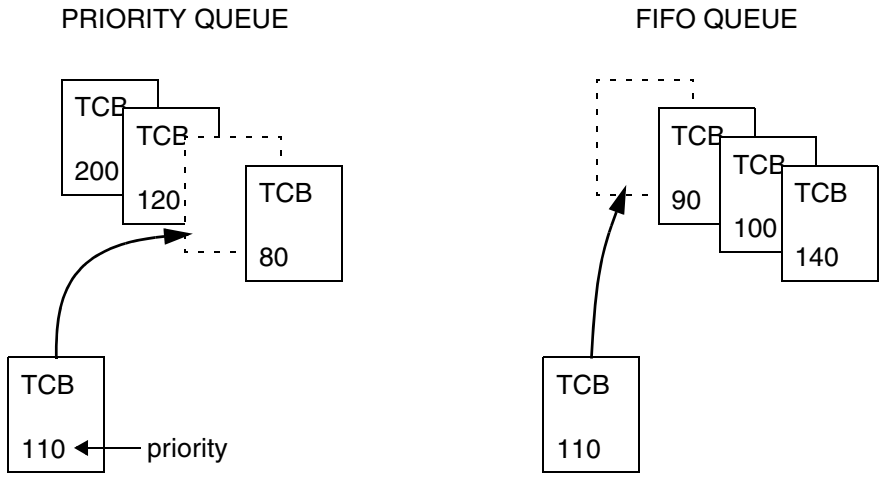
This behavior is controlled by a parameter to **semTake( )** that specifies the amount of time in ticks that the task is willing to wait in the pended state. If the task succeeds in taking the semaphore within the allotted time, **semTake( )** returns **OK**. The **errno** set when a **semTake( )** returns **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

VxWorks 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 3-13.

Figure 3-13 **Task Queue Types**



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.

Interruptible

By default, a task that receives a signal while pending on a semaphore, executes the associated signal handler, and then returns to pending on the semaphore.

The **SEM_INTERRUPTIBLE** option for counting binary and mutex semaphores changes this behavior. When a task receives a signal while pending on a semaphore that was created with the **SEM_INTERRUPTIBLE** option, the associated signal handler is executed, as with the default behavior. However, the **semTake( )** call then returns **ERROR** with errno set to **EINTR** to indicate to the caller than a signal occurred while pending on the semaphore.

Semaphores and VxWorks Events

Semaphores can send VxWorks events to a specified task when they becomes free. For more information, see *3.3.7 VxWorks Events*, p.121.

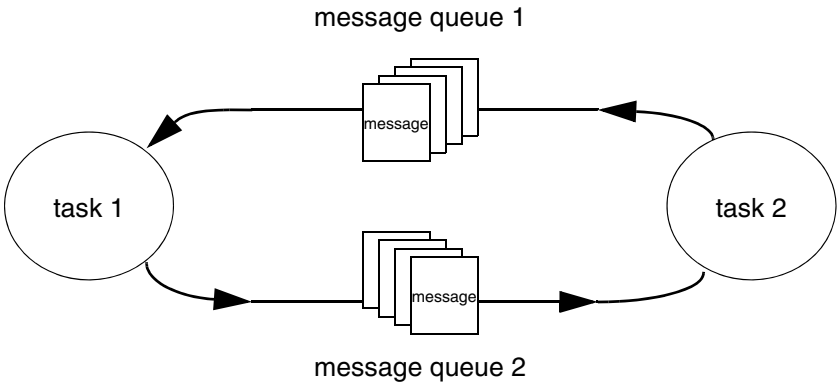
3.3.5 Message Queues

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.*

For information about socket-based message communication across memory spaces (kernel and processes), and between multiple nodes, see *3.3.8 Message Channels*, p.127.

Message queues allow a variable number of messages, each of variable length, to be queued. Tasks and ISRs can send messages to a message queue, and tasks can receive messages from a message queue.

Figure 3-14 **Full Duplex Communication Using Message Queues**



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 3-14.

VxWorks message queues can be created as private objects, which accessible only within the memory space in which they were created (process or kernel); or as public objects, which accessible throughout the system. For more information, see *3.3.1 Public and Private Objects*, p.100.

There are two message-queue subroutine libraries in VxWorks. The first of these, **msgQLib**, provides VxWorks message queues, designed expressly for VxWorks; the second, **mqPxLib**, is compatible with the POSIX standard (1003.1b) for real-time extensions. See *4.10.1 Comparison of POSIX and VxWorks Scheduling*, p.170 for a discussion of the differences between the two message-queue designs.

VxWorks Message Queues

VxWorks message queues are created, used, and deleted with the routines shown in Table 3-13. 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 3-13 **VxWorks Message Queue Control**

Call	Description
msgQCreate( )	Allocates and initializes a message queue.
msgQDelete( )	Terminates and frees a message queue.
msgQSend( )	Sends a message to a message queue.
msgQReceive( )	Receives 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 allocated 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 3-3 **VxWorks 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);
    }
```

Interruptible

By default, a task that receives a signal while pending on a message queue, executes the associated signal handler, and then returns to pending.

The **MSG_Q_INTERRUPTIBLE** option for message queues changes this behavior. When a task receives a signal while pending on a message queue that was created with the **MSG_Q_INTERRUPTIBLE** option, the associated signal handler is executed, as with the default behavior. However, the **msgQSend( ) or msgQReceive( )** call then returns **ERROR** with errno set to **EINTR** to indicate to the caller than a signal occurred while pending on the message queue.

Queuing

VxWorks message queues include the ability to select the queuing mechanism employed for tasks blocked on a message queue. The **MSG_Q_FIFO** and **MSG_Q_PRIORITY** options are provided to specify (to the **msgQCreate( )** and **msgQOpen( )** routines) the queuing mechanism that should be used for tasks that pend on **msgQSend( )** and **msgQReceive( )**.

Displaying Message Queue Attributes

The VxWorks **show( )** command produces a display of the key message queue attributes, for either kind of message queue. For example, if **myMsgQId** is a VxWorks message queue, the output is sent to the standard output device, and looks like the following from the shell (using the C interpreter):

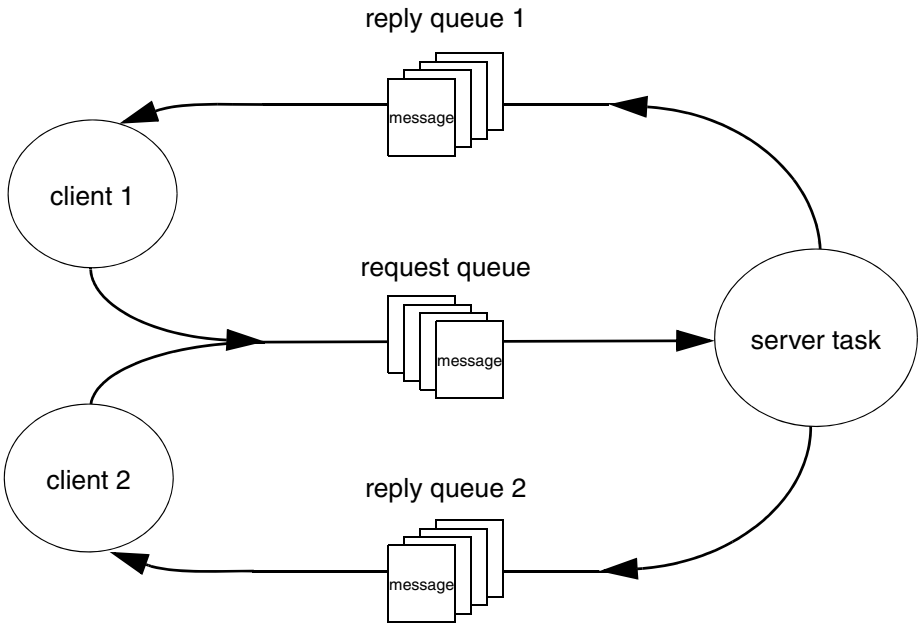
```
-> show myMsgQId
Message Queue Id  : 0x3adaf0
Task Queuing      : FIFO
Message Byte Len  : 4
Messages Max      : 30
Messages Queued   : 14
Receivers Blocked : 0
Send timeouts     : 0
Receive timeouts    : 0
```

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 intertask messages. In VxWorks, message queues or pipes (see *3.3.6 Pipes*, p.120) are a natural way to implement this functionality.

For example, client-server communications might be implemented as shown in Figure 3-15. 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 3-15 **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.

Message Queues and VxWorks Events

Message queues can send VxWorks events to a specified task when a message arrives on the queue and no task is waiting on it. For more information, see *3.3.7 VxWorks Events*, p.121.

3.3.6 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.

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 *6.3.9 Pending on Multiple File Descriptors: The Select Facility*, p.237.

Pipes allow you to implement a client-server model of intertask communications; see *Servers and Clients with Message Queues*, p.119.

3.3.7 VxWorks Events

VxWorks events provide a means of communication and synchronization between tasks and other tasks, interrupt service routines (ISRs) and tasks, semaphores and tasks, and message queues and tasks.[1]

Events can be used as a lighter-weight alternative to binary semaphores for task-to-task and ISR-to-task synchronization (because no object needs to be created). They can also be used to notify a task that a semaphore has become available, or that a message has arrived on a message queue.

The events facility provides a mechanism for coordinating the activity of a task using up to thirty-two *events* that can be sent to it by other tasks, ISRs, semaphores, and message queues. A task can wait on multiple events from multiple sources. Events thereby provide a means for coordination of complex matrix of activity without allocation of additional system resources.

Each task has 32 event flags, bit-wise encoded in a 32-bit word (bits 25 to 32 are reserved for Wind River use). These flags are stored in the task's *event register*. Note that an event flag itself has no intrinsic meaning. The significance of each of the 32 event flags depends entirely on how any given task is coded to respond to their being set. There is no mechanism for recording how many times any given event

1. VxWorks events are based on pSOS operating system events. VxWorks introduced functionality similar to pSOS events (but with enhancements) with the VxWorks 5.5 release.

has been received by a task. Once a flag has been set, its being set again by the same or a different sender is essentially an *invisible* operation.

Events are similar to signals in that they are sent to a task asynchronously; but differ in that receipt is synchronous. That is, the receiving task must call a routine to receive at will, and can choose to pend while waiting for events to arrive. Unlike signals, therefore, events do not require a handler.

For a code example of how events can be used, see the **eventLib** API reference.

NOTE: VxWorks events, which are also simply referred to as *events* in this section, should not be confused with System Viewer events.

Configuring VxWorks for Events

To provide events facilities, VxWorks must be configured with the **INCLUDE_VXEVENTS** component.

Preparing a Task to Receive Events

A task can pend on one or more events, or simply check on which events have been received, with a call to **eventReceive( )**. The routine specifies which events to wait for, and provides options for waiting for one or all of those events. It also provides various options for how to manage unsolicited events.

In order for a task to receive events from a semaphore or a message queue, however, it must first register with the specific object, using **semEvStart( )** for a semaphore or **msgQEvStart( )** for a message queue. Only one task can be registered with any given semaphore or message queue at a time.

The **semEvStart( )** routine identifies the semaphore and the events that it should send to the task when the semaphore is free. It also provides a set of options to specify whether the events are sent only the first time the semaphore is free, or each time; whether to send events if the semaphore is free at the time of registration; and whether a subsequent **semEvStart( )** call from another task is allowed to take effect (and to unregister the previously registered task).

Once a task has registered with a semaphore, every time the semaphore is released with **semGive( )**, and as long as no other tasks are pending on it, the semaphore sends events to the registered task.

To request that the semaphore stop sending events to it, the registered task calls **semEvStop( )**.

Registration with a message queue is similar to registration with a semaphore. The **msgQEvStart( )** routine identifies the message queue and the events that it should send to the task when a message arrives and no tasks are pending on it. It provides a set of options to specify whether the events are sent only the first time a message is available, or each time; whether a subsequent call to **msgQEvStart( )** from another task is allowed to take effect (and to unregister the previously registered task).

Once a task has registered with a message queue, every time the message queue receives a message and there are no tasks pending on it, the message queue sends events to the registered task.

To request that the message queue stop sending events to it, the registered task calls **msgQEvStop( )**.

Sending Events to a Task

Tasks and ISRs can send specific events to a task using **eventSend( )**, whether or not the receiving task is prepared to make use of them.

Semaphores and message queues send events automatically to tasks that have registered for notification with **semEvStart( )** or **msgQEvStart( )**, respectively. These objects send events when they are *free*. The conditions under which objects are free are as follows:

Mutex Semaphore
: A mutex semaphore is considered free when it no longer has an owner and no task is pending on it. For example, following a call to **semGive( )**, the semaphore will not send events if another task is pending on a **semTake( )** for the same semaphore.

Binary Semaphore
: A binary semaphore is considered free when no task owns it and no task is waiting for it.

Counting Semaphore
: A counting semaphore is considered free when its count is nonzero and no task is pending on it. Events cannot, therefore, be used as a mechanism to compute the number of times a semaphore is released or given.

Message Queue
: A message queue is considered free when a message is present in the queue and no task is pending for the arrival of a message in that queue. Events

cannot, therefore, be used as a mechanism to compute the number of messages sent to a message queue.

Note that just because an object has been released does not mean that it is free. For example, if a semaphore is *given*, it is released; but it is not free if another task is waiting for it at the time it is released. When two or more tasks are constantly exchanging ownership of an object, it is therefore possible that the object never becomes free, and never sends events.

Also note that when a semaphore or message queue sends events to a task to indicate that it is free, it does not mean that the object is in any way *reserved* for the task. A task waiting for events from an object unpends when the resource becomes free, but the object may be taken in the interval between notification and unpending. The object could be taken by a higher priority task if the task receiving the event was pended in **eventReceive( )**. Or a lower priority task might *steal* the object: if the task receiving the event was pended in some routine other than **eventReceive( )**, a low priority task could execute and (for example) perform a **semTake( )** after the event is sent, but before the receiving task unpends from the blocking call. There is, therefore, no guarantee that the resource will still be available when the task subsequently attempts to take ownership of it.

WARNING: Because events cannot be reserved for an application in any way, care should be taken to ensure that events are used uniquely and unambiguously. Note that events 25 to 32 (VXEV25 to VXEV32) are reserved for Wind River's use, and should not be used by customers. Third parties should be sure to document their use of events so that their customers do not use the same ones for their applications.

Events and Object Deletion

If a semaphore or message queue is deleted while a task is waiting for events from it, the task is automatically unpended by the **semDelete( )** or **msgQDelete( )** implementation. This prevents the task from pending indefinitely while waiting for events from an object that has been deleted. The pending task then returns to the ready state (just as if it were pending on the semaphore itself) and receives an **ERROR** return value from the **eventReceive( )** call that caused it to pend initially.

If, however, the object is deleted between a tasks' registration call and its **eventReceive( )** call, the task pends anyway. For example, if a semaphore is deleted while the task is between the **semEvStart( )** and **eventReceive( )** calls, the task pends in **eventReceive( )**, but the event is never sent. It is important, therefore, to use a timeout other than **WAIT_FOREVER** when object deletion is expected.

Events and Task Deletion

If a task is deleted before a semaphore or message queue sends events to it, the events can still be sent, but are obviously not received. By default, VxWorks handles this event-delivery failure silently.

It can, however, be useful for an application that created an object to be informed when events were not received by the (now absent) task that registered for them. In this case, semaphores and message queues can be created with an option that causes an error to be returned if event delivery fails (the **SEM_EVENTSEND_ERROR_NOTIFY** and **MSG_Q_EVENTSEND_ERROR_NOTIFY** options, respectively). The **semGive( )** or **msgQSend( )** call then returns **ERROR** when the object becomes free.

The error does not mean the semaphore was not given or that the message was not properly delivered. It simply means the resource could not send events to the registered task. Note that a failure to send a message or give a semaphore takes precedence over an events failure.

Accessing Event Flags

When events are sent to a task, they are stored in the task's events register (see *Task Events Register*, p.126), which is not directly accessible to the task itself.

When the events specified with an **eventReceive( )** call have been received and the task unpends, the contents of the events register is copied to a variable that is accessible to the task.

When **eventReceive( )** is used with the **EVENTS_WAIT_ANY** option—which means that the task unpends for the first of any of the specfied events that it receives—the contents of the events variable can be checked to determine which event caused the task to unpend.

The **eventReceive( )** routine also provides an option that allows for checking which events have been received prior to the full set being received.

Events Routines

The routines used for working with events are listed in Table 3-14.

Table 3-14 **Events Routines**

Routine	Description
eventSend( )	Sends specified events to a task.
eventReceive( )	Pends a task until the specified events have been received. Can also be used to check what events have been received in the interim.
eventClear( )	Clears the calling task's event register.
semEvStart( )	Registers a task to be notified of semaphore availability.
semEvStop( )	Unregisters a task that had previously registered for notification of semaphore availability.
msgQEvStart( )	Registers a task to be notified of message arrival on a message queue when no recipients are pending.
msgQEvStop( )	Unregisters a task that had previously registered for notification of message arrival on a message queue.

For more information about these routines, see the VxWorks API references for **eventLib**, **semEvLib**, and **msgQEvLib**.

Task Events Register

Each task has its own *task events register*. The task events register is a 32-bit field used to store the events that the task receives from other tasks (or itself), ISRs, semaphores, and message queues.

Events 25 to 32 (VXEV25 or 0x01000000 to VXEV32 or 0x80000000) are reserved for Wind River use only, and should not be used by customers.

As noted above (*Accessing Event Flags*, p.125), a task cannot access the contents of its events registry directly.

Table 3-15 describes the routines that affect the contents of the events register.

Table 3-15 **Routines That Modify the Task Events Register**

Routine	Effect on the Task Events Register
eventReceive( )	Clears or leaves the contents of the task's events register intact, depending on the options selected.
eventClear( )	Clears the contents of the task's events register.
eventSend( )	Writes events to a tasks's events register.
semGive( )	Writes events to the tasks's events register, if the task is registered with the semaphore.
msgQSend( )	Writes events to a task's events register, if the task is registered with the message queue.

Show Routines and Events

For the purpose of debugging systems that make use of events, the **taskShow**, **semShow**, and **msgQShow** libraries display event information.

The **taskShow** library displays the following information:

- the contents of the event register
- the desired events
- the options specified when **eventReceive( )** was called

The **semShow** and **msgQShow** libraries display the following information:

- the task registered to receive events
- the events the resource is meant to send to that task
- the options passed to **semEvStart( )** or **msgQEvStart( )**

3.3.8 Message Channels

Message channels are a socket-based facility that provides for inter-process communication across memory boundaries on a single node (processor), as well as for inter-process communication between multiple nodes (multi-processor). That is, message channel communications can take place between tasks running in the kernel and tasks running in processes (RTPs) on a single node, as well as between multiple nodes, regardless of the memory context in which the tasks are running. For example, message channels can be used to communicate between:

- a task in the kernel and a task in a process on a single node
- a task in one process and a task in another process on a single node
- a task in the kernel of one node and a task in a process on another node
- a task in a process on one node and a task in a process on another node

and so on.

The scope of message channel communication can be configured to limit server access to:

- one memory space on a node (either the kernel or one process)
- all memory spaces on a node (the kernel and all processes)
- a cluster of nodes in a system (including all memory spaces in each node)

Message channels provide a connection-oriented messaging mechanism. Tasks exchange information in the form of messages that can be of variable size and format. They can be passed back and forth in full duplex mode once the connection is established. Message channels can also provide a connection-oriented messaging mechanism between separate nodes in a cluster.

Message Channel Facilities

The message channel technology consists of the following basic facilities:

- The Connection-Oriented Message Passing (COMP) infrastructure for single node communication. See *Single-Node Communication with COMP*, p.129.
- The Transparent Inter-Process Communication (TIPC) infrastructure for multi-node communication. See *Multi-Node Communication with TIPC*, p.132.
- The Socket Name Service (SNS), which provides location and interface transparency for message channel communication between tasks on a single node, and maintains communication between nodes for multi-node message channel communications. In addition, it controls the scope of message channel communication (to two memory spaces, a node, or a cluster of nodes). See *Socket Name Service*, p.133.
- The Socket Application Libraries (SAL), which provide APIs for using message channels in applications, as well as the mechanism for registering the tasks that are using a message channel with a Socket Name Service. See *Socket Application Libraries*, p.136.

Also see *Comparing Message Channels and Message Queues*, p.142.

Single-Node Communication with COMP

The underlying transport mechanism for single-node message channels is based on the Connection-Oriented Message Passing protocol (COMP), which provides a fast method for transferring messages across memory boundaries on a single node.

COMP is designed for use with the standard socket API. Because it provides connection-oriented messaging, the socket type associated with message channels is the **SOCK_SEQPACKET**. The protocol is connection-based, like other stream-based protocols such as TCP, but it carries variable-sized messages, like datagram-based protocols such as UDP.

While COMP provides for standard socket support, it has no dependency on TCP/IP networking facilities, which can be left out of a system if the facilities are not otherwise needed.

In providing single-node local communications, COMP sockets are available as part of the **AF_LOCAL** domain. Although this domain is traditionally related to the UNIX file system, in VxWorks the addressing is completely independent of any file system. Like UNIX sockets, COMP uses a string to define the address, and it has a structure similar to a file path name, but this is the extent of the similarity in this regard. The address is simply a logical representation of the end-point.

The transfer of data in message channels is based on an internal buffer management implementation that allows for deterministic memory allocation, which reduces the amount of copies needed to transfer the data whenever possible. Only one copy is needed for the internal transfer; the data coming from the user is directly moved into the receiver buffer space. Another copy is required to submit and retrieve the data to and from the channel.

COMP supports the standard socket options, such as **SO_SNDBUF** or **SO_RECVBUF** and **SO_SNDTIMEO** and **SO_RCVTIME**. For information about the socket options, refer to the socket API references. For information about how COMP uses them, see *installDir*/**vxworks-6.***x*/**target/src/dsi/backend/dsiSockLib.c**.

Express Messaging

Express messaging is also available for sending and receiving a message. An express message is placed on a special queue on the sending side and placed at the front of the normal queue at the receiving end. This allows for urgent messages to be sent and received with a higher priority than the normal messages. In order to send an express message, the *flags* parameter of the standard **send( )** routine must have the **MSG_EXP** bit set. (Also see the **socket send( )** API reference).

Show Routines

Because COMP is based on the standard socket API, traditional network show routines can be used, such as **netstat( )**. In addition, information on local sockets can be retrieved with the **unstatShow( )** routine.

COMP Socket Support with DSI

The COMP socket functional interface is provided by the DSI back end. The back end provides the set of implementations of the standard socket functions for the COMP protocol specific calls. The traditional network protocols in VxWorks, such as TCP and UDP, use the BSD Internet Domain Socket back end and are described in the *Wind River Network Stack for VxWorks 6 Programmer's Guide*. The DSI back end is a simplified version of the BSD back-end. It is designed for optimized communications when both end points are in a single node (which is true for COMP).

The DSI back end requires its own system and data memory pools, which are used to handle the creation of sockets and the data transfers between two endpoints. The pools are similar to those required for the network stack. In addition, the pools are configured so as to enhance performance for the local transfers. The system pool provides COMP with the memory it needs for its internal structures and data types. The data pool provides COMP with the memory it needs for receiving data. Because COMP is local, data transfer has been optimized so that data are put directly in the receiver's packet queue.

Both the DSI back end and DSI memory pools complement the BSD equivalent. Therefore, both BSD and DSI sockets can coexist in the system. They do not depend on each other, so that they can be added or removed, as needed.

COMP uses **netBufLib** to manage its internal system and data memory pools. For detailed information on how buffers are configured, see the coverage of the similar technology, **netBufPool**, in the *Wind River Network Stack for VxWorks 6 Programmer's Guide*.

These pools are created automatically by the **INCLUDE_DSI_POOL** component. The DSI parameters listed in Table 3-16 are used for memory pool configuration. These parameters are used when **usrNetDsiPoolConfig( )** routine is called, which happens automatically when the system boots. The **dsiSysPoolShow( )** and **dsiDataPoolShow( )** can be used to display related information (see the VxWorks API reference for **dsiSockLib**).

Table 3-16 **INCLUDE_DSI_POOL Component Parameters**

Parameter	Default Value
DSI_NUM_SOCKETS	200
DSI_DATA_32	50
DSI_DATA_64	100
DSI_DATA_128	200
DSI_DATA_256	40
DSI_DATA_512	40
DSI_DATA_1K	10
DSI_DATA_2K	10
DSI_DATA_4K	10
DSI_DATA_8K	10
DSI_DATA_16K	4
DSI_DATA_32K	0
DSI_DATA_64K	0

The DSI pool is configured more strictly and more efficiently than the core network pool since it is more contained, fewer scenarios are possible, and everything is known in advance (as there is only the one node involved). The **DSI_NUM_SOCKETS** parameter controls the size of the system pool. It controls the number of clusters needed to fit a socket, for each family and each protocol supported by the back end. Currently, only the **AF_LOCAL** address family is supported by COMP.

The clusters allocated in the back end are of these sizes:

- **aligned sizeof (struct socket)**
- **aligned sizeof (struct uncompcb)**
- **aligned sizeof (struct sockaddr_un)**

One cluster of size 328 and of size 36 are needed for each socket that is created since currently, the COMP protocol is always linked to a DSI socket. Only one cluster of **sizeof (struct sockaddr_un)** is required, therefore the size of the system pool is

basically determined by: (**DSI_NUM_SOCKETS** * (328 + 36) + 108)). Using these sizes prevents any loss of space since they are the actual sizes needed.

All other parameters for the DSI pool are used to calculate the size of clusters in the data pool, and at the same time, the size of the pool itself. The data pool is used as packet holders during the transmissions between two sockets, between the time the data is copied from the sender's buffer to the receiver's buffer. Each of them represent a cluster size from 32 bytes to 64 kilobytes and the number of allocated clusters of that specific size.

To set reasonable values for the parameters in this component, you need to know how much memory your deployed application will require. There is no simple formula that you can use to anticipate memory usage. Your only real option is to determine memory usage empirically. This means running your application under control of the debugger, pausing the application at critical points in its execution, and monitoring the state of the memory pool. You will need to perform these tests under both stressed and unstressed conditions.

Multi-Node Communication with TIPC

The underlying transport mechanism for multi-node message channels is based on the Transparent Inter-Process Communication (TIPC) protocol, which provides a fast method for transferring messages across node boundaries in a cluster environment. TIPC can also be used within a single node.

TIPC is designed for use with the standard socket API. For connection-oriented messaging, the socket type associated with message channels is the **SOCK_SEQPACKET**.

The TIPC protocol is connection-based, like other stream-based protocols such as TCP, but it carries variable-sized messages, like datagram-based protocols such as UDP. In providing cluster and node based communications, TIPC sockets are available in the **AF_TIPC** domain. TIPC provides several means of identifying end points that are handled transparently through the SNS name server. In this release, TIPC has a dependency on the TCP/IP stack. For more information about TIPC, see the *Wind River TIPC for VxWorks 6 Programmer's Guide*.

TIPC Socket Support With BSD

The TIPC socket functionality is provided by the BSD socket back end. In a future VxWorks release, the socket functionality will be provided by a new back end.

Socket Name Service

A Socket Name Service (SNS) allows a server application to associate a service name with a collection of listening sockets, as well as to limit the visibility of the service name to a restricted (but not arbitrary) set of clients.

Both Socket Application Library (SAL) client and server routines make use of an SNS server to establish a connection to a specified service without the client having to be aware of the address of the server's listening sockets, or the exact interface type being utilized (see *Socket Application Libraries*, p.136). This provides both location transparency and interface transparency. Such transparency makes it possible to design client and server applications that can operate efficiently without requiring any knowledge of the system's topology.

An SNS server is a simple database that provides an easy mapping of service names and their associated sockets. The service name has this URL format:

```
[SNS:]service_name[@scope]
```

The **[SNS:]** prefix is the only prefix accepted, and it can be omitted. The scope can have the following values: **private**, **node**, or **cluster**. These values designate an access scope for limiting access to the same single memory space (the kernel or a process), the same node (the kernel and all processes on that node), and a set of nodes, respectively. A server can be accessed by clients within the scope that is defined when the server is created with the **salCreate( )** routine (see *SAL Server Library*, p.137).

SNS provides a resource reclamation mechanism for servers created within processes. If a process dies before **salDelete( )** has been called on a SAL server, SNS will be notified and will remove the entry from the database. Note, however, that this mechanism is not available for tasks in the kernel. If a task in the kernel terminates before **salDelete( )** is called, the service name is not automatically removed from SNS. In order to avoid stale entries that may prevent new services with the same name from being created, the **salRemove( )** routine should be used.

The SNS server can be configured to run in either kernel or user space. A node should not be configured with more than one SNS server. The server starts at boot time, and is named **tSnsServer** if it is running in the kernel, or **iSnsServer** if it is running as a process. For a multi-node system, a monitoring task is automatically spawned to maintain a list of all the SNS servers in the cluster. The monitoring task is named **tDsalMonitor**, and it runs in the kernel.

The **snsShow( )** command allows a user to verify that SAL-based services are correctly registered with the SNS server from the shell (see *snsShow( ) Example*, p.135).

For more information, see theVxWorks API reference for **snsLib**.

Multi-Node Socket Name Service

For a multi-node system, a Socket Name Service (SNS) runs on each node that is configured to use SAL. Note that VxWorks SNS components for multi-node use are different from those used on single node systems (see *onfiguring VxWorks for Message Channels*, p.140).

When a distributed SNS server starts on a node at boot time, it uses a TIPC bind operation to publish a TIPC port name. This is visible to all other nodes in the cluster. The other existing SNS servers then register the node in their tables of SNS servers. A separate monitoring task (called **tDsalMonitor**) is started on each node at boot time, which uses the TIPC subscription feature to detect topology-change events such as a new SNS server coming online, or an existing SNS server leaving the cluster.

Note that if the TIPC networking layer does not start up properly at boot time, the distributed SAL system will not initialize itself correctly with TIPC, and the SNS server will work strictly in local mode. The SNS server does not check for a working TIPC layer after the system boots, so that it will not detect the layer if it is subsequently started manually, and the SNS server will continue to run in local mode.

When a new node appears, each SNS server sends a command to that node requesting a full listing of all sockets that are remotely accessible. The SNS server on the new node sends a list of sockets that can be reached remotely.

Each time a new socket is created with **salCreate( )** on a node that has a server scope greater than **node**, this information is sent to all known SNS servers in the cluster. All SNS servers are thereby kept up to date with relevant information. Similarly, when a socket is deleted using the **salRemove( )** function, this information is sent to all known SNS servers in the cluster. The addition and removal of sockets is an infrequent occurrence in most anticipated uses and should be of minimal impact on network traffic and on the performance of the node.

When the **tDsalMonitor** task detects that an SNS server has been withdrawn from the system, the local SNS server purges all entries related to the node that is no longer a part of the distributed SNS cluster.

Note that only information on accessible sockets is transmitted to remote SNS servers. While it is acceptable to create an **AF_LOCAL** socket with **cluster** scope, this socket will use the COMP protocol which can only be accessed locally. SNS servers on remote nodes will not be informed of the existence of this socket.

On a local node, if a socket name exists in the SNS database in both the **AF_LOCAL** and **AF_TIPC** families, when a connection is made to that name using **salOpen( )**, the **AF_LOCAL** socket will be used.

snsShow( ) Example

The **snsShow( )** shell command provides information about all sockets that are accessible from the local node, whether the sockets are local or remote. The command is provided by the VxWorks **INCLUDE_SNS_SHOW** component.

The following examples illustrate **snsShow( )** output from three different nodes in a system.

From Node <1.1.22>

```
            NAME             SCOPE FAMILY  TYPE   PROTO            ADDR
--------------------------- ----- ------ ------- ----- -------------------
astronaut_display           clust LOCAL  SEQPKT  0     /comp/socket/0x5
                                  TIPC   SEQPKT  0     <1.1.22>,1086717967
ground_control_timestamp    clust TIPC   SEQPKT  0   * <1.1.25>,1086717965
ground_control_weblog       clust TIPC   SEQPKT  0   * <1.1.25>,1086717961
heartbeat_private           priv  LOCAL  SEQPKT  0     /comp/socket/0x4
                                  TIPC   SEQPKT  0     <1.1.22>,1086717966
local_temperature           node  LOCAL  SEQPKT  0     /comp/socket/0x2
newsfeed                    clust TIPC   SEQPKT  0   * <1.1.50>,1086717962
rocket_diagnostic_port      clust TIPC   SEQPKT  0     <1.1.22>,1086717964
rocket_propellant_fuel_level_interface
            ----            clust TIPC   SEQPKT  0     <1.1.22>,1086717960
spacestation_docking_port   clust TIPC   SEQPKT  0   * <1.1.55>,1086717963
```

From Node <1.1.25>

```
            NAME             SCOPE FAMILY  TYPE   PROTO            ADDR
--------------------------- ----- ------ ------- ----- -------------------
astronaut_display           clust TIPC   SEQPKT  0   * <1.1.22>,1086717967
ground_control_timestamp    clust LOCAL  SEQPKT  0     /comp/socket/0x3
                                  TIPC   SEQPKT  0     <1.1.25>,1086717965
ground_control_weblog       clust TIPC   SEQPKT  0     <1.1.25>,1086717961
local_billboard             node  LOCAL  SEQPKT  0     /comp/socket/0x2
                                  TIPC   SEQPKT  0     <1.1.25>,1086717964
newsfeed                    clust TIPC   SEQPKT  0   * <1.1.50>,1086717962
rocket_diagnostic_port      clust TIPC   SEQPKT  0   * <1.1.22>,1086717964
rocket_propellant_fuel_level_interface
            ----            clust TIPC   SEQPKT  0   * <1.1.22>,1086717960
spacestation_docking_port   clust TIPC   SEQPKT  0   * <1.1.55>,1086717963
```

From Node <1.1.55>

```
            NAME             SCOPE FAMILY  TYPE   PROTO            ADDR
-------------------------- ----- ------ ------- ----- -------------------
astronaut_display          clust TIPC   SEQPKT  0   * <1.1.22>,1086717967
ground_control_timestamp   clust TIPC   SEQPKT  0   * <1.1.25>,1086717965
ground_control_weblog      clust TIPC   SEQPKT  0   * <1.1.25>,1086717961
newsfeed                   clust TIPC   SEQPKT  0   * <1.1.50>,1086717962
rocket_diagnostic_port     clust TIPC   SEQPKT  0   * <1.1.22>,1086717964
rocket_propellant_fuel_level_interface
           ----            clust TIPC   SEQPKT  0   * <1.1.22>,1086717960
spacestation_docking_port  clust LOCAL  SEQPKT  0     /comp/socket/0x2
                                 TIPC   SEQPKT  0     <1.1.55>,1086717963
```

The output of the **snsShow( )** command is fairly self-explanatory. The first field is the name of the socket. If the name is longer than the space allocated in the output, the entire name is printed and the other information is presented on the next line with the name field containing several dashes.

The scope values are **priv** for private, **node** for node, and **clust** for cluster.

The family types can be **TIPC** for **AF_TIPC** or **LOCAL** for **AF_LOCAL**.

The socket type can be **SEQPKT** for **SOCK_SEQPACKET**, **RDM**.

The protocol field displays a numeric value and a location indicator. The numeric value is reserved for future use, and currently only zero is displayed. The final character in the field indicates whether the socket was created on a remote or local node, with an asterisk (*) designating remote.

The address field indicates the address of the socket. All addresses of the form **/comp/socket** belong to the **AF_LOCAL** family. All addresses of the form **<x.y.z>,refID** belong to the **AF_TIPC** family. The TIPC address gives the TIPC **portID** which consists of the **nodeID** and the unique reference number.

Socket Application Libraries

The Socket Application Libraries (SAL) simplify creation of both server and client applications by providing routines to facilitate use of the sockets API.

SAL also provides an infrastructure for the development of location-transparent and interface-transparent applications. By allowing SAL to handle the basic housekeeping associated with a socket-based application, developers can focus on the application-specific portions of their designs. Developers are free to use the complete range of SAL capabilities in their applications, or just the subset that suits their needs; they can even bypass SAL entirely and develop a socket-based

application using nothing but custom software. The SAL client and server APIs can be used in both kernel and user space.

Several VxWorks components are available to provide SAL support in different memory spaces, for single or multi-node systems, and so on (see *onfiguring VxWorks for Message Channels*, p.140).

SAL-based applications can also utilize the Socket Name Service (SNS), which allows a client application to establish communication with a server application without having to know the socket addresses used by the server (see *Socket Name Service*, p.133).

SAL Server Library

The SAL server routines provide the infrastructure for implementing a socket-based server application. The SAL server allows a server application to provide service to any number of client applications. A server application normally utilizes a single SAL server in its main task, but is free to spawn additional tasks to handle the processing for individual clients if parallel processing of client requests is required. The SAL server library is made of the following routines:

salCreate( )
Creates a named socket-based server.

salDelete( )
Deletes a named socket-based server.

salServerRtnSet( )
Configures the processing routine with the SAL server.

salRun( )
Activates a socket-based server.

salRemove( )
Removes a service from the SNS by name.

A server application typically calls **salCreate( )** to configure a SAL server with one or more sockets that are then automatically registered with SNS under a specified service identifier. The number of sockets created depends on which address families, socket types, and socket protocols are specified by the server application. **AF_LOCAL** and **AF_TIPC** sockets are supported.

If the address family specified is **AF_UNSPEC**, the system attempts to create sockets in all of the supported address families (**AF_LOCAL** and **AF_TIPC**). The socket addresses used for the server's sockets are selected automatically, and cannot be specified by the server application with **salCreate( )**.

A server can be accessed by clients within the scope that is defined when the server is created with the **salCreate( )** routine. The scope can have the following values: **private**, **node**, or **cluster**. These values designate an access scope for limiting access to the same task (kernel or process), the same node (the kernel and all processes on that node), and a set of nodes, respectively. For example, the following call would create a socket named **foo** with **cluster** scope:

```
salCreate("foo@cluster",1,5)
```

Once created, a SAL server must be configured with one or more processing routines before it is activated. These routines can be configured by calling **salServerRtnSet( )**.

Once the server is ready, **salRun( )** is called to start the server activities. The **salRun( )** routine never returns unless there is an error or one of the server processing routines requests it. You must call **salDelete( )** to delete the server and its sockets regardless of whether or not the routine has terminated. This is accomplished with **salDelete( )**. This routine can be called only by tasks in the process (or the kernel) where the server was created. In order for tasks outside the process to remove a service name from SNS, **salRemove( )** must be used. The **salRemove( )** routine does not close sockets, nor does it delete the server. It only deletes the SNS entry, and therefore access to any potential clients.

For more information, including sample service code, see the VxWorks API reference for the **salServer** library.

SAL Client Library

The SAL client library provides a simple means for implementing a socket-based client application. The data structures and routines provided by SAL allow the application to easily communicate with socket-based server applications that are registered with the Socket Name Service (see *Socket Name Service*, p.133). Additional routines can be used to communicate with server applications that are not registered with the SNS. The SAL client library is made of the following routines:

salOpen( )
Establishes communication with a named socket-based server.

salSocketFind( )
Finds sockets for a named socket-based server.

salNameFind( )
Finds services with the specified name.

salCall( )
Invokes a socket-based server.

A client application typically calls **salOpen( )** to create a client socket and connect it to the named server application. The client application can then communicate with the server by passing the socket descriptor to standard socket API routines, such as **send( )** and **recv( )**.

As an alternative, the client application can perform a **send( )** and **recv( )** as a single operation using **salCall( )**. When the client application no longer needs to communicate with a server it calls the standard socket **close( )** routine to close the socket to the server.

A client socket can be shared between two or more tasks. In this case, however, special care must be taken to ensure that a reply returned by the server application is handled by the correct task.

The **salNameFind( )** and **salSocketFind( )** routines facilitate the search of the server and provide more flexibility for the client application.

The **salNameFind( )** routine provides a lookup mechanism for services based on pattern matching, which can be used with (multiple) wild cards to locate similar names. For example, if the names are **foo**, **foo2**, and **foobar**, then a search using **foo*** would return them all. The scope of the search can also be specified. For example, a client might want to find any server up to a given scope, or only within a given scope. In the former case the **upto_** prefix can be added to the scope specification. For example, **upto_node** defines a search that look for services in all processes and in the kernel in a node.

Once a service is found, the **salSocketFind( )** routine can be used to return the proper socket ID. This can be useful if the service has multiple sockets, and the client requires use of a specific one. This routine can also be used with wild cards, in which case the first matching server socket is returned.

For more information, including sample client code, see the VxWorks API reference for the **salClient** library.

onfiguring VxWorks for Message Channels

To provide the full set of message channel facilities in a system, configure VxWorks with the following components:

- **INCLUDE_UN_COMP**
- **INCLUDE_DSI_POOL**
- **INCLUDE_DSI_SOCKET**
- **INCLUDE_SAL_SERVER**
- **INCLUDE_SAL_CLIENT**

Note that **INCLUDE_UN_COMP** is required for both single and multi-node systems, as it provides support for communication between SAL and SNS.

While COMP provides for standard socket support, it has no dependency on TCP/IP networking facilities, which can be left out of a system if they are not otherwise needed.

For multi-node systems, TIPC components must also be included. See the *Wind River TIPC Programmer's Guide* for more information.

SNS Configuration

In addition to the COMP, DSI, and SAL components, one of the four following components is required for SNS:

- **INCLUDE_SNS** to run SNS as a kernel daemon.
- **INCLUDE_SNS_RTP** to start SNS as a process automatically at boot time.
- **INCLUDE_SNS_MP** to run SNS as a kernel daemon supporting distributed named sockets.
- **INCLUDE_SNS_MP_RTP** to start SNS as a process automatically at boot time supporting distributed named sockets.

Note that including a distributed SNS server will cause the inclusion of TIPC which in turn will force the inclusion of other networking components.

Running SNS as a Process

In order to run SNS as a process (RTP), the developer must also build the server, add it to ROMFS, configure VxWorks with ROMFS support, and then rebuild the entire system:

a. Build *installDir*/**vxworks-6.***x*/**target/usr/apps/dsi/snsd/snsd.c** (using the makefile in the same directory) to create **snsServer.vxe**.

b. Copy **snsServer.vxe** to the ROMFS directory (creating the directory first, if necessary.

   The **INCLUDE_SNS_RTP** and **INCLUDE_SNS_MP_RTP** components need to know the location of the server in order to start it at boot time. They expect to find the server in the ROMFS directory. If you wish to store the server somewhere else (in another file system to reduce the VxWorks image size, for example) use the **SNS_PATHNAME** parameter to identify the location.

c. Configure VxWorks with the ROMFS component.

d. Rebuild VxWorks.

These steps can also be performed with Wind River Workbench (see the *Wind River Workbench User's Guide*). For information about ROMFS, see *7.7 Read-Only Memory File System: ROMFS*, p.284.

SNS Configuration

The following SNS component parameters can usually be used without modification:

SNS_LISTEN_BACKLOG
This parameter defines the number of outstanding service requests that the SNS server can track on the socket that it uses to service SNS requests from SAL routines. The default value is 5. The value may be increased if some SAL requests are not processed on a busy system.

SNS_DISTRIBUTED_SERVER_TYPE and SNS_DISTRIBUTED_SERVER_INSTANCE
These parameters are used in the multi-node configuration of SNS servers to define the TIPC port name that all SNS servers use. The default is type 51 and instance 51 in the TIPC name tables. If this type and instance conflict with other usages in the network, they can be changed to values that are unique for the network. Note that it is recommended to use a type of 50 or above (types 0 through 7 are reserved by TIPC).

The SNS server creates a COMP socket for local communication with the socket address of 0x0405. All of the SAL routines send messages to the SNS server at this socket address.

⚠ **CAUTION:** It is recommended that you do not change the default values of the **SNS_PRIORITY** and **SNS_STACK_SIZE** parameters. The default for **SNS_PRIORITY** is 50 and the default for **SNS_STACK_SIZE** is 20000.

Show Routines

The show routines related to COMP can be included by adding the **INCLUDE_UN_COMP_SHOW** component. The **snsShow( )**routine is included with the **INCLUDE_SNS_SHOW** component. In order to use **netstat( )** the network show routines need to be included. Note that this will force the inclusion of networking components.

For information about processes and applications, see *2. Applications and Processes*.

Comparing Message Channels and Message Queues

Message channels can be used similarly to message queues, to exchange data between two tasks. Both methods allow multiple tasks to send and receive from the same channel. The main differences between these two mechanisms are:

- Message channels can be used to communicate between nodes, but message queues cannot.
- Message channels are connection-oriented while message queues are not. There is no way to establish a connection between two tasks with message queues. In a connection-oriented communication, the two end-points are aware of each other, and if one leaves the other eventually finds out. By way of analogy, a connection-oriented communication is like a telephone call, whereas a connection-less communication is like sending a letter. Both models are valid, and the requirements of the application should determine their use.

  Each message queue is unidirectional. In order to establish a bidirectional communication, two queues are needed, one for each end-point (see Figure 3-14). Each message channel is bidirectional and data can be sent from both end-points at any time. That is, each message channel provides connection-oriented full-duplex communication.
- The messages communicated by message channels can be of variable size, whereas those communicated by message queues have a maximum size that is defined when the queue is created. Message channels therefore allow for a better utilization of system resources by using exactly what is needed for the message, and nothing more.
- Message queues have a fixed capacity. Only a pre-defined number of messages can be in a queue at any one time. Message channels, on the other hand, have a flexible capacity. There is no limit to the number of messages that a message channel can handle.

- Message channels provide location transparency. An endpoint can be referred to by a name, that is by a simple string of characters (but a specific address can also be used). Message queues only provide location transparency for interprocess communication when they are created as public objects.
- Message channels provide a simple interface for implementing a client/server paradigm. A location transparent connection can be established by using two simple calls, one for the client and one for the server. Message queues do not provide support for client/server applications.
- Message channels use the standard socket interface and support the **select( )** routine; message queues do not.
- Message channels cannot be used with VxWorks events; message queues can.
- Message queues are based entirely on a proprietary API and are therefore more difficult to port to a different operating systems than message channels, which are based primarily on the standard socket API.

Message channels are better suited to applications that are based on a client/server paradigm and for which location transparency is important.

3.3.9 Network Communication

To communicate peer on a remote networked system, you can use an Internet domain socket or RPC. For information on working with Internet domain sockets under VxWorks, see the *Wind River Network Stack for VxWorks 6 Programmer's Guide: Sockets under the Wind River Network Stack*. For information on RPC, see *Wind River Network Stack for VxWorks 6 Programmer's Guide: RPC Components* and the VxWorks API reference for **rpcLib**.

3.3.10 Signals

VxWorks provides a software signal facility. Signals asynchronously alter the control flow of a task or process.

Signals are the means by which processes are notified of the occurrence of significant events in the system. Examples of significant events include hardware exceptions, signals to kill processes, and so on. Each signal has a unique number, and there are 31 signals in all. The value 0 is reserved for use as the null signal. Each signal has a default action associated with itself. Developers can change the default. Signals can either be disabled, so that they will not interrupt the process, or enabled, which allows signals to be received.

When a process starts running, it inherits a the signal mask of the process that created it. If it was created by a kernel task, the initial task of the process has all signals unblocked. It also inherits default actions associated with each signal. Both can later be changed with routines that are provided by the **sigLib** library.

Most signals are sent to the process as a whole. Individual tasks in a process can block out signals. Signals sent to a process are delivered to the task that has the signal enabled.

By default, signals sent to a task in a process result in the termination of the process.

Tasks in processes cannot raise signals for kernel tasks, but any task in a process can raise a signal for:

- itself
- any other task in its process
- any public task in the system
- its own process
- any other process in the system

For information about public tasks, see *Task Names and IDs*, p.86.

The process of delivering a signal involves setting up the signal context so that the action associated with the signal is executed, and the return path after the signal handler returns gets the target task back to its original execution context. Unlike kernel signal generation and delivery, which runs in the context of the task or ISR that generates the signal, process signal generation is performed by the sender task, but the signal delivery actions take place in the context of the receiving task.

For information about POSIX queued signals extension from POSIX 1003.1, see *4.14 POSIX Queued Signals*, p.200.

For information about using signals in processes, see *VxWorks Application Programmer's Guide: Multitasking*.

NOTE: The VxWorks implementation of **sigLib** does not impose any special restrictions on operations on **SIGKILL**, **SIGCONT**, and **SIGSTOP** signals such as those imposed by UNIX. For example, the UNIX implementation of **signal( )** cannot be called on **SIGKILL** and **SIGSTOP**.

Configuring VxWorks for Signals

By default, VxWorks includes the basic signal facility component **INCLUDE_SIGNALS**. This component automatically initializes signals with **sigInit( )**.

Basic Signal Routines

Signals are in many ways 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.

VxWorks also provides a POSIX and BSD-like **kill( )** routine, which sends a signal to a task.

For a list and description of the basic set of POSIX and BSD-compatible signal calls provided by VxWorks for use with processes, see Table 3-17.

Table 3-17 **Basic Signal Calls**

POSIX 1003.1b Compatible Call	Description
signal( )	Specifies the handler associated with a signal.
kill( )	Sends a signal to a process.
raise( )	Sends a signal to the caller's process.
sigaction( )	Examines or sets the signal handler for a signal.
sigsuspend( )	Suspends a task until a signal is delivered.
sigpending( )	Retrieves a set of pending signals blocked from delivery.
sigemptyset( ) **sigfillset( )** **sigaddset( )** **sigdelset( )** **sigismember( )**	Manipulates a signal mask.
sigprocmask( )	Sets the mask of blocked signals.
sigprocmask( )	Adds to a set of blocked signals.
sigaltstack( )	Set or get a signal's alternate stack context.

For more information about signal routines, see the VxWorks API reference for **sigLib**.

Signal Handlers

Signals are more appropriate for error and exception handling than as a general-purpose intertask communication mechanism. And 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 listed in Table 3-18. Deviate from this practice only if you are certain that your signal handler cannot create a deadlock situation.

Table 3-18 **Routines Called by Signal Handlers**

Library	Routines
bLib	All routines
errnoLib	**errnoGet( )**, **errnoSet( )**
eventLib	**eventSend( )**
logLib	**logMsg( )**
lstLib	All routines except **lstFree( )**
msgQLib	**msgQSend( )**
rngLib	All routines except **rngCreate( )** and **rngDelete( )**
semLib	**semGive( )** except mutual-exclusion semaphores, **semFlush( )**
sigLib	**kill( )**
taskLib	**taskSuspend( )**, **taskResume( )**, **taskPrioritySet( )**, **taskPriorityGet( )**, **taskIdVerify( )**, **taskIdDefault( )**, **taskIsReady( )**, **taskIsSuspended( )**, **taskTcb( )**
tickLib	**tickAnnounce( )**, **tickSet( )**, **tickGet( )**

Most signals are delivered asynchronously to the execution of a program. Therefore programs must be written to account for the unexpected occurrence of signals, and handle them gracefully. Unlike ISR's, signal handlers execute in the context of the interrupted task or process. And the VxWorks kernel does not distinguish between normal task execution and a signal context, as it distinguishes between a task context and an ISR. Therefore the system has no way of distinguishing between a task execution context and a task executing a signal handler. To the system, they are the same.

When you write signal handlers make sure that they:

- Release resources prior to exiting:
  - Free any allocated memory.
  - Close any open files.
  - Release any mutual exclusion resources such as semaphores.
- Leave any modified data structures in a sane state.

Notify the parent process with an appropriate error return value. Mutual exclusion between signal handlers and tasks must be managed with care. In general, users should completely avoid the following activity in signal handlers:

- Taking mutual exclusion (such as semaphores) resources that can also be taken by any other element of the application code. This can lead to deadlock.
- Modifying any shared data memory that may have been in the process of modification by any other element of the application code when the signal was delivered. This compromises mutual exclusion and leads to data corruption.

Both scenarios are very difficult to debug, and should be avoided. One safe way to synchronize other elements of the application code and a signal handler is to set up dedicated flags and data structures that are set from signal handlers and read from the other elements. This ensures a consistency in usage of the data structure. In addition, the other elements of the application code must check for the occurrence of signals at any time by periodically checking to see if the synchronizing data structure or flag has been modified in the background by a signal handler, and then acting accordingly. The use of the **volatile** keyword is useful for memory locations that are accessed from both a signal handler and other elements of the application.

Taking a mutex semaphore in a signal handler is an especially bad idea. Mutex semaphores can be taken recursively. A signal handler can therefore easily re-acquire a mutex that was taken by any other element of the application. Since the signal handler is an asynchronously executing entity, it has thereby broken the mutual exclusion that the mutex was supposed to provide.

Taking a binary semaphore in a signal handler is an equally bad idea. If any other element has already taken it, the signal handler will cause the task to block on itself. This is a deadlock from which no recovery is possible. Counting semaphores, if available, suffer from the same issue as mutexes, and if unavailable, are equivalent to the binary semaphore situation that causes an unrecoverable deadlock.

On a general note, the signal facility should be used only for notifying/handling exceptional or error conditions. Usage of signals as a general purpose IPC

mechanism or in the data flow path of an application can cause some of the pitfalls described above.

3.4 Timers

VxWorks provides watchdog timers, but they can only be used in the kernel (see *VxWorks Kernel Programmer's Guide: Multitasking*. However, process-based applications can use POSIX timers (see *4.6 POSIX Clocks and Timers*, p.159).

4

POSIX Standard Interfaces

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4.1 Introduction

VxWorks POSIX support in user mode (real-time processes) aims at providing a higher level of POSIX compatibility than in the kernel environment—the C library support in particular is highly POSIX compliant. Various APIs which operate on a task in kernel mode, operate on a process in user mode (such as **kill( )**, **exit( )**, and so on). It is worthwhile noting that VxWorks' user-mode application environment is similar to the Realtime Controller System Profile (PSE52) described by POSIX.13 (IEEE Std 1003.13), which is itself based on POSIX.1 (IEEE Std 1003.1).

For information about POSIX support in the kernel, see the *VxWorks Kernel Programmer's Guide: POSIX Standard Interfaces.*

For information about VxWorks real-time processes (RTPs), see *2. Applications and Processes*.

VxWorks provides many POSIX compliant APIs. However, not all POSIX APIs are suitable for embedded and real-time systems, or are entirely compatible with the VxWorks operating system architecture. In a few cases, therefore, Wind River has imposed minor limitations on POSIX functionality to serve either real-time systems or VxWorks compatibility. For example:

- Swapping memory to disk is not appropriate in real-time systems, and VxWorks provides no facilities for doing so. It does, however, provide POSIX page-locking routines to facilitate porting code to VxWorks. The routines otherwise provide no useful function—pages are always locked in VxWorks systems (for more information see *4.8 POSIX Page-Locking Interface*, p.162).
- VxWorks tasks (threads) are scheduled on a system-wide basis; processes themselves cannot be scheduled. As a consequence, while POSIX access routines allow two values for contention scope (**PTHREAD_SCOPE_SYSTEM** and **PTHREAD_SCOPE_PROCESS**), only system-wide scope is implemented in VxWorks for these routines (for more information, see *4.9 POSIX Threads*, p.163).

Any such limitations on POSIX functionality are identified in this chapter, or in other chapters of this guide that provide more detailed information on specific POSIX APIs.

Note that this chapter uses the qualifier *VxWorks* to identify native non-POSIX APIs for purposes of comparison with POSIX APIs. For example, you can find a discussion of VxWorks semaphores contrasted to POSIX semaphores in *4.11.1 Comparison of POSIX and VxWorks Semaphores*, p.180, although POSIX semaphores are also implemented in VxWorks.

4.2 Configuring VxWorks with POSIX Facilities

Process-based applications are automatically linked with the appropriate user-side POSIX libraries when they are compiled. The libraries are automatically initialized at run time. User-side POSIX applications also require support from the kernel—and if VxWorks is not configured with the POSIX components required by an application, the calls lacking support return an **ENOSYS** error at run-time. To include support for VxWorks real-time processes, the operating system must be configured with the **INCLUDE_RTP** component. To include support for user-side POSIX applications, the operating system may have to be configured with additional components.

General POSIX support can be provided by configuring VxWorks with the **BUNDLE_POSIX** component bundle. If memory constraints require a finer-grained configuration, individual components can be used for selected features. See the configuration instructions for individual POSIX features.

Table 4-1 provides an overview of the individual VxWorks components that must be configured in the kernel to provide support for the specified POSIX facilities.

Note that the POSIX thread support in processes requires that the kernel be configured with the component **INCLUDE_POSIX_PTHREAD_SCHEDULER**. This component is not part of the **BUNDLE_POSIX** bundle.

Table 4-1 **VxWorks Components Providing POSIX Facilities**

POSIX Facility	Required VxWorks Component	
	for Kernel	**for Processes**
Asynchronous I/O with system driver	**INCLUDE_POSIX_AIO**, **INCLUDE_POSIX_AIO_SYSDRV** and **INCLUDE_PIPES**	**INCLUDE_POSIX_CLOCKS** and **INCLUDE_POSIX_TIMERS**
Clocks	**INCLUDE_POSIX_CLOCKS**	**INCLUDE_POSIX_CLOCKS**
dirLib directory utilities	**INCLUDE_POSIX_DIRLIB**	N/A
ftruncate	**INCLUDE_POSIX_FTRUNCATE**	N/A
Memory locking	**INCLUDE_POSIX_MEM**	N/A
Message queues	**INCLUDE_POSIX_MQ**	**INCLUDE_POSIX_MQ**

Table 4-1 **VxWorks Components Providing POSIX Facilities** (cont'd)

POSIX Facility	Required VxWorks Component	
	for Kernel	**for Processes**
pthreads	**INCLUDE_POSIX_THREADS**	**INCLUDE_POSIX_CLOCKS** and **INCLUDE_POSIX_PTHREAD_SCHEDULER**
Scheduler	**INCLUDE_POSIX_SCHED**	**INCLUDE_POSIX_SCHED**
Semaphores	**INCLUDE_POSIX_SEM**	**INCLUDE_POSIX_SEM**
Signals	**INCLUDE_POSIX_SIGNALS**	N/A
Timers	**INCLUDE_POSIX_TIMERS**	**INCLUDE_POSIX_TIMERS**

4.3 General POSIX Support

Many POSIX-compliant libraries are provided for VxWorks. These libraries are listed in Table 4-2; see the API references for these libraries for detailed information.

Wind River advises that you do not combine use of the POSIX libraries with native VxWorks libraries that provide similar functionality. Doing so may result in undesirable interactions between the two, as some POSIX APIs manipulate resources that are also used by native VxWorks APIs. For example, do not use **tickLib** routines to manipulate the system's tick counter if you are also using **clockLib** routines; do not use the **taskLib** API to change the priority of a POSIX thread instead of the **pthread** API, and so on.

The following sections of this chapter describe the POSIX APIs available to user-mode applications in addition to the native VxWorks APIs.

Table 4-2 **POSIX Libraries**

Functionality	Library
Asynchronous I/O	**aioPxLib**
Buffer manipulation	**bLib**

Table 4-2 **POSIX Libraries** (cont'd)

Functionality	Library
Clock facility	**clockLib**
Directory handling	**dirLib**
Environment handling	C Library
Environment information	**sysconf** and **uname**
File duplication	**ioLib** for user mode, and **iosLib** for the kernel
File management	**fsPxLib** and **ioLib**
I/O functions	**ioLib**
Options handling	**getOpt**
POSIX message queues	**mqPxLib**
POSIX semaphores	**semPxLib**
POSIX timers	**timerLib**
POSIX threads	**pthreadLib**
Standard I/O and some ANSI	C Library
Math	C Library
Memory allocation	**memLib**
Network/Socket APIs	network libraries
String manipulation	C Library
Wide character support	C library

4.4 POSIX Header Files

The POSIX 1003.1 standard defines a set of header files as part of the environment of development of applications. VxWorks' user-side development environment provides more POSIX header files than the kernel's, and their content is also more in agreement with the standard than the kernel's header files.

⚠ **CAUTION:** Currently the test macro **_POSIX_C_SOURCE** is not supported, so native symbols (types, macros, routine prototypes) from the VxWorks namespace cannot be hidden from the application and may conflict with its own symbols.

Some of the type definitions in user-side POSIX header files may conflict with the native VxWorks types that are made visible via the **vxWorks.h** header file. This is the case with **stdint.h** which should not be included if **vxWorks.h** is included. This situation will be resolved in future releases

Table 4-3 lists the POSIX header files available for both kernel and user development environments.

Table 4-3 **POSIX Header Files**

Header File	Description
aio.h	asynchronous input and output
assert.h	verify program assertion
complex.h	complex arithmetic (user-side only)
ctype.h	character types
dirent.h	format of directory entries
dlfcn.h	dynamic linking (user-side only)
errno.h	system error numbers
fcntl.h	file control options
fenv.h	floating-point environment (user-side only)
float.h	floating types (user-side only)
inttypes.h	fixed size integer types (user-side only)
iso646.h	alternative spellings (user-side only)

Table 4-3 **POSIX Header Files**

Header File	Description
limits.h	implementation-defined constants
locale.h	category macros
math.h	mathematical declarations
mqueue.h	message queues
pthread.h	threads
sched.h	execution scheduling
search.h	search tables (user-side only)
semaphore.h	semaphores
setjmp.h	stack environment declarations
signal.h	signals
stdbool.h	boolean type and values (user-side only)
stddef.h	standard type definitions (user-side only)
stdint.h	integer types (user-side only)
stdio.h	standard buffered input/output
stdlib.h	standard library definitions
string.h	string operations
strings.h	string operations (user-side only)
sys/mman.h	memory management declarations
sys/resource.h	definitions for XSI resource operations
sys/select.h	select types (user-side only)
sys/stat.h	data returned by the stat() function
sys/types.h	data types
sys/un.h	definitions for UNIX domain sockets

Table 4-3 **POSIX Header Files**

Header File	Description
sys/utsname.h	system name structure (user-side only)
sys/wait.h	declarations for waiting (user-side only)
tgmath.h	type-generic macros (user-side only)
time.h	time types
unistd.h	standard symbolic constants and types
utime.h	access and modification times structure
wchar.h	wide-character handling (user-side only)
wctype.h	wide-character classification and mapping utilities (user-side only)

4.5 POSIX Process Support

VxWorks provides support for a user-mode process model. The POSIX APIs described in Table 4-4 are present in user mode for manipulating processes, and take a **_pid_** argument (also known as an **RTP_ID** in VxWorks). Basic VxWorks process facilities are provided with the **INCLUDE_RTP** component.

Table 4-4 **POSIX Process Routines**

Routine	Description
atexit( )	Register a handler to be called at **exit( )**.
_exit( )	Terminate the calling process (system call).
exit( )	Terminate a process, calling **atexit( )** handlers.
getpid( )	Get the process ID of the current process.
getppid( )	Get the process ID of the parent's process ID.

Table 4-4 **POSIX Process Routines** (cont'd)

Routine	Description
kill( )	Send a signal to a process.
raise( )	Send a signal to the caller's process.
wait( )	Wait for any child process to die.
waitpid( )	Wait for a specific child process to die.

4.6 POSIX Clocks and Timers

A clock is a software construct 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.

See Table 4-5 for a list of the POSIX clock routines. The obsolete VxWorks-specific POSIX extension **clock_setres( )** is available for backwards-compatibility purposes.

Table 4-5 **POSIX Clock Routines**

Routine	Description
clock_getres( )	Get the clock resolution.
clock_setres( )	Set the clock resolution. Obsolete VxWorks-specific POSIX extension.
clock_gettime( )	Get the current clock time.
clock_settime( )	Set the clock to a specified time.

The POSIX standard provides a means of identifying multiple virtual clocks, but only one clock is required: the system-wide real-time clock. Virtual clocks are not supported in VxWorks.

The system-wide real-time clock is identified in the clock and timer routines as **CLOCK_REALTIME**, and is defined in **time.h**. VxWorks provides routines to access

the system-wide real-time clock. For more information, see the kernel and application API references for **clockLib**.

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. For more information, see the kernel and application API references for **timerLib**. When a timer goes off, the default signal, **SIGALRM**, is sent to the task. To install a signal handler that executes when the timer expires, use the **sigaction( )** routine (see *3.3.10 Signals*, p.143).

See Table 4-6 for a list of the POSIX timer routines. The VxWorks **timerLib** library includes a set of VxWorks-specific POSIX extensions: **timer_open( )**, **timer_close( )**, **timer_cancel( )**, **timer_connect( )**, and **timer_unlink( )**. These routines allow for an easier and more powerful use of POSIX timers on VxWorks.

Table 4-6 **POSIX Timer Routines**

Routine	Description
timer_create( )	Allocate a timer using the specified clock for a timing base.
timer_delete( )	Remove a previously created timer.
timer_open( )	Open a name timer. VxWorks-specific POSIX extension.
timer_close( )	Close a name timer. VxWorks-specific POSIX extension.
timer_gettime( )	Get the remaining time before expiration and the reload value.
timer_getoverrun( )	Return the timer expiration overrun.
timer_settime( )	Set the time until the next expiration and arm timer.
timer_cancel( )	Cancel a timer. VxWorks-specific POSIX extension.
timer_connect( )	Connect a user routine to the timer signal. VxWorks-specific POSIX extension.
timer_unlink( )	Unlink a named timer. VxWorks-specific POSIX extension.
nanosleep( )	Suspend the current task until the time interval elapses.
sleep( )	Delay for a specified amount of time.
alarm( )	Set an alarm clock for delivery of a signal.

Example 4-1 **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);
    }
```

The POSIX **nanosleep( )** routine provides specification of sleep or delay time in units of seconds and nanoseconds, in contrast to the ticks used by the VxWorks **taskDelay( )** function. Nevertheless, the precision of both is the same, and is determined by the system clock rate; only the units differ.

To include the **timerLib** library in the system, configure VxWorks with the **INCLUDE_POSIX_TIMERS** component. To include the **clockLib** library, configure VxWorks with the **INCLUDE_POSIX_CLOCKS** component.

Process-based applications are automatically linked with the **timerLib** and **clockLib** libraries when they are compiled. The libraries are automatically initialized when the process starts.

4.7 POSIX Asynchronous I/O

POSIX asynchronous I/O (AIO) routines are provided by the **aioPxLib** library, for both kernel and user mode. The VxWorks AIO implementation meets the specification of the POSIX 1003.1 standard. For more information, see *6.6 Asynchronous Input/Output*, p.241.

4.8 POSIX Page-Locking Interface

Many operating systems perform memory *paging* and *swapping*, which copy blocks of memory to disk and back. These techniques allow you to use more virtual memory than there is physical memory on a system. Because they impose severe and unpredictable delays in execution time, paging and swapping are undesirable in real-time systems. Consequently, VxWorks does not support this functionality.

The real-time extensions of the POSIX 1003.1 standard are used with operating systems that do perform paging and swapping. On such systems, applications that attempt real-time performance can use the POSIX *page-locking* facilities to protect certain blocks of memory from paging and swapping.

To facilitate porting programs between other POSIX-conforming systems and VxWorks, VxWorks therefore includes the POSIX page-locking routines. The routines have no adverse effect in VxWorks systems, because all memory is essentially always locked.

The POSIX page-locking routines are part of the memory management library, **mmanPxLib**, and are listed in Table 4-7. When used in VxWorks, these routines do nothing except return a value of **OK** (0), since all pages are always kept in memory.

To include the **mmanPxLib** library in the system, configure VxWorks with the **INCLUDE_POSIX_MEM** component.

Process-based applications are automatically linked with the **mmanPxLib** library when they are compiled.

Table 4-7 **POSIX Page-Locking Routines**

Routine	Purpose on Systems with Paging or Swapping
mlockall( )	Locks into memory all pages used by a task.
munlockall( )	Unlocks all pages used by a task.
mlock( )	Locks a specified page.
munlock( )	Unlocks a specified page.

4.9 POSIX Threads

POSIX threads (pthreads) are similar to VxWorks tasks, but with additional characteristics. VxWorks implements POSIX threads on top of native tasks, and maintains thread IDs that differ from the ID of the underlying task. POSIX threads are provided primarily for code portability—to simplify using POSIX code with VxWorks.

A major difference between VxWorks tasks and POSIX threads is the way in which options and settings are specified. For VxWorks tasks these options are set with the task creation API, usually **taskSpawn( )**. On the other hand, POSIX threads have characteristics that are called *attributes*. Each attribute contains a set of values, and a set of *access routines* to retrieve and set those values. You have to specify all thread attributes in an attributes object, **pthread_attr_t**, before thread creation. In a few cases, you can dynamically modify the attribute values of a running thread.

Unlike VxWorks tasks and kernel pthreads, which are submitted to the system's global scheduling policy, user-mode POSIX threads can be scheduled according to the POSIX scheduling model. They can therefore be started with different policies, or even have their scheduling policy changed during their lifetime. These policies are as follows:

- **SCHED_FIFO** is a preemptive priority scheduling policy. For a given priority level threads scheduled with this policy are handled as peers of the VxWorks tasks at the same level.
- **SCHED_RR** is a per-priority round-robin scheduling policy. For a given priority level all threads scheduled with this policy are given the same time of execution before giving up the CPU.
- **SCHED_OTHER** corresponds to the native VxWorks scheduling policy currently in use, which is either preemptive priority or round-robin. Threads scheduled with this policy are submitted to the system's global scheduling policy, exactly like VxWorks tasks or kernel pthreads.

Using POSIX threads in processes (RTPs) requires the POSIX thread scheduler in the kernel.

The POSIX attribute-access routines are described in Table 4-8. The VxWorks-specific POSIX extension routines are described in section *4.9.1 VxWorks-Specific Thread Attributes*, p.166.

For more information, see *4.10.1 Comparison of POSIX and VxWorks Scheduling*, p.170 and *4.10.4 Getting and Displaying the Current Scheduling Policy*, p.177.

Table 4-8 **POSIX Thread Attribute-Access Routines**

Routine	Description
pthread_attr_getstacksize( )	Get value of the stack size attribute.
pthread_attr_setstacksize( )	Set the stack size attribute.
pthread_attr_getstackaddr( )	Get value of stack address attribute.
pthread_attr_setstackaddr( )	Set value of stack address attribute.
pthread_attr_getdetachstate( )	Get value of *detachstate* attribute (joinable or detached).
pthread_attr_setdetachstate( )	Set value of *detachstate* attribute (joinable or detached).
pthread_attr_getscope( )	Get contention scope. (For VxWorks only **PTHREAD_SCOPE_SYSTEM** is supported.)
pthread_attr_setscope( )	Set contention scope. (For VxWorks, only **PTHREAD_SCOPE_SYSTEM** is supported.)
pthread_attr_getinheritsched( )	Get value of scheduling-inheritance attribute.
pthread_attr_setinheritsched( )	Set value of scheduling-inheritance attribute.
pthread_attr_getschedpolicy( )	Get value of the scheduling-policy attribute (which is not used by default).
pthread_attr_setschedpolicy( )	Set scheduling-policy attribute (which is not used by default).
pthread_attr_getschedparam( )	Get value of scheduling priority attribute.
pthread_attr_setschedparam( )	Set scheduling priority attribute.
pthread_attr_getopt( )	Get the task options applying to the thread. VxWorks-specific POSIX extension.
pthread_attr_setopt( )	Set non-default task options for the thread. VxWorks-specific POSIX extension.
pthread_attr_getname( )	Get the name of the thread. VxWorks-specific POSIX extension.

Table 4-8 **POSIX Thread Attribute-Access Routines** (cont'd)

Routine	Description
pthread_attr_setname( )	Set a non-default name for the thread. VxWorks-specific POSIX extension.

There are many routines provided with the POSIX thread functionality. Table 4-9 lists a few that are directly relevant to pthread creation or execution. See the API reference for information about the other routines, and more details about all of them.

Table 4-9 **POSIX Thread Routines**

Routine	Description
pthread_create( )	Create a POSIX thread.
pthread_cancel( )	Cancel the execution of a thread
pthread_detach( )	Detach a running thread so that it cannot be joined by another thread.
pthread_join( )	Wait for a thread to terminate.
pthread_getschedparam( )	Dynamically set value of scheduling priority attribute.
pthread_setschedparam( )	Dynamically set scheduling priority and policy parameter.
pthread_setschedprio( )	Dynamically set scheduling priority parameter.
sched_get_priority_max( )	Get the maximum priority that a thread can get.
sched_get_priority_min( )	Get the minimum priority that a thread can get.
sched_rr_get_interval( )	Get the time quantum of execution of the Round-Robin policy.
sched_yield( )	Relinquishes the processor.

4.9.1 VxWorks-Specific Thread Attributes

The VxWorks implementation of POSIX threads provides two additional thread attributes (which are POSIX extensions)—thread name and thread options—and routines for accessing them.

Thread Name

Although POSIX threads are not named entities, the VxWorks tasks upon which they are constructed are (VxWorks tasks effectively *impersonate* POSIX threads). By default these tasks are named **pthr***Number* (for example, **pthr3**). The number part of the name is incremented each time a new thread is created (with a roll-over at 2^32 - 1). It is, however, possible to name these tasks using the thread name attribute.

- Attribute Name: **threadname**
- Possible Values: a null-terminated string of characters
- Default Value: none (the default naming policy is used)
- Access Functions (VxWorks-specific POSIX extensions): **pthread_attr_setname( )** and **pthread_attr_getname( )**

Thread Options

POSIX threads are agnostic with regard to target architecture. Some VxWorks tasks, on the other hand, may be created with specific options in order to benefit from certain features of the architecture. For example, for the Altivec-capable PowerPC architecture, tasks must be created with the **VX_ALTIVEC_TASK** in order to make use of the Altivec processor. The thread options attribute can be used to set such options for the VxWorks task that impersonates the POSIX thread.

- Attribute Name: **threadoptions**
- Possible Values: the same as the VxWorks task options. See **taskLib.h**
- Default Value: none (the default task options are used)
- Access Functions (VxWorks-specific POSIX extensions): **pthread_attr_setopt( )** and **pthread_attr_getopt( )**

4.9.2 Specifying Attributes when Creating pthreads

The following examples create a thread using the default attributes and use explicit attributes.

Example 4-2 **Creating a pthread Using Explicit Scheduling Attributes**

```
pthread_t tid;
pthread_attr_t attr;
int ret;

pthread_attr_init(&attr);

/* set the inheritsched attribute to explicit */
pthread_attr_setinheritsched(&attr, PTHREAD_EXPLICIT_SCHED);

/* set the schedpolicy attribute to SCHED_FIFO */
pthread_attr_setschedpolicy(&attr, SCHED_FIFO);

/* create the pthread */
ret = pthread_create(&tid, &attr, entryFunction, entryArg);
```

Example 4-3 **Creating a pthread Using Default Attributes**

```
pthread_t tid;
int ret;

/* create the pthread with NULL attributes to designate default values */
ret = pthread_create(&tid, NULL, entryFunction, entryArg);
```

Example 4-4 **Designating Your Own Stack for a pthread**

```
pthread_t threadId;
pthread_attr_t attr;
void * stackaddr = NULL;
int stacksize = 0;

/* initialize the thread's attributes */

pthread_attr_init (&attr);

/*
 * Allocate memory for a stack region for the thread. Malloc() is used
 * for simplification since a real-life case is likely to use
memPartAlloc()
 * on the kernel side, or mmap() on the user side.
 */

stacksize = 2 * 4096 /* let's allocate two pages */ stackaddr = malloc
(stacksize);

if (stackbase == NULL)
    {
    printf ("FAILED: mystack: malloc failed\n");
    return (-1);
    }

/* set the stackaddr attribute */

pthread_attr_setstackaddr (&attr, stackaddr);
```

```
/* set the stacksize attribute */

pthread_attr_setstacksize (&attr, stacksize);

/* set the schedpolicy attribute to SCHED_FIFO */

pthread_attr_setschedpolicy (&attr, SCHED_FIFO);

/* create the pthread */

ret = pthread_create (&threadId, &attr, mystack_thread, 0);
```

4.9.3 Thread Private Data

POSIX threads can store and access private data; that is, thread-specific data. They use a *key* maintained for each pthread by the pthread library to access that data. A key corresponds to a location associated with the data. It is created by calling **pthread_key_create( )** and released by calling **pthread_key_delete( )**. The location is accessed by calling **pthread_getspecific( )** and **pthread_setspecific( )**. This location represents a pointer to the data, and not the data itself, so there is no limitation on the size and content of the data associated with a key.

The pthread library supports a maximum of 256 keys for all the threads in a process.

The **pthread_key_create( )** routine has an option for a destructor function, which is called when the creating thread exits or is cancelled, if the value associated with the key is non-NULL.

This destructor function frees the storage associated with the data itself, and not with the key. It is important to set a destructor function for preventing memory leaks to occur when the thread that allocated memory for the data is cancelled. The key itself should be freed as well, by calling **pthread_key_delete( )**, otherwise the key cannot be reused by the pthread library.

4.9.4 Thread Cancellation

POSIX provides a mechanism, called *cancellation*, to terminate a thread gracefully. There are two types of cancellation: *deferred* and *asynchronous*.

Deferred cancellation causes the thread to explicitly check to see if it was cancelled. This happens in one of the two following ways:

- The code of the thread executes calls to **pthread_testcancel( )** at regular interval.
- The thread calls a function that contains a *cancellation point* during which the thread may be automatically cancelled.

Asynchronous cancellation causes the execution of the thread to be forcefully interrupted and a handler to be called, much like a signal.[1]

Automatic cancellation points are library routines that can block the execution of the thread for a lengthy period of time. Note that although the **msync( )**, **fcntl( )**, and **tcdrain( )** routines are mandated POSIX 1003.1 cancellation points, they are not provided with VxWorks for this release.

The POSIX cancellation points provided in VxWorks libraries (kernel and application) are described in Table 4-10.

Table 4-10 **Thread Cancellation Points in VxWorks Libraries**

Library	Routines
aioPxLib	**aio_suspend( )**
ioLib	**creat( )**, **open( )**, **read( )**, **write( )**, **close( )**, **fsync( )**, **fdatasync( )**
mqPxLib	**mq_receive( )**, **mq_send( )**
pthreadLib	**pthread_cond_timedwait( )**, **pthread_cond_wait( )**, **pthread_join( )**, **pthread_testcancel( )**
semPxLib	**sem_wait( )**
sigLib	**pause( )**, **sigsuspend( )**, **sigtimedwait( )**, **sigwait( )**, **sigwaitinfo( )**, **waitpid( )** Note: The **waitpid( )** routine is available only in user-mode. It is not available in the kernel.
timerLib	**sleep( )**, **nanosleep( )**

Routines that can be used with cancellation points of pthreads are listed in Table 4-11.

1. Asynchronous cancellation is actually implemented with a special signal, **SIGCNCL**, which users should be careful not to block or to ignore.

Table 4-11 **Thread Cancellation Routines**

Routine	Description
pthread_cancel( )	Cancel execution of a thread.
pthread_testcancel( )	Create a cancellation point in the calling thread.
pthread_setcancelstate( )	Enables or disables cancellation.
pthread_setcanceltype( )	Selects deferred or asynchronous cancellation.
pthread_cleanup_push( )	Registers a function to be called when the thread is cancelled, exits, or calls **pthread_cleanup_pop( )** with a non-null *run* parameter.
pthread_cleanup_pop( )	Unregisters a function previously registered with **pthread_cleanup_push( )**. This function is immediately executed if the *run* parameter is non-null.

4.10 POSIX Scheduling

4.10.1 Comparison of POSIX and VxWorks Scheduling

VxWorks provides two different schedulers: the native VxWorks scheduler and the POSIX thread scheduler. Only one of them can be used at a time and their relationships and differences to POSIX are described below.

Also see the *VxWorks Kernel Programmer's Guide: Kernel*, for information about schedulers.

Native VxWorks Scheduler

- The native VxWorks scheduler is the original VxWorks scheduler. POSIX and the native VxWorks scheduling differ in the following ways:

- POSIX supports a two-level scheduling model that supports the concept known as *contention scope*, by which the scheduling of threads (that is, how they compete for the CPU) can apply system wide or on a process basis. In contrast, VxWorks scheduling is based system wide on tasks and pthreads—in the kernel and in processes. VxWorks real-time processes cannot themselves be scheduled.
- POSIX applies scheduling algorithms on a process-by-process and thread-by-thread basis. VxWorks applies scheduling algorithms on a system-wide basis, for all tasks and pthreads, whether in the kernel or in processes. This means that all tasks and pthreads use either a preemptive priority scheme or a round-robin scheme.
- POSIX supports the concept of scheduling allocation domain; that is, the association between processes or threads and processors. VxWorks does not support multi-processor hardware then there is only one domain on VxWorks and all the tasks and pthreads are associated to it.

The VxWorks scheduling policies are very similar to the POSIX ones, so when the native scheduler is in place the POSIX, the scheduling policies are simply mapped on the VxWorks ones:

- **SCHED_FIFO** is mapped on VxWorks' preemptive priority scheduling.
- **SCHED_RR** is mapped on VxWorks' round-robin scheduling.
- **SCHED_OTHER** corresponds to the currently active VxWorks scheduling policy. This policy is the one used by default by all pthreads.

There is one minor difference between POSIX and VxWorks:

- The POSIX priority numbering scheme is the inverse of the VxWorks scheme. In POSIX, the higher the number, the higher the priority; in the VxWorks 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, **schedPxLib** uses the VxWorks numbering scheme (a smaller number means a higher priority) and its priority numbers match those used by the other components of VxWorks.

POSIX Threads Scheduler

Although it is possible to use the native scheduler for VxWorks tasks in a process (RTP) as well as for POSIX threads in the kernel, the POSIX threads scheduler must be used if pthreads are used in processes. Failure to configure the operating system with **INCLUDE_POSIX_PTHREAD_SCHEDULER** makes it impossible to create threads in a process.

The POSIX threads scheduler is conformant with POSIX 1003.1. This scheduler still applies to all tasks and threads in the system, but only the user-side POSIX threads (that is pthreads executing in processes) are scheduled accordingly to POSIX. VxWorks tasks in the kernel and in processes, and pthreads in the kernel, are scheduled accordingly to the VxWorks scheduling model.

When the POSIX threads scheduler is included in the system it is possible to assign a different scheduling policy to each pthread and change a pthread's scheduling policy dynamically. See *Configuring VxWorks for POSIX Thread Scheduling*, p.172. for more information.

The POSIX scheduling policies are as follows:

- **SCHED_FIFO** is *first in, first out*, preemptive priority scheduling.
- **SCHED_RR** is round-robin, time-bound preemptive priority scheduling.
- **SCHED_OTHER** strictly corresponds to the current native VxWorks scheduling policy (that is, a thread using this policy is scheduled exactly like a VxWorks task. This can be useful for backward-compatibility reasons).
- **SCHED_SPORADIC** is preemptive scheduling with variable priority. It is not supported on VxWorks.

Configuring VxWorks for POSIX Thread Scheduling

To enable the POSIX thread scheduling support for threads in processes, the component **INCLUDE_POSIX_PTHREAD_SCHEDULER** must be included in VxWorks. This configuration applies strictly to threads in processes and does not apply to threads in the kernel. The **INCLUDE_POSIX_PTHREAD_SCHEDULING** component has a dependency on the **INCLUDE_RTP** component since this POSIX thread scheduling support only applies to threads in processes.

For the **SCHED_RR** policy threads, the configuration parameter **POSIX_PTHREAD_RR_TIMESLICE** may be used to configure the default time slicing interval. To modify the time slice at run time, the routine **kernelTimeSlice( )** may be called with a different time slice value. The updated time slice value only affects new threads created after the **kernelTimeSlice( )** call.

INCLUDE_POSIX_PTHREAD_SCHEDULER is a standalone component that is not depended on by other POSIX components. If POSIX threads are configured with **INCLUDE_POSIX_PTHREADS**, the POSIX scheduler is not automatically included. Explicit inclusion of **INCLUDE_POSIX_PTHREAD_SCHEDULING** must be done to get the POSIX thread scheduling behavior. This enables VxWorks to support processes with (for POSIX conforming-applications) or without POSIX thread scheduling.

Once the POSIX thread scheduler is configured, all POSIX RTP applications using threads will have the expected POSIX-conforming thread scheduling behavior.

The inclusion of the **INCLUDE_POSIX_PTHREAD_SCHEDULER** component does not have an impact on VxWorks task scheduling since the VxWorks task scheduling decision has not been changed to support POSIX threads in user space.

Scheduling Behaviors

VxWorks tasks and POSIX threads, regardless of the policy, share a single priority range and the same priority based queuing scheme. Both VxWorks tasks and POSIX threads use the same queuing mechanism to schedule threads and tasks to run; and thus all tasks and threads share a global scheduling scheme.

The inclusion of the POSIX thread scheduling will have minimal impact on kernel tasks, since VxWorks task scheduling behavior is preserved. However, minor side effects may occur. When the POSIX scheduler is configured, the fairness expectation of VxWorks tasks in a system configured with round robin scheduling may not be achieved, because POSIX threads with the **SCHED_FIFO** policy, and at the same priority as the VxWorks tasks, may potentially usurp the CPU. Starvation of the VxWorks round robin tasks may occur. Care must be taken when mixing VxWorks round robin tasks and threads using **SCHED_RR** and **SCHED_FIFO** policies.

Threads with the **SCHED_OTHER** policy behave the same as the default VxWorks system-wide scheduling scheme. In other words, VxWorks configured with round robin scheduling means that threads created with the **SCHED_OTHER** policy will also execute in the round robin mode. VxWorks round robin will not affect POSIX threads created with the **SCHED_RR** and **SCHED_FIFO** policies but will affect POSIX threads created with the **SCHED_OTHER** policy.

One difference in the scheduling behavior when the POSIX scheduler is configured is that threads may be placed at the head of a priority list when the thread is lowered by a call to the POSIX **pthread_setschedprio( )** routine. The lowering of the thread places the lowered thread at the head of its priority list. This is different from VxWorks task scheduling when tasks are lowered using the **taskPrioritySet( )** routine, where the lowered task will be placed at the end of its

priority list. The significance of this change is that threads that were of higher priority, when lowered, are considered to have more preference than tasks and threads in its lowered priority list.

The addition of the POSIX scheduler will change the behavior of existing POSIX applications. For existing applications that require backward-compatibility, the POSIX applications can change their scheduling policy to **SCHED_OTHER** for all POSIX threads since the **SCHED_OTHER** threads defaults to the VxWorks system-wide scheduling scheme as in previous versions of VxWorks.

Mixing POSIX thread APIs and VxWorks APIs in an application is not recommended, and may make a POSIX application non-POSIX conformant.

For information about VxWorks scheduling, see *3.2.2 Task Scheduling*, p.80.

4.10.2 POSIX Scheduling Model

CAUTION: The API part of the **_POSIX_PRIORITY_SCHEDULING** option, and provided by **schedPxLib** on VxWorks, does not currently support processes (RTPs) and are simply meant to be used for VxWorks tasks or POSIX threads

The POSIX 1003.1b scheduling routines, provided by **schedPxLib**, are shown in Table 4-12. These routines provide a portable interface for:

- Getting and setting task priority.
- Getting and setting scheduling policy.
- Getting the maximum and minimum priorities for tasks.
- If round-robin scheduling is in effect, getting the length of a time slice.

This section describes how to use these routines, beginning with a list of the minor differences between the POSIX and VxWorks methods of scheduling.

Table 4-12 **POSIX Scheduling Routines**

Routine	Description
sched_setparam( )	Sets a task's priority.
sched_getparam( )	Gets the scheduling parameters for a specified task.
sched_setscheduler( )	Sets the scheduling policy and parameters for a task (kernel-only routine).

Table 4-12 **POSIX Scheduling Routines** (cont'd)

Routine	Description
sched_yield( )	Relinquishes the CPU.
sched_getscheduler( )	Gets the current scheduling policy.
sched_get_priority_max( )	Gets the maximum task priority.
sched_get_priority_min( )	Gets the minimum task priority.
sched_rr_get_interval( )	If round-robin scheduling, gets the time slice length.

To include the **schedPxLib** library in the system, configure VxWorks with the **INCLUDE_POSIX_SCHED** component.

Process-based applications are automatically linked with the **schedPxLib** library when they are compiled.

4.10.3 Getting and Setting Task Priorities

⚠ **CAUTION:** The **sched_setparam( )** and **sched_getparam( )** routines do not currently support the POSIX thread scheduler with this release, and are simply meant to be used with VxWorks tasks. POSIX threads have their own API which should be used instead: **pthread_setschedparam( )** and **pthread_getschedparam( )**.

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*/**vxworks-6.***x*/**target/h/sched.h** for kernel code and *installDir*/**vxworks-6.***x*/**target/usr/h/sched.h** for user-space application code). A task ID of 0 sets or gets the priority for the calling task.

The **sched_setparam( )** routine writes the specified task's current priority into the the **sched_priority** member of the **sched_param** structure that is passed in.

Example 4-5 **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. Its behavior is, however, necessarily different for VxWorks because of differences in scheduling functionality.

All scheduling in VxWorks is done at the task level—processes themselves are not scheduled—and all tasks have the same scheduling policy. Therefore, the implementation of **sched_setscheduler( )** for VxWorks only controls task priority, and only when the policy specification used in the call matches the system-wide policy. If it does not, the call fails. In other words:

- If the policy specification defined with a **sched_setscheduler( )** call matches the current system-wide scheduling policy, the task priority is set to the new value (thereby acting like the **sched_setparam( )** routine).
- If the policy specification defined with a **sched_setscheduler( )** call does not match the current system-wide scheduling policy, it returns an error, and the priority of the task is not changed.

In VxWorks, the only way to change the scheduling policy is to change it for all tasks in the system. There is no POSIX routine for this purpose, and for security reasons, the scheduling policy cannot be changed from user mode. To set a system-wide scheduling policy, use the VxWorks kernel routine **kernelTimeSlice( )**, which is described in *Round-Robin Scheduling*, p.82.

4.10.4 Getting and Displaying the Current Scheduling Policy

The POSIX routine **sched_getscheduler( )** returns the current scheduling policy.

There are the only two valid scheduling policies in VxWorks when the native scheduler is active: preemptive priority scheduling (in POSIX terms, **SCHED_FIFO**) and round-robin scheduling by priority (**SCHED_RR**).

Example 4-6 **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);
    }
```

4.10.5 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, respectively.

User tasks and pthreads 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.

Note that a non-null result does not imply that the POSIX thread calling this routine is being scheduled with the **SCHED_RR** policy. To make this determination, a pthread must use the **pthread_getschedparam( )** routine.

Example 4-7 **Getting the POSIX Round-Robin Time Slice**

```
/*
 * The following example gets the length of the time slice,
 * and then displays the time slice.
 */

/* includes */

#include <time.h>
#include <sched.h>

STATUS rrgetintervalTest (void)
{
struct timespec slice;

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);
}
```

4.11 POSIX Semaphores

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

When opening a named semaphore, you assign a symbolic name,[2] which the other named-semaphore routines accept as an argument. The POSIX semaphore routines provided by **semPxLib** are shown in Table 4-13.

Table 4-13 **POSIX Semaphore Routines**

Routine	Description
sem_init( )	Initializes an unnamed semaphore.
sem_destroy( )	Destroys an unnamed semaphore.
sem_open( )	Initializes/opens a named semaphore.
sem_close( )	Closes a named semaphore.
sem_unlink( )	Removes 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.

To include the POSIX **semPxLib** library semaphore routines in the system, configure VxWorks with the **INCLUDE_POSIX_SEM** component.

VxWorks also provides **semPxLibInit( )**, a non-POSIX (kernel-only) routine that initializes the kernel's POSIX semaphore library. It is called by default at boot time when POSIX semaphores have been included in the VxWorks configuration.

2. Some 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, named semaphores can be used to share semaphores between real-time processes. In the VxWorks kernel there is no need for named semaphores, because all kernel objects have unique identifiers. However, using named semaphores of the POSIX variety provides a convenient way of determining the object's ID.

Process-based applications are automatically linked with the **semPxLib** library when they are compiled. The library is automatically initialized when the process starts.

4.11.1 Comparison of POSIX and VxWorks Semaphores

POSIX semaphores are *counting* semaphores; that is, they keep track of the number of times they are given. The VxWorks semaphore mechanism is similar to that specified by POSIX, except that VxWorks semaphores offer these 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
- queuing mechanism options

When these features are important, VxWorks semaphores are preferable to POSIX semaphores. (For information about these features, see *3. Multitasking*.)

The POSIX terms *wait* (or *lock*) and *post* (or *unlock*) correspond to the VxWorks terms *take* and *give*, respectively. The POSIX routines for locking, unlocking, and getting the value of semaphores are used for both named and unnamed semaphores.

The routines **sem_init( )** and **sem_destroy( )** are used for initializing and destroying unnamed semaphores only. The **sem_destroy( )** call terminates an unnamed semaphore and deallocates all associated memory.

The routines **sem_open( )**, **sem_unlink( )**, and **sem_close( )** are for opening and closing (destroying) named semaphores only. The combination of **sem_close( )** and **sem_unlink( )** has the same effect for named semaphores as **sem_destroy( )** does for unnamed semaphores. That is, it terminates the semaphore and deallocates the associated memory.

WARNING: When deleting semaphores, particularly mutual-exclusion semaphores, avoid deleting a semaphore still required by another task. Do not delete a semaphore unless the deleting task first succeeds in locking that semaphore. Similarly for named semaphores, close semaphores only from the same task that opens them.

4.11.2 Using Unnamed Semaphores

When using unnamed semaphores, typically 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( )**, lets you 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( )**.

Semaphores can be used for both synchronization and exclusion. Thus, 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 that is 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, setting the semaphore to 0 (locked). Subsequent tasks will block until the semaphore is released. As with the previous scenario, when the semaphore is released the task with the highest priority is unblocked.

When used in a user application, unnamed semaphores can be accessed only by the tasks belonging to the process executing the application. Only named semaphores can be shared between user applications (that is, different processes).

Example 4-8 **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");
        free ((char *) pSem);
        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");
        sem_destroy (pSem);
        free ((char *) pSem);
        return;
        }

    /* all done - destroy semaphore */
    if (sem_destroy (pSem) == -1)
      {
      printf ("unnameSem: sem_destroy failed\n");
      return;
      }
    free ((char *) pSem);
    }

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 */
    }
```

4.11.3 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 results, based on the flags and whether the semaphore accessed already exists, are shown in Table 4-14. There is no entry for **O_EXCL** alone, because using that flag alone is not meaningful.

Table 4-14 **Possible Outcomes of Calling sem_open( )**

Flag Settings	If Semaphore Exists	If 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.
O_EXCL	Routine fails.	Routine fails.

Once initialized, a semaphore remains usable until explicitly destroyed. Tasks can explicitly mark a semaphore for destruction at any time, but the system only destroys the semaphore when no task has the semaphore open.

If VxWorks is configured with **INCLUDE_POSIX_SEM_SHOW**, you can use **show( )** from the shell (with the C interpreter) to display information about a POSIX semaphore. [3]

This example shows information about the POSIX semaphore **mySem** with two tasks blocked and waiting for it:

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

3. The **show( )** routine is not a POSIX routine, nor is it meant to be used programmatically. It is designed for interactive use with the shell (with the shell's C interpreter).

```
    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 then unlocking it with **sem_post( )** when the task is finished with the semaphore.

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. If a task tries to open the semaphore without the **O_CREAT** flag, the operation fails. An unlinked semaphore is deleted by the system when the last task closes it.

POSIX named semaphores may be shared between processes only if their names start with a **/** (forward slash) character. They are otherwise private to the process in which they were created, and cannot be accessed from another process.

Example 4-9 **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;
    }
}
```

4.12 POSIX Mutexes and Condition Variables

Thread mutexes (mutual exclusion variables) and condition variables provide compatibility with the POSIX 1003.1c standard. They perform essentially the same role as VxWorks mutual exclusion and binary semaphores (and are in fact implemented using them). They are available with **pthreadLib.** Like POSIX threads, mutexes and condition variables have *attributes* associated with them. Mutex attributes are held in a data type called **pthread_mutexattr_t**, which contains two attributes, **protocol** and **prioceiling**.

For information about VxWorks mutual exclusion and binary semaphores, see *3.3.4 Semaphores*, p.104, as well as the API references for **semBLib** and **semMLib**.

Protocol

The **protocol** mutex attribute describes how the mutex variable deals with the priority inversion problem described in the section for VxWorks mutual-exclusion semaphores (*Mutual-Exclusion Semaphores*, p.108).

- Attribute Name: **protocol**
- Possible Values: **PTHREAD_PRIO_INHERIT** (default) and **PTHREAD_PRIO_PROTECT**

- Access Routines: **pthread_mutexattr_getprotocol( )** and **pthread_mutexattr_setprotocol( )**

To create a mutual-exclusion variable with *priority inheritance*, use the **PTHREAD_PRIO_INHERIT** value (which is equivalent to the association of **SEM_Q_PRIORITY** and **INHERITSEM_INVERSION_SAFE** options with **semMCreate( )**). A thread owning a mutex variable created with the **PTHREAD_PRIO_INHERIT** value inherits the priority of any higher-priority thread waiting for this mutex and executes at this elevated priority until it releases the mutex, at which points it returns to its original priority. The **PTHREAD_PRIO_INHERIT** option is the default value for the protocol attribute.

Because it might not be desirable to elevate a lower-priority thread to a too-high priority, POSIX defines the notion of priority ceiling, described below. Mutual-exclusion variables created with *priority protection* use the **PTHREAD_PRIO_PROTECT** value.

Priority Ceiling

The **prioceiling** attribute is the POSIX priority ceiling for mutex variables created with the **protocol** attribute set to **PTHREAD_PRIO_PROTECT**.

- Attribute Name: **prioceiling**
- Possible Values: any valid (POSIX) priority value (0-255, with zero being the lowest).
- Access Routines: **pthread_mutexattr_getprioceiling( )** and **pthread_mutexattr_setprioceiling( )**
- Dynamic Access Routines: **pthread_mutex_getprioceiling( )** and **pthread_mutex_setprioceiling( )**

Note that the POSIX priority numbering scheme is the inverse of the VxWorks scheme. See *4.10.1 Comparison of POSIX and VxWorks Scheduling*, p.170.

A priority ceiling is defined by the following conditions:

- Any thread attempting to acquire a mutex, whose priority is higher than the ceiling, cannot acquire the mutex.
- Any thread whose priority is lower than the ceiling value has its priority elevated to the ceiling value for the duration that the mutex is held.
- The thread's priority is restored to its previous value when the mutex is released.

4.13 POSIX Message Queues

The POSIX message queue routines, provided by **mqPxLib**, are shown in Table 4-15.

Table 4-15 **POSIX Message Queue Routines**

Routine	Description
mq_open( )	Opens a message queue.
mq_close( )	Closes a message queue.
mq_unlink( )	Removes a message queue.
mq_send( )	Sends a message to a queue.
mq_receive( )	Gets a message from a queue.
mq_notify( )	Signals a task that a message is waiting on a queue.
mq_setattr( )	Sets a queue attribute.
mq_getattr( )	Gets a queue attribute.

Process-based applications are automatically linked with the **mqPxLib** library when they are compiled. Initialization of the library is automatic as well, when the process is started.

For information about the VxWorks message queue library, see the **msgQLib** API reference.

4.13.1 Comparison of POSIX and VxWorks Message Queues

The POSIX message queues are similar to VxWorks message queues, except that POSIX message queues provide messages with a range of priorities. The differences between the POSIX and VxWorks message queues are summarized in Table 4-16.

Table 4-16 **Message Queue Feature Comparison**

Feature	VxWorks Message Queues	POSIX Message Queues
Message Priority Levels	1	32

Table 4-16 **Message Queue Feature Comparison** (cont'd)

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

4.13.2 POSIX Message Queue Attributes

A POSIX message queue has the following attributes:

- an optional **O_NONBLOCK** flag, which prevents a **mq_receive( )** call from being a blocking call if the message queue is empty
- 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 using **mq_setattr( )**, and get the values of all the attributes using **mq_getattr( )**. (As allowed by POSIX, this implementation of message queues makes use of a number of internal flags that are not public.)

Example 4-10 **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);
}
```

4.13.3 Displaying Message Queue Attributes

The VxWorks shell command **show( )** produces a display of the key message queue attributes, for either POSIX or VxWorks message queues. VxWorks must be configured with include the **INCLUDE_POSIX_MQ_SHOW** component to provide this functionality.[4]

For example, if **mqPXId** is a POSIX message queue, the **show( )** command can be used from the shell (with the C interpreter) as follows:

```
-> show mqPXId
value = 0 = 0x0
Message queue name          : MyQueue
No. of messages in queue    : 1
Maximum no. of messages     : 16
Maximum message size        : 16
```

Compare this to the output for **myMsgQId**, a VxWorks message queue:

```
-> 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
```

4. The **show( )** routine is not a POSIX routine, nor is it meant to be used programmatically. It is designed for interactive use with the shell (with the shell' C interpreter).

4.13.4 Communicating Through a Message Queue

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); see *4.10.1 Comparison of POSIX and VxWorks Scheduling*, p.170.

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 (blocking) 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.

In VxWorks, POSIX message queues can be shared between processes only if their names start with a **/** (forward slash) character. POSIX message queues are otherwise private to the process in which they were created, and they cannot be accessed from another process. See *3.3.1 Public and Private Objects*, p.100.

Example 4-11 **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");
}
```


4.13.5 Notifying a Task that a Message is Waiting

A task can use the **mq_notify( )** routine to request notification when a message it arrives for it 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( )** routine 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 *4.14 POSIX Queued Signals*, p.200).

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 further 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 for each **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.

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

Example 4-12 **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 and 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);
        }
    }
```

4.14 POSIX Queued Signals

Signals are handled differently in the kernel and in real-time processes. In the kernel the target of a signal is always a task; but in user space, the target of a signal may be either a specific task or an entire process.

For user-mode applications (processes), all POSIX API that take a process identifier as one of their parameters use a process ID (a **pid_t** mapping on a **RTP_ID**) in the VxWorks implementation of the signal support for processes.

However, for the VxWorks kernel—for backward compatibility with prior versions of VxWorks—these API continue to use a task identifier for the kernel APIs. Also, in order to maintain functionality equivalent to that provided by previous releases of VxWorks and to support signals between kernel and user applications, additional non-POSIX APIs have been added: **taskSigqueue( )**, **rtpSigqueue( )**, **rtpTaskSigqueue( )**, **taskKill( )**, **rtpKill( )**, and **rtpTaskKill( )**.

In accordance with the POSIX standard, a signal sent to a process is handled by the first available task in the process.

The **sigqueue( )** family of routines provides an alternative to the **kill( )** family of routines for sending signals. 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.

Currently, VxWorks includes signals reserved for application use, numbered consecutively from **SIGRTMIN**. The presence of a minimum of eight (**_POSIX_RTSIG_MAX**) of these reserved signals is required by POSIX 1003.1, but VxWorks supports only seven (**RTSIG_MAX**). The specific signal values are not specified by POSIX; 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 1003.1 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.

Basic queued signal routines are described in Table 4-17. For detailed information on signals, see the kernel and application (process) API references for **sigLib**.

Table 4-17 **POSIX 1003.1b Queued Signal Routines**

Routine	Description
sigqueue( )	Sends a queued signal to a task (kernel API) or to a process (application API).
sigwaitinfo( )	Waits for a signal.
sigtimedwait( )	Waits for a signal with a timeout.

Additional non-POSIX VxWorks queued signal routines are described in Table 4-18. These routines are provided for assisting in porting VxWorks 5.x kernel applications to processes. The POSIX routines described in Table 4-17 should be used for developing new applications that execute as real-time processes.

Note that a parallel set of non-POSIX APIs are provided for the **kill( )** family of POSIX routines.

Table 4-18 **Non-POSIX Queued Signal Routines**

Routine	Description
taskSigqueue( )	Sends a queued signal from a task in a process to another task in the same process (user-space only).
rtpSigqueue( )	Sends a queues signal from a kernel task to a process (kernel-space only).
rtpTaskSigqueue( )	Sends a queued signal from a kernel task to a specified task in a process (kernel-space only).

To include POSIX queued signals in the system, configure VxWorks with the **INCLUDE_POSIX_SIGNALS** component. This component automatically initializes POSIX queued signals with **sigqueueInit( )**. The **sigqueueInit( )** routine allocates buffers for use by **sigqueue( )**, which requires a buffer for each currently queued signal. A call to **sigqueue( )** fails if no buffer is available.

The maximum number of queued signals in a process is set with the configuration parameter **RTP_SIGNAL_QUEUE_SIZE**. The default value, 32, is set in concordance with the POSIX 1003.1 standard (**_POSIX_SIGQUEUE_MAX**). Changing the value to a lower number may cause problems for applications relying on POSIX guidelines.

Process-based applications are automatically linked with the application API **mqPxLib** when they are compiled. Initialization of the library is automatic when the process starts.

Example 4-13 **Queued Signals**

```
/* queSig.c - signal demo */
/*
DESCRIPTION
This demo program exhibits the following functionalities in queued signals.
1) Sending a queued signal  to a kernel task
2) Sending a queued signal to a RTP task
3) Sending a queued signal to a RTP

For simplicity the sender is assumed to be a kernel task.

Do the following in order to see the demo.

Sending a queued signal to a kernel task
----------------------------------------

1) Build this file (queSig.c) alongwith the VxWorks image.
2) Spawn a task with main() as the entry address. For e.g. from the kernel
shell
   do "sp main".
3) sig (int id, int value) provided in this file is a helper function to send
   a queued signal. Where <id> is the kernel task Id and <value> is the
signal
   value to be sent.
4) Send a queued signal to the spawned kernel task.  From kernel shell do
   sig <kernelTaskId> , <value>

Sending a queued signal to a RTP task
-------------------------------------

1) Build this file (queSig.c) as an RTP executable.
2) Spawn the queSig RTP.
3) From a kernel task, use the sig (int id, int value); helper routine to
send
   a queued signal to the RTP task. The <id> being the RTP task Id.

Sending a queued signal to a RTP
--------------------------------

1) Build this file (queSig.c) as an RTP executable.
2) Spawn the queSig RTP.
3) From a kernel task, use the sig (int id, int value); helper routine to
send
```

```
   a queued signal to the RTP. The <id> being the RTP Id.

*/

#include <stdio.h>
#include <signal.h>
#include <taskLib.h>
#include "rtpLib.h"
#ifdef _WRS_KERNEL
#include "private/rtpLibP.h"
#include "private/taskLibP.h"
#endif


typedef void (*FPTR) (int);

void sigMasterHandler
    (
    int     sig,                /* caught signal */
#ifdef _WRS_KERNEL
    int      code,
#else
    siginfo_t * pInfo ,         /* signal info */
#endif
    struct sigcontext *pContext /* unused */
    );


/*****************************************************************************
*
* main - entry point for the queued signal demo
*
* This routine acts the task entry point in the case of the demo spawned as a
* kernel task. It also can act as a RTP entry point in the case of RTP based
* demo
*/

STATUS main ()
    {
    sigset_t sig = sigmask (SIGUSR1);
    union sigval sval;
    struct sigaction in;


    sigprocmask (SIG_UNBLOCK, &sig, NULL);

    in.sa_handler = (FPTR) sigMasterHandler;
    in.sa_flags = 0;
    (void) sigemptyset (&in.sa_mask);

    sigaction (SIGUSR1, &in, NULL);

    printf ("Task 0x%x installed signal handler for signal # %d.\
  Ready for signal.\n", taskIdCurrent,  SIGUSR1);

    for (;;);
```

```
    }


/*******************************************************************************
*
* sigMasterHandler - signal handler
*
* This routine is the signal handler for the SIGUSR1 signal
*/

void sigMasterHandler
    (
    int     sig,                /* caught signal */
#ifdef _WRS_KERNEL
    int     code,
#else
    siginfo_t * pInfo ,         /* signal info */
#endif
    struct sigcontext *pContext /* unused */
    )
    {
    printf ("Task 0x%x got signal # %d  signal value %d \n", taskIdCurrent,
sig,
#ifdef _WRS_KERNEL
            code
#else
            pInfo->si_value.sival_int
#endif
           );
    }


/*******************************************************************************
*
* sig - helper routine to send a queued signal
*
* This routine can send a queued signal to a kernel task or RTP task or RTP.
* <id> is the ID of the receiver entity. <value> is the value to be sent
* along with the signal. The signal number being sent is SIGUSR1.
*/

#ifdef _WRS_KERNEL
STATUS sig (int id, int val)
    {
    union sigval        valueCode;

    valueCode.sival_int = val;

    if (TASK_ID_VERIFY (id) == OK)
        {
        if (IS_KERNEL_TASK (id))
            {
            sigqueue (id, SIGUSR1, valueCode);
            }
        else
```

```
            {
            rtpTaskSigqueue ((WIND_TCB *)id, SIGUSR1, valueCode);
            }
        }
    else if (OBJ_VERIFY ((RTP_ID)id, rtpClassId) != ERROR)
        {
        rtpSigqueue ((RTP_ID)id, SIGUSR1, valueCode);
        }
    else
        {
        return (ERROR);
        }

    return (OK);
    }
#endif
```

5

Memory Management

in Processes

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5.1 Introduction

This chapter describes the memory management facilities available to applications that execute as real-time processes (see *2. Applications and Processes*). Each process has its own heap, and can allocate and free buffers from its heap with the routines provided in the **memLib** and **memPartLib** libraries. User applications that need to manage their memory space can do so with the **mmanLib** API. Applications can request additional mapped memory, change the access permissions of these mapped memory areas, or unmap them with the **mmap( ) mprotect( )**, and **munmap( )** routines.

In addition, run-time error detection facilities provide the ability to debug memory related errors in application code. For information about additional error detection facilities useful for debugging software faults, see *8. Error Detection and Reporting*.

See *VxWorks Kernel Programmer's Guide: Memory Management* for information about:

- Memory management facilities available to code running in the VxWorks kernel.
- The layout of memory for configurations of VxWorks that include processes and related facilities.
- Configuring VxWorks with process support, but without MMU support.

NOTE: This chapter provides information about facilities available for real-time processes. For information about facilities available in the VxWorks kernel, see the corresponding chapter in the *VxWorks Kernel Programmer's Guide*.

5.2 VxWorks Component Requirements

When VxWorks is configured with real-time process support, it includes the basic memory management features required for process-based applications (see *2.2 Configuring VxWorks For Real-time Processes*, p.8).

For the error detection features provided by heap and memory partition instrumentation, the **INCLUDE_EDR_RTP_SHOW** component is also required (*5.5.2 Compiler Instrumentation*, p.220).

5.3 Heap and Memory Partition Management

VxWorks provides support for heap and memory partition management in processes. By default, the heap is implemented as a memory partition within the process.

The heap is automatically created during the process initialization phase. The initial size of the heap, and the automatic incrementation size, are configurable with the environment variables **HEAP_INITIAL_SIZE**, **HEAP_INCR_SIZE** and **HEAP_MAX_SIZE**. These environment variables only have effect if they are set when the application is started. The application cannot change it's own values. For

more information on these environment variables, refer to the VxWorks API reference for **memLib**.

Memory partitions are contiguous areas of memory that are used for dynamic memory allocation by applications. Applications can create their own partitions and allocate and free memory from these partitions.

The heap and any partition created in a process are private to that process, which means that only that process is allowed to allocate memory to it, or free from it.

For more information, see the VxWorks API references for **memPartLib** and **memLib**.

Alternative Heap Manager

The VxWorks process heap implementation can be replaced by a custom version simply by linking the replacement library into the application (the replacement library must precede **vxlib.a** in the link order).

The memory used as heap can be obtained with either one of the following:

- A statically created array variable; for example:

  ```
  char heapMem[HEAP_SIZE];
  ```

  This solution is simple, but it creates a fixed sized heap.

- Using the dynamic memory mapping function, **mmap( )**. With **mmap( )**, it is possible to implement automatic or non-automatic growth of the heap. However, it is important to keep in mind that subsequent calls to **mmap( )** are not guaranteed to provide memory blocks that are adjacent. For more information about **mmap( )** see *5.4 Dynamic Memory Space Management for Applications*, p.210.

In case of applications that are dynamically linked with **libc.so** (which by default contains **memLib.o**), the default heap provided by **memLib** is automatically created. To avoid creation of the default heap, it is necessary to create a custom **libc.so** file that does not hold **memLib.o**. For information about creating a custom shared library that provides this functionality, please contact Wind River Support.

To ensure that process initialization code has access to the replacement heap manager early enough, the user-supplied heap manager must either:

- Initialize the heap automatically the very first time **malloc( )** or any other heap routine is called.

- Have its initialization routine linked with the application, and declared as an automatic constructor using the **_WRS_CONSTRUCTOR** macro with an

initialization order lower than 6 (for information about this macro, see 2.5.1 Library Initialization, p.27).

5.4 Dynamic Memory Space Management for Applications

A limited implementation of the POSIX memory mapped file API is provided to allow processes to dynamically extend their own memory space. This API allows an application to request pages of memory mapped into the process' context, as well as to un-map, or to change protection attributes of dynamically mapped memory pages.

Dynamically-mapped memory is used to create the process heap, and to extend it if necessary. It also can be used to create user memory partitions, or it can be directly managed by an application. When an process is terminated or deleted, all mapped pages are automatically unmapped.

The **mmanLib** library provides the following routines:

mmap( )
Dynamically map pages of memory into the process' memory context.

munmap( )
Unmap pages of memory from the process memory context.

mprotect( )
Change protection of memory pages.

Restrictions

The restrictions of the VxWorks memory-mapped file API implementation are:

- Only private, anonymous mappings are supported (**MAP_PRIVATE** and **MAP_ANON** flags must be used). Shared (**MAP_SHARED**) or fixed (**MAP_FIXED**) mappings are not supported.
- The **unmap( )** routine cannot be used for a partial memory block obtained with **mmap( )**. It only accepts full blocks obtained with a single **mmap( )** call.
- The **mprotect( )** routine only works for memory pages obtained with **mmap( )**.

- It is not possible to specify a specific virtual address to map. The *addr* parameter must be NULL; the kernel will assign the virtual address from the available address space.
- The offset parameter *off* must be 0.
- The address parameter for **mprotect( )**, *addr* , must be page aligned.
- The length of the block is rounded up to a multiple of the page size, and the entire block must be within a block obtained with a single **mmap( )** call.

The following application code illustrates the use of **mmap( )**, **mprotect( )**, and **unmap( )**.

```
#include <sys/mman.h>
#include <sys/sysctl.h>

/*****************************************************************************
* main - User application entry function
*
* This application illustrates the usage of the mmap(),mprotect(),and
munmap()
* API. It does not perform any other useful function.
*
* EXIT STATUS: 0 if all calls succeeded, otherwise 1.
*/

int main ()
    {
    int    mib[3]; /*MIB array for sysctl() */
    size_t pgSize;     /*variable to store page size */
    size_t sz = sizeof (pgSize);    /* size of pgSize variable */
    size_t bufSize;            /* size of buffer */
    char * pBuf;            /* buffer  */

    /* get "hw.mmu.pageSize" info */

    mib[0] = CTL_HW;
    mib[1] = HW_MMU;
    mib[2] = HW_MMU_PAGESIZE;

    if (sysctl (mib, 3, &pgSize, &sz, NULL, 0) != 0)
    exit (1);

    /* buffer size is 4 pages */

    bufSize = 4 * pgSize;

    /* request mapped memory for a buffer */

    pBuf = mmap (NULL, bufSize, (PROT_READ | PROT_WRITE),
         (MAP_PRIVATE | MAP_ANON), MAP_ANON_FD, 0);
```

```
/* check for error */

if (pBuf == MAP_FAILED)
     exit (1);

/* write protect the first page */

if (mprotect (pBuf, pgSize, PROT_READ) != 0)
    {
/*
 * no need to call unmap before exiting as all memory mapped for
 * a process is automatically released.
 */

exit (1);
}

/*
 * Unmap the buffer; the unmap() has to be called for the entire buffer.
 * Note that unmapping before exit() is not necesary; it is shown here
 * only for illustration purpose.
 */

if (munmap (pBuf, bufSize) != 0)
exit (1);

printf ("execution succeded\n");
exit (0);
}
```

For more information see the VxWorksAPI reference for **mmanLib**.

5.5 Memory Error Detection

Support for memory error detection is provided by two optional instrumentation libraries. The **memEdrLib** library performs error checks of operations in the user heap and memory partitions in a process. The Run-Time Error Checking (RTEC) feature of the Wind River Compiler can be used to check for additional errors, such as buffer overruns and underruns, static and automatic variable reference checks.

Errors detected by these facilities are reported with the logging facility of the error detection and reporting component; which must be included in the VxWorks configuration to provide this functionality. For more information, see *8. Error Detection and Reporting*.

NOTE: The memory error detection facilities described in this section are not included in any shared library provided by Wind River with this release. They can only be statically linked with application code.

5.5.1 Heap and Partition Memory Instrumentation

To supplement the error detection features built into **memLib** and **memPartLib** (such as valid block checking), the memory partition debugging library, **memEdrLib**, can be used to perform automatic, programmatic, and interactive error checks on **memLib** and **memPartLib** operations. This is performed by installing instrumentation hooks for **memPartLib**.

The instrumentation helps detect common programming errors such as double-freeing an allocated block, freeing or reallocating an invalid pointer, and memory leaks. In addition, with compiler-assisted code instrumentation, it helps detect bounds-check violations, buffer over-runs and under-runs, pointer references to free memory blocks, pointer references to automatic variables outside the scope of the variable, and so on.

VxWorks Kernel Configuration

A VxWorks kernel configured for process support (with the **INCLUDE_RTP** component) is sufficient for providing processes with heap instrumentation. The optional **INCLUDE_MEM_EDR_RTP_SHOW** component can be used to provide show routines for the heap and memory partition instrumentation. Note that the kernel's heap instrumentation component (**INCLUDE_MEM_EDR**) is not required.

Linking

In order to enable heap and memory partition instrumentation of a process, the executable must be linked with the **memEdrLib** library support included. This can be accomplished by using the following linker option:

-Wl,-umemEdrEnable

For example, the following makefile based on the provided user-side build environment can be used:

```
EXE = heapErr.vxe
OBJS = main.o
LD_EXEC_FLAGS += -Wl,-umemEdrEnable
include $(WIND_USR)/make/rules.rtp
```

Alternatively, adding the following lines to the application code can also be used:

```
extern int memEdrEnable;
memEdrEnable = TRUE;
```

The location of these lines in the code is not important.

Environment Variables

When executing an application, the following environment variables may be set to override the defaults. The variables have to be set when the process is started (see *2.4.1 Application Structure*, p.18).

MEDR_EXTENDED_ENABLE
Set to **TRUE** to enable saving trace information for each allocated block, but at the cost of increased memory used to store entries in the allocation database. Without this feature enabled the database entry for each allocated block is 32 bytes, with this feature enabled it is 64 bytes. Default setting is **FALSE**.

MEDR_FILL_FREE_ENABLE
Set to **TRUE** to enable pattern-filling queued free blocks. This aids detecting writes into freed buffers. Default setting is **FALSE**.

MEDR_FREE_QUEUE_LEN
Maximum allowed length of the free queue. When a memory block is freed by an application, instead of immediately returning it to the memory pool, it is kept in a queue. When the queue reaches the maximum length allowed, the blocks are returned to the memory pool in a FIFO order. Queuing is disabled when this parameter is 0. Default setting is 64.

MEDR_BLOCK_GUARD_ENABLE
Enable guard signatures in the front and the end of each allocated block. Enabling this feature aids in detecting buffer overruns, under-runs, and some heap memory corruption. Default setting is **FALSE**.

MEDR_POOL_SIZE
Set the size of the memory pool used to maintain the memory block database. Default setting in processes is 64 K. The database uses 32 bytes per memory block without extended information enabled, and 64 bytes per block with extended information enabled (call stack trace).

MEDR_SHOW_ENABLE
Enable heap instrumentation show support in the process. This is needed in addition to configuring VxWorks with the **INCLUDE_MEM_EDR_RTP_SHOW** component. When enabled, the kernel routines communicate with a dedicated task in the process with message queues. The default setting is **FALSE**.

Error Types

During execution, errors are automatically logged when the allocation, free, and re-allocation functions are called. The following error types are automatically identified and logged:

- Allocation returns a block address within an already allocated block from the same partition. This would indicate corruption in the partition data structures.
- Allocation returns a block address which is in the task's stack space. This would indicate corruption in the partition data structures.
- Allocation returns a block address that is in the kernel's static data section. This would indicate corruption in the partition data structures.
- Freeing a pointer which is in the task's stack space.
- Freeing a memory that was already freed and is still in the free queue.
- Freeing memory which is in the kernel's static data section.
- Freeing memory in a different partition than where it was allocated.
- Freeing a partial memory block.
- Freeing memory block with the guard zone corrupted, when the **MEDR_BLOCK_GUARD_ENABLE** environment variable is **TRUE**.
- Pattern in a memory block which is in the free queue has been corrupted, when the **MEDR_FILL_FREE_ENABLE** environment variable is **TRUE**.

Shell Commands

The show routines and commands described in Table 5-1 are available for use with the shell's C and command interpreters to display information.

Table 5-1 **Shell Commands**

C Interpreter	Command Interpreter	Description
edrShow( )	**edr show**	Displays error records.
memEdrRtpPartShow( )	**mem rtp part list**	Displays a summary of the instrumentation information for memory partitions located in a given process.
memEdrRtpBlockShow( )	**mem rtp block list**	Displays information about allocated blocks in a given process. Blocks can be selected using a combination of various querying criteria: partition ID, block address, allocating task ID, block type.
memEdrRtpBlockMark( )	**mem rtp block mark** **mem rtp block unmark**	Marks or unmarks selected blocks allocated at the time of the call. The selection criteria may include partition ID and/or allocating task ID. Can be used to monitor memory leaks by displaying information of unmarked blocks with **memEdrRtpBlockShow( )** and **mem rtp block list**.

Code Example

The following application code can be used to generate various errors that can be monitored from the shell (line numbers are included for reference purposes). Its use is illustrated in *Shell Session Example*, p.217.

```
1   #include <vxWorks.h>
2   #include <stdlib.h>
3   #include <taskLib.h>
4   int main ()
5
6       {
7       char * pChar;
8
9       taskSuspend(0);         /* stop here first */
10
11      pChar = malloc (24);
12      free (pChar + 2);       /* free partial block */
13      free (pChar);
14      free (pChar);           /* double-free block */
15      pChar = malloc (32);    /* leaked memory */
16
17      taskSuspend (0);        /* stop again to keep RTP alive */
18      }
```


Shell Session Example

First set up the environment variables in the shell task. These variables will be inherited by processes created with **rtpSp( )**. The first environment variable enables trace information to be saved for each allocation, the second one enables the show command support inside the process.

```
-> putenv "MEDR_EXTENDED_ENABLE=TRUE"
value = 0 = 0x0
-> putenv "MEDR_SHOW_ENABLE=TRUE"
value = 0 = 0x0
```

Spawn the process using the executable produced from the example code:

```
-> rtp = rtpSp ("heapErr.vxe")
rtp = 0x223ced0: value = 36464240 = 0x22c6670
```

At this point, the initial process task (**iheapErr**), which is executing **main( )**, is stopped at the first **taskSuspend( )** call (line 9 of the source code). Now mark all allocated blocks in the process which resulted from the process initialization phase:

```
-> memEdrRtpBlockMark rtp
value = 27 = 0x1b
```

Next, clear all entries in the error log. This step is optional, and is used to limit the number of events displayed by the **edrShow( )** command that will follow:

```
-> edrClear
value = 0 = 0x0
```

Resume the initial task **iheapErr** to continue execution of the application code:

```
-> tr iheapErr
value = 0 = 0x0
```

After resuming the process will continue execution until the second **taskSuspend( )** call (line 17). Now list all blocks in the process that are unmarked. These are blocks that have been allocated since **memEdrRtpBlockMark( )** was called, but have not been freed. Such blocks are possible memory leaks:

```
-> memEdrRtpBlockShow rtp, 0, 0, 0, 5, 1

  Addr    Type    Size    Part ID  Task ID  Task Name       Trace
-------- ------ -------- -------- -------- ------------ ------------
30053970  alloc       32 30010698  22c8750    iheapErr  main()
                            malloc()
                            0x30004ae4()
value = 0 = 0x0
```

Display the error log. The first error corresponds to line 12 in the test code, while the second error corresponds to line 14.

```
-> edrShow
ERROR LOG
=========
Log Size:          524288 bytes (128 pages)
Record Size:       4096 bytes
Max Records:       123
CPU Type:          0x5a
Errors Missed:     0 (old) + 0 (recent)
Error count:       2
Boot count:        4
Generation count: 6

==[1/2]============================================================
Severity/Facility:   NON-FATAL/RTP
Boot Cycle:          4
OS Version:          6.0.0
Time:                THU JAN 01 00:09:56 1970 (ticks = 35761)
Task:                "iheapErr" (0x022c8750)
RTP:                 "heapErr.vxe" (0x022c6670)
RTP Address Space:   0x30000000 -> 0x30057000

freeing part of allocated memory block
       PARTITION: 0x30010698
       PTR=0x30053942
       BLOCK: allocated at 0x30053940, 24 bytes

<<<<<Traceback>>>>>

0x300001b4 _start       +0x4c : main ()
0x300001e4 main         +0x2c : free ()
0x30007280 memPartFree  +0x5c : 0x30004a10 ()
0x30004ac8 memEdrItemGet+0x6e8: 0x30004514 ()
0x30003cb8 memEdrErrorLog+0x138: saveRegs ()

==[2/2]============================================================
Severity/Facility:   NON-FATAL/RTP
Boot Cycle:          4
OS Version:          6.0.0
```

```
Time:                THU JAN 01 00:09:56 1970 (ticks = 35761)
Task:                "iheapErr" (0x022c8750)
RTP:                 "heapErr.vxe" (0x022c6670)
RTP Address Space:   0x30000000 -> 0x30057000

freeing memory in free list
    PARTITION: 0x30010698
    PTR=0x30053940
    BLOCK: free block at 0x30053940, 24 bytes

<<<<<Traceback>>>>>

0x300001b4 _start       +0x4c : main ()
0x300001f4 main         +0x3c : free ()
0x30007280 memPartFree  +0x5c : 0x30004a10 ()
0x30004ac8 memEdrItemGet+0x6e8: 0x30004514 ()
0x30003cb8 memEdrErrorLog+0x138: saveRegs ()
value = 0 = 0x0
```

Finally, resume **iheapErr** again to allow it to complete and to be deleted:

```
-> tr iheapErr
value = 0 = 0x0
```

5.5.2 Compiler Instrumentation

Additional errors are detected if the application is compiled using the Run-Time Error Checking (RTEC) feature of the Wind River Compiler. The following flag should be used:

-Xrtc=*option*

NOTE: This feature is not available with the GNU compiler.

Code compiled with the **-Xrtc** flag is instrumented for runtime checks such as pointer reference check and pointer arithmetic validation, standard library parameter validation, and so on. These instrumentations are supported through the memory partition run-time error detection library. Table 5-2 lists the **-Xrtc** options that are supported.

Table 5-2 **-Xrtc Options**

Option	Description
0x01	register and check static (global) variables
0x02	register and check automatic variables
0x08	pointer reference checks
0x10	pointer arithmetic checks
0x20	pointer increment/decrement checks
0x40	standard function checks; for example **memset( )** and **bcopy( )**
0x80	report source code filename and line number in error logs

The errors and warnings detected by the RTEC compile-in instrumentation are logged by the error detection and reporting facility (see *8. Error Detection and Reporting*). The following error types are identified:

- Bounds-check violation for allocated memory blocks.
- Bounds-check violation of static (global) variables.
- Bounds-check violation of automatic variables.
- Reference to a block in the free queue.
- Reference to the free part of the task's stack.
- De-referencing a NULL pointer.

Configuring VxWorks for RTEC Support

Support for this feature in the kernel is enabled by configuring VxWorks with the basic error detection and reporting facilities. See *8.2 Configuring Error Detection and Reporting Facilities*, p.293.

Shell Commands

The compiler provided instrumentation automatically logs errors detected in applications using the error detection and reporting facility. For information about using shell commands with error logs, see *8.4 Displaying and Clearing Error Records*, p.296.

Code Example

This application code generates various errors that can be recorded and displayed, if built with the Wind River Compiler and its **-Xrtc** option (line numbers are included for reference purposes). Its use is illustrated in *Shell Session Example*, p.221.

```
1    #include <vxWorks.h>
2    #include <stdlib.h>
3
4    int main ()
5        {
6        char   name[] = "very_long_name";
7        char * pChar;
8        int    state[] = { 0, 1, 2, 3 };
9        int    ix = 0;
10
11       pChar = (char *) malloc (13);
12
13       memcpy (pChar, name, strlen (name)); /* bounds check violation
*/
14                           /* of allocated block */
15
16       for (ix = 0; ix < 4; ix++)
17       state[ix] = state [ix + 1];        /* bounds check violation */
18                           /* of automatic variable */
19       free (pChar);
20
21       *pChar = '\0'; /* reference a free block */
22       }
```

Shell Session Example

In the following shell session example, the C interpreter is used to execute **edrClear( )**, which clears the error log of any existing error records. Then the application is started with **rtpSp( )**. Finally, the errors are displayed with **edrShow( )**.

First, clear the error log. This step is only performed to limit the number of events that are later displayed, when the events are listed:

```
-> edrClear
value = 0 = 0x0
```

Start the process using the executable created from the sample code listed above:

```
-> rtpSp "refErr.vxe"
value = 36283472 = 0x229a450
```

Next, list the error log. As shown below, three errors are detected by the compiler instrumentation:

```
-> edrShow
ERROR LOG
=========
Log Size:          524288 bytes (128 pages)
Record Size:       4096 bytes
Max Records:       123
CPU Type:          0x5a
Errors Missed:     0 (old) + 0 (recent)
Error count:       3
Boot count:        4
Generation count: 8
```

The first one is caused by the code on line 13. A string of length 14 is copied into a allocated buffer of size 13:

```
==[1/3]============================================================
Severity/Facility:   NON-FATAL/RTP
Boot Cycle:          4
OS Version:          6.0.0
Time:                THU JAN 01 01:55:42 1970 (ticks = 416523)
Task:                "irefErr"   (0x0229c500)
RTP:                 "refErr.vxe" (0x0229a450)
RTP Address Space:   0x30000000 -> 0x30058000
Injection Point:     main.c:13

memory block bounds-check violation
    PTR=0x30054940  OFFSET=0  SIZE=14
    BLOCK: allocated at 0x30054940, 13 bytes

<<<<<Traceback>>>>>

0x300001b4 _start       +0x4c : main ()
0x300002ac main         +0xf4 : __rtc_chk_at ()
```

The second error refers to line 17. The local **state** array is referenced with index 4. Since the array has only four elements, the range of valid indexes is 0 to 3:

```
==[2/3]============================================================
Severity/Facility:   NON-FATAL/RTP
Boot Cycle:          4
OS Version:          6.0.0
```

```
    Time:                THU JAN 01 01:55:42 1970 (ticks = 416523)
    Task:                "irefErr"   (0x0229c500)
    RTP:                 "refErr.vxe" (0x0229a450)
    RTP Address Space:   0x30000000 -> 0x30058000
    Injection Point:     main.c:17

    memory block bounds-check violation
        PTR=0x30022f34  OFFSET=16  SIZE=4
        BLOCK: automatic at 0x30022f34, 16 bytes

    <<<<<Traceback>>>>>

    0x300001b4 _start       +0x4c : main ()
    0x300002dc main         +0x124: __rtc_chk_at ()
```

The last error is caused by the code on line 21. A memory block that has been freed is being modified:

```
==[3/3]============================================================
    Severity/Facility:   NON-FATAL/RTP
    Boot Cycle:          4
    OS Version:          6.0.0
    Time:                THU JAN 01 01:55:42 1970 (ticks = 416523)
    Task:                "irefErr"   (0x0229c500)
    RTP:                 "refErr.vxe" (0x0229a450)
    RTP Address Space:   0x30000000 -> 0x30058000
    Injection Point:     main.c:21

    pointer to free memory block
        PTR=0x30054940  OFFSET=0  SIZE=1
        BLOCK: free block at 0x30054940, 13 bytes

    <<<<<Traceback>>>>>

    0x300001b4 _start       +0x4c : main ()
    0x30000330 main         +0x178: __rtc_chk_at ()
    value = 0 = 0x0
```

6 I/O System

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6.1 Introduction

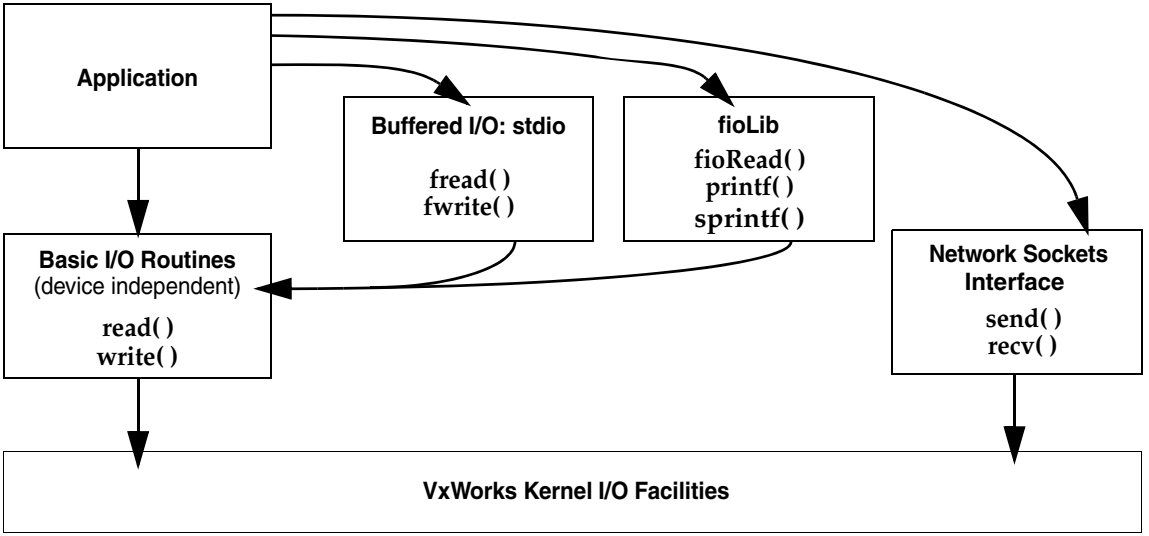
The VxWorks I/O system is designed to present a simple, uniform, device-independent interface to any kind of device, including:

- 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 and 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.

The diagram in Figure 6-1 illustrates the relationships between the different elements of the VxWorks I/O system available to real-time processes (RTPs). All of these elements are discussed in this chapter.

Figure 6-1 **Overview of the VxWorks I/O System for Processes**



NOTE: This chapter provides information about facilities available for real-time processes. For information about facilities available in the VxWorks kernel, see the corresponding chapter in the *VxWorks Kernel Programmer's Guide*.

6.2 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 conform to the conventional user view presented here, but can differ in the specifics. See *6.7 Devices in VxWorks*, p.244.

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.

6.2.1 Filenames and the Default Device

A filename 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 filename. Thus, the name **/tyCo/0** might name a particular serial I/O channel, and the name **DEV1:/file1** indicates the file **file1** on the **DEV1:** device.

When a filename 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 filename. 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. You can obtain the current default path by using **ioDefPathGet( )**. You can set the default path by using **ioDefPathSet( )**.

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 filenames in any way, other than during the search for matching device and filenames.

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 HRFS and dosFs file system devices.

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 filename in the remote directory on the remote system.

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

```
DEV1:
```

NOTE: Filenames 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 (/ or \) should not be used alone as a device name, nor should a slash be used as any part of a device name itself.

6.3 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 Table 6-1.

Table 6-1 **Basic I/O Routines**

Routine	Description
creat( )	Creates a file.
remove( )	Deletes a file.
open( )	Opens a file (optionally, creates a file if it does not already exist.)
close( )	Closes a file.
read( )	Reads a previously created or opened file.
write( )	Writes to a previously created or opened file.
ioctl( )	Performs special control functions on files.

6.3.1 File Descriptors

At the basic I/O level, files are referred to by a *file descriptor*. A file descriptor is a small integer returned by a call to **open( )** or **creat( )**. The other basic I/O calls take a file descriptor as a parameter to specify a file.

File descriptors are not global. The kernel has its own set of file descriptors, and each process (RTP) has its own set. Tasks within the kernel, or within a specific process share file descriptors. The only instance in which file descriptors may be shared across these boundaries, is when one process is a child of another process or of the kernel (processes created by kernel tasks share only the spawning kernel

task's standard I/O file descriptors 0, 1 and 2), and it does not explicitly close a file using the descriptors it inherits from its parent. For example:

- If task **A** and task **B** are running in process **foo**, and they each perform a **write( )** on file descriptor 7, they will write to the same file (and device).
- If process **bar** is started independently of process **foo** (it is not **foo**'s child) and its tasks **X** and **Y** each perform a **write( )** on file descriptor 7, they will be writing to a different file than tasks **A** and **B** in process **foo**.
- If process **foobar** is started by process **foo** (it is **foo**'s child) and its tasks **M** and **N** each perform a **write( )** on file descriptor 7, they will be writing to the same file as tasks **A** and **B** in process **foo**. However, this is only true as long as the tasks do not close the file. If they close it, and subsequently open file descriptor 7 they will operate on a different file.

When a file is opened, a file descriptor is allocated and returned. When the file is closed, the file descriptor is deallocated.

The size of the file descriptor table, which defines the maximum number of files that can be open simultaneously in a process, is inherited from the spawning environment. If the process is spawned by a kernel task, the size of the kernel file descriptor table is used for the initial size of the table for the new process.

The size of the file descriptor table for each process can be changed programmatically. The **rtpIoTableSizeGet( )** routine reads the current size of the table, and the **rtpIoTableSizeSet( )** routine changes it.

By default, file descriptors are reclaimed only when the file is closed for the last time. However, the **dup( )** and **dup2( )** routines can be used to duplicate a file descriptor. For more information, see *6.3.3 Standard I/O Redirection*, p.231.

6.3.2 Standard Input, Standard Output, and Standard Error

Three file descriptors have special meanings:

- 0 is used for standard input (**stdin**).
- 1 is used for standard output (**stdout**).
- 2 is used for standard error output (**stderr**).

All real time processes read their standard input—like **getchar( )**—from file descriptor 0. Similarly file descriptor 1 is used for standard output—like **printf( )**. And file descriptor 2 is used for outputting error messages. You can use these descriptors to manipulate the input and output for all tasks in a process at once by changing the files associated with these descriptors.

These standard file descriptors are used to make an application independent of its actual I/O assignments. If a process sends its output to standard output (where the file descriptor is 1), then its output can be redirected to any file of any device, without altering the application's source code.

6.3.3 Standard I/O Redirection

If a process is spawned by a kernel task, the process inherits the standard I/O file descriptor assignments of the spawning kernel task. These may be the same as the global standard I/O file descriptors for the kernel, or they may be different, task-specific standard I/O file descriptors. (For more information about kernel standard I/O assignments, see the *VxWorks Kernel Programmer's Guide: I/O System*.)

If a process is spawned by another process, it inherits the standard I/O file descriptor assignments of the spawning process.

After a process has been spawned, its standard I/O file descriptors can be changed to any file descriptor that it owns.

The POSIX **dup( )** and **dup2( )** routines are used for redirecting standard I/O to a different file and then restoring them, if necessary. (Note that this is a very different process from standard I/O redirection in the kernel).

The first routine is used to save the original file descriptors so they can be restored later. The second routine assigns a new descriptor for standard I/O, and can also be used to restore the original. Every duplicated file descriptor should be closed explicitly when it is no longer in use. The following example illustrates how the routines are used.

First use the **dup( )** routine to duplicate and save the standard I/O file descriptors, as follows:

```
/* Temporary fd variables */
int  oldFd0;
int  oldFd1;
int  oldFd2;
int  newFd;

/* Save the original standard file descriptor. */
oldFd0 = dup(0);
oldFd1 = dup(1);
oldFd2 = dup(2);
```

Then use **dup2( )** to change the standard I/O files:

```
/* Open new file for stdin/out/err */
newFd = open ("newstandardoutputfile", O_RDWR, 0);
```

```
/* Set newFd to fd 0, 1, 2 */
dup2 (newFd, 0);
dup2 (newFd, 1);
dup2 (newFd, 2);
```

If the process' standard I/O needs to be redirected again, the preceding step can be repeated with a another new file descriptor.

If the original standard I/O file descriptors need to be restored, the following procedure can be performed:

```
/* When complete, restore the original standard IO */
dup2 (oldFd0, 0);
dup2 (oldFd1, 1);
dup2 (oldFd2, 2);

/* Close them after they are duplicated to fd 0, 1, 2 */
close (oldFd0);
close (oldFd1);
close (oldFd2);
```

This redirection only affect the process in which it is done. It does not affect the standard I/O of any other process or the kernel. Note, however, that any new processes spawned by this process inherit the current standard I/O file descriptors of the spawning process (whatever they may be) as their initial standard I/O setting.

For more information, see the VxWorks API references for **dup( )** and **dup2( )**.

6.3.4 Open and Close

Before I/O can be performed on a device, a file descriptor must be opened to the device by invoking the **open( )** routine—or **creat( )**, as discussed in the next section. The arguments to **open( )** are the filename, the type of access, and the mode (file permissions):

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

For **open( )** calls made in processes, the mode parameter is optional.

The file-access options that can be used with the *flags* parameter to **open( )** are listed in Table 6-2.

Table 6-2 **File Access Options**

Flag	Description
O_RDONLY	Open for reading only.
O_WRONLY	Open for writing only.
O_RDWR	Open for reading and writing.
O_CREAT	Create a file if it does not already exist.
O_EXCL	Error on open if the file exists and **O_CREAT** is also set.
O_SYNC	Write on the file descriptor complete as defined by synchronized I/O file integrity completion.
O_DSYNC	Write on the file descriptor complete as defined by synchronized I/O data integrity completion.
O_RSYNC	Read on the file descriptor complete at the same sync level as **O_DSYNC** and **O_SYNC** flags.
O_APPEND	Set the file offset to the end of the file prior to each write, which guarantees that writes are made at the end of the file. It has no effect on devices other than the regular file system.
O_NONBLOCK	Non-blocking I/O.
O_NOCTTY	If the named file is a terminal device, don't make it the controlling terminal for the process.
O_TRUNC	Open with truncation. If the file exists and is a regular file, and the file is successfully opened, its length is truncated to 0. It has no effect on devices other than the regular file system.

Note the following special cases with regard to use of the file access and mode (file permissions) parameters to **open( )**:

- In general, you can open only preexisting devices and files with **open( )**. However, with NFS network, dosFs, and HRFS devices, you can also create files with **open( )** by OR'ing **O_CREAT** with one of the other access flags.
- HRFS directories can be opened with the **open( )** routine, but only using the **O_RDONLY** flag.

- With both dosFs and NFS devices, you can use the **O_CREAT** flag to create a subdirectory by setting *mode* to **FSTAT_DIR**. Other uses of the mode parameter with dosFs devices are ignored.
- With an HRFS device you cannot use the **O_CREAT** flag and the **FSTAT_DIR** mode option to create a subdirectory. HRFS will ignore the mode option and simply create a regular file.
- The netDrv default file system does not support the **F_STAT_DIR** mode option or the **O_CREAT** flag.
- For NFS devices, the third parameter to **open( )** is normally used to specify the mode of the file. For example:

```
myFd = open ("fooFile", O_CREAT | O_RDWR, 0644);
```

- While HRFS supports setting the permission mode for a file, it is not used by the VxWorks operating system.
- Files can be opened with the **O_SYNC** flag, indicating that each write should be immediately written to the backing media. This flag is currently supported by the dosFs file system, and includes synchronizing the FAT and the directory entries.
- The **O_SYNC** flag has no effect with HRFS because file system is always synchronous. HRFS updates files as though the **O_SYNC** flag were set.

NOTE: Drivers or file systems may or may not honor the flag values or the mode values. A file opened with **O_RDONLY** mode may in fact be writable if the driver allows it. Consult the driver or file system information for specifics.

Refer to the VxWorks file system API references for more information about the features that each file system supports.

The **open( )** routine, if successful, returns a file descriptor. This file descriptor is then used in subsequent I/O calls to specify that file. The file descriptor is an identifier that is not task specific; that is, it is shared by all tasks within the memory space. Within a given process or the kernel, therefore, one task can open a file and any other task can then use the file descriptor. The file descriptor remains valid until **close( )** is invoked with that file descriptor, as follows:

```
close (fd);
```

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

For processes, files descriptors are closed automatically only when a process terminates. It is, therefore, recommended that tasks running in processes explicitly close all file descriptors when they are no longer needed. As stated previously (*6.3.1 File Descriptors*, p.229), there is a limit to the number of files that can be open at one time. Note that a process owns the files, so that when a process is destroyed, its file descriptors are automatically closed.

6.3.5 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 filename specifies the name of the new file rather than an existing one; the **creat( )** routine returns a file descriptor identifying the new file.

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

Note that with the HRFS file system the **creat( )** routine is POSIX compliant, and the second parameter is used to specify file permissions; the file is opened in **O_RDWR** mode.

With dosFs, however, the **creat( )** routine is not POSIX compliant and the second parameter is used for open mode flags.

The **remove( )** routine deletes a named file on a file-system device:

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

Files should be closed before they are removed.

With non-file-system devices, the **creat( )** routine performs the same function as **open( )**. The **remove( )** routine, however has no effect.

6.3.6 Read and Write

After a file descriptor 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 file descriptor, 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 file descriptor, 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). The **write( )** routine returns the number of bytes written; if the number returned is not equal to the number requested, an error has occurred.

The **read( )** and **write( )**routines are POSIX-conformant, both with regard to their interface and the location of their declarations (**target/usr/h/unistd.h**).

6.3.7 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 a file descriptor and the desired length of the file in bytes:

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

If it succeeds in truncating the file, **ftruncate( )** returns **OK**.

If the file descriptor refers to a device that cannot be truncated, **ftruncate( )** returns **ERROR**, and sets **errno** to **EINVAL**.

If the size specified is larger than the actual size of the file, the result depends on the file system. For both dosFs and HRFS, the size of the file is extended to the specified size; however, for other file systems, **ftruncate( )** returns **ERROR**, and sets **errno** to **EINVAL** (just as if the file descriptor referred to a device that cannot be truncated).

The **ftruncate( )** routine is part of the POSIX 1003.1b standard. It is fully supported as such by the HRFS. The dosFs implementation is, however, only partially compliant: creation and modification times are not changed.

Also note that with HRFS the *seek* position is not modified by truncation, but with dosFs the seek position is set to the end of the file.

6.3.8 I/O Control

The **ioctl( )** routine provides an open-ended mechanism for performing I/O functions that are not performed by 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 file descriptor, a code that identifies the control function requested, and an optional function-dependent argument:

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

For **ioctl( )** calls made in processes, the *arg* parameter is optional. Both of the following are legitimate calls:

```
fd = ioctl (fd, func, arg);
fd = ioctl (fd, func);
```

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 **ioctl( )** routine is POSIX-conformant, both with regard to its interface and the location of its declarations (**target/usr/h/unistd.h**).

The discussion of specific devices in *6.7 Devices in VxWorks*, p.244 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 or file systems.

6.3.9 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. An example of using the select facility to pend on multiple file descriptors is 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 6-3.

Table 6-3 **Select Macros**

Macro	Description
FD_ZERO	Zeroes all bits.
FD_SET	Sets the bit corresponding to a specified file descriptor.
FD_CLR	Clears a specified bit.
FD_ISSET	Returns non-zero if the 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).

6.3.10 POSIX File System Routines

The POSIX **fsPxLib** library provides I/O and file system routines for various file manipulations. These routines are described in Table 6-4.

Table 6-4 **File System Routines**

Routine	Description
unlink( )	Unlink a file.
link( )	Link a file.
fsync( )	Synchronize a file.
fdatasync( )	Synchronize a file data.
rename( )	Change the name of a file.
fpathconf( )	Determine the current value of a configurable limit.
pathconf( )	Determine the current value of a configurable limit.
access( )	Determine accessibility of a file.
chmod( )	Change the permission mode of a file.

For more information, see the API reference for **fsPxLib**.

6.4 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. Configure VxWorks with the ANSI Standard component bundle to provide buffered I/O support.

6.4.1 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.

This overhead is quite small because the VxWorks primitives are fast. 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* is a handle for the opened file and its associated buffers and pointers. A file pointer 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, which is a small integer. In fact, the **FILE** structure pointed to by the file pointer contains the underlying file descriptor of the open file.

A file descriptor that is already open 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.

6.4.2 Standard Input, Standard Output, and Standard Error

As discussed in 6.3 Basic I/O, p.229, 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 file descriptors. Each task using the standard I/O file descriptors has its own *stdio* **FILE** buffers. The **FILE** buffers are deallocated when the task exits.

6.5 Other Formatted I/O: 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 file descriptor (2). The routine **fdprintf( )** outputs formatted strings to a specified file descriptor.

6.6 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 de-couple 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. Include AIO in your VxWorks configuration with the **INCLUDE_POSIX_AIO** and **INCLUDE_POSIX_AIO_SYSDRV** components. The

second configuration constant enables the auxiliary AIO system driver, required for asynchronous I/O on all current VxWorks devices.

NOTE: The asynchronous I/O facilities are not included in any RTP shared library provided by Wind River for use with this release. They can only be statically linked with application code. For information about creating a custom shared library that provides this functionality, please contact Wind River Support.

6.6.1 The POSIX AIO Routines

The VxWorks library **aioPxLib** provides 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 6-5.

Table 6-5 **Asynchronous Input/Output Routines**

Function	Description
aio_read( )	Initiates an asynchronous read operation.
aio_write( )	Initiates an asynchronous write operation.
aio_listio( )	Initiates a list of up to **LIO_MAX** asynchronous I/O requests.
aio_error( )	Retrieves the error status of an AIO operation.
aio_return( )	Retrieves the return status of a completed AIO operation.
aio_cancel( )	Cancels a previously submitted AIO operation.
aio_suspend( )	Waits until an AIO operation is done, interrupted, or timed out.
aio_fsync( )	Asynchronously forces file synchronization.

6.6.2 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.

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

aio_fildes
The file descriptor for I/O.

aio_offset
The offset from the beginning of the file.

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

aio_nbytes
The number of bytes to read or write.

aio_reqprio
The priority reduction for this AIO request.

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

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

aio_sys_p
The address of VxWorks-specific data (non-POSIX).

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

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

6.6.3 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 this 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( )**. To force all I/O operations to the synchronized I/O completion state, use **aio_fsync( )**.

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.

6.7 Devices in VxWorks

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

See the *VxWorks Kernel Programmer's Guide: I/O System* for more detailed information about I/O device drivers.

6.7.1 Serial I/O Devices: Terminal and Pseudo-Terminal Devices

VxWorks provides terminal and pseudo-terminal devices (*tty* and *pty*). The *tty* device is for actual terminals; the *pty* device is for processes that simulate

terminals. These pseudo terminals are useful in applications such as remote login facilities.

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.

NOTE: 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. For example, to set all the *tty* options except **OPT_MON_TRAP**:

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

For more information about I/O control functions, see *VxWorks Kernel Programmer's Guide: I/O System*.

Table 6-6 is a summary of the available options. The listed names are defined in the header file **ioLib.h**. For more detailed information, see the API reference entry for **tyLib**.

Table 6-6 **Tty Options**

Library	Description
OPT_LINE	Selects *line mode*. (See *Raw Mode and Line Mode*, p.246.)
OPT_ECHO	Echoes input characters to the output of the same channel.
OPT_CRMOD	Translates input **RETURN** characters into **NEWLINE** (\n); translates output **NEWLINE** into **RETURN-LINEFEED**.
OPT_TANDEM	Responds software flow control characters **CTRL+Q** and **CTRL+S** (**XON** and **XOFF**).
OPT_7_BIT	Strips the most significant bit from all input bytes.

Table 6-6 **Tty Options** (cont'd)

Library	Description
OPT_MON_TRAP	Enables the special *ROM monitor trap* character, **CTRL+X** by default.
OPT_ABORT	Enables the special kernel shell abort character, **CTRL+C** by default. (Only useful if the kernel shell is configured into the system)
OPT_TERMINAL	Sets all of the above option bits.
OPT_RAW	Sets 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.245).

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.246.

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 software flow control characters **CTRL+Q** and **CTRL+S** (**XON** and **XOFF**). 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. The software flow control characters are 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.[1] The monitor trap character is enabled by **OPT_MON_TRAP**.
- The special *kernel shell abort* character, by default **CTRL+C**. This character restarts the kernel 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 kernel 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 6-7.

Table 6-7 **Tty Special Characters**

Character	Description	Modifier
CTRL+H	backspace (character delete)	**tyBackspaceSet( )**
CTRL+U	line delete	**tyDeleteLineSet( )**

1. It will not be possible to restart VxWorks if un-handled external interrupts occur during the boot countdown.

Table 6-7 **Tty Special Characters** (cont'd)

Character	Description	Modifier
CTRL+D	EOF (end of file)	**tyEOFSet( )**
CTRL+C	kernel shell abort	**tyAbortSet( )**
CTRL+X	trap to boot ROMs	**tyMonitorTrapSet( )**
CTRL+S	output suspend	N/A
CTRL+Q	output resume	N/A

6.7.2 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.

Named pipes can be created in processes. However, unless they are specifically deleted by the application they will persist beyond the life of the process in which they were created. Applications should allow for the possibility that the named pipe already exists, from a previous invocation, when the application is started.

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 blocked 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.

I/O Control Functions

Pipe devices respond to the **ioctl( )** functions summarized in Table 6-8. 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 6-8 **I/O Control Functions Supported by pipeDrv**

Function	Description
FIOFLUSH	Discards all messages in the pipe.
FIOGETNAME	Gets the pipe name of the file descriptor.
FIONMSGS	Gets the number of messages remaining in the pipe.
FIONREAD	Gets the size in bytes of the first message in the pipe.

6.7.3 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, unlike **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.

For information about the **memDrv** and **ramDrv** drivers, see the *VxWorks Kernel Programmer's Guide: I/O System*.

I/O Control Functions

The memory device responds to the **ioctl( )** functions summarized in Table 6-9. The functions listed are defined in the header file **ioLib.h**.

Table 6-9 **I/O Control Functions Supported by memDrv**

Function	Description
FIOSEEK	Sets the current byte offset in the file.
FIOWHERE	Returns the current byte position in the file.

For more information, see the reference entries for **memDrv**, **ioLib**, and **ioctl( )**.

6.7.4 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 *Wind River Network Stack for VxWorks 6 Programmer's Guide*.

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*.

I/O Control Functions for NFS Clients

NFS client devices respond to the **ioctl( )** functions summarized in Table 6-10. The functions listed are defined in **ioLib.h**. For more information, see the reference entries for **nfsDrv**, **ioLib**, and **ioctl( )**.

Table 6-10 **I/O Control Functions Supported by nfsDrv**

Function	Description
FIOFSTATGET	Gets file status information (directory entry data).
FIOGETNAME	Gets the filename of the file descriptor.
FIONREAD	Gets the number of unread bytes in the file.
FIOREADDIR	Reads the next directory entry.
FIOSEEK	Sets the current byte offset in the file.
FIOSYNC	Flushes data to a remote NFS file.
FIOWHERE	Returns the current byte position in the file.

6.7.5 Non-NFS Network Devices

VxWorks also supports network access to files on a remote host through the Remote Shell protocol (RSH) or the File Transfer Protocol (FTP).

These implementations of network devices use the driver **netDrv**, which is included in the Wind River Network Stack. Using this driver, you can open, read,

write, and close files located on remote systems without needing to manage the details of the underlying protocol used to effect the transfer of information. (For more information, see the *Wind River Network Stack for VxWorks 6 Programmer's Guide: Working With Device Instances*.)

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 memory-resident 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.

NOTE: Within processes, there are limitations on RSH and FTP usage: directories cannot be created and the contents of file systems cannot be listed.

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 API reference entries for **netDrv** and **ioctl( )**.

6.7.6 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 file descriptor.

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 *Wind River Network Stack for VxWorks 6 Programmer's Guide*.

6.8 Transaction-Based Reliable File System Facility: TRFS

The transaction-based reliable file system (TRFS) component (**INCLUDE_XBD_TRANS**) is an I/O facility that provides a fault-tolerant file system layer for the dosFs file system.

TRFS provides both file system consistency and fast recovery for the dosFs file system (DOS-compatible file systems are themselves neither reliable nor transaction-based). It is designed to operate with XBD-compliant device drivers for hard disks, floppy disks, compact flash media, TrueFFS flash devices, and so on. It can also be used with the XBD wrapper component for device drivers that are not XBD-compliant.

TRFS provides reliability in resistance to sudden power loss: files and data that are already written to media are unaffected, they will not be deleted or corrupted because data is always written either in its entirety or not at all.

TRFS provides additional guarantees in its transactional feature: data is always maintained intact up to a given commit transaction. User applications set transaction points on the file system. If there is an unexpected failure of the system, the file system is returned to the state it was in at the last transaction point. That is, if data has changed on the media after a commit transaction but prior to a power loss, it is automatically restored to the its state at the last commit transaction to further ensure data integrity. On mounting the file system, TRFS detects any failure and rolls back data to the last secure transaction.

Unlike some facilities that provide data integrity on a file-by-file basis, TRFS protects the medium as a whole. It is transactional for a file system, which means that setting transaction points will commit all files, not just the one used to set the transaction point.

NOTE: While TRFS is a I/O layer added to dosFs, it uses a modified on-media format that is not compatible with other FAT-based file systems, including Microsoft Windows and the VxWorks dosFs file system without the TRFS layer. It should not, therefore, be used when compatibility with other systems is a requirement

For information about dosFs, see *7.4 MS-DOS-Compatible File System: dosFs*, p.265.

6.8.1 Configuring VxWorks With TRFS

Configure VxWorks with the **INCLUDE_XBD_TRANS** component to provide TRFS functionality for your dosFs file system.

6.8.2 Creating a TRFS Shim Layer

For information about creating TRFS, see *VxWorks Kernel Programmer's Guide: I/O System*.

6.8.3 Using the TRFS in Applications

Once TRFS and dosFs are created, the dosFs file system may be used with the ordinary file creation and manipulation commands. No changes to the file system become permanent, however, until TRFS is used to commit them.

It is important to note that the entire dosFs file system—and not individual files—are committed. The entire disk state must therefore be consistent before executing a commit; that is, there must not be a file system operation in progress (by another task, for example) when the file system is committed. If multiple tasks update the file system, care must be taken to ensure the file data is in a known state before setting a transaction point.

To commit a file system from a process, call:

```
ioctl(fd, CBIO_TRANS_COMMIT, 0);
```

where *fd* is any file descriptor that is open.

TRFS Code Example

The following code example illustrates setting a transaction point.

```
void transTrfs
    (
    void
    )
    {
    int fd;
    /* This assumes a TRFS with DosFs on "/trfs" */

    fd = open ("/trfs/test.1", O_RDWR | O_CREAT, 0);

    ... /* Perform file operations here */
    ioctl (fd, CBIO_TRANS_COMMIT, 0);

    ... /* Perform more file operations here */
    ioctl (fd, CBIO_TRANS_COMMIT, 0);

    close (fd);
    }
```

7

Local File Systems

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7.1 Introduction

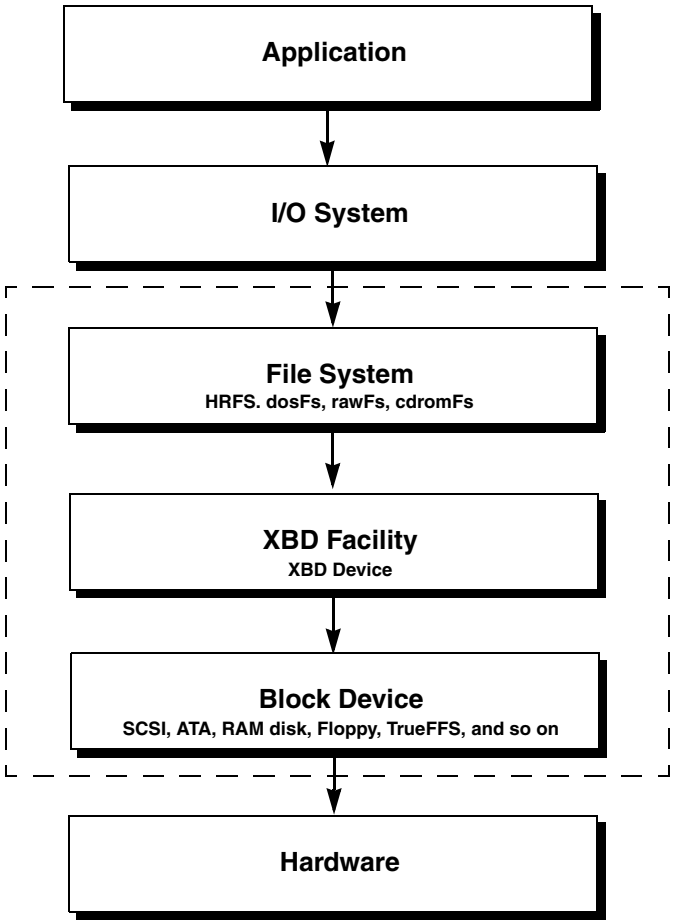
VxWorks provides a variety of file systems that are suitable for different types of applications. The file systems can be used simultaneously, and in most cases in multiple instances, for a single VxWorks system.

Most VxWorks file systems rely on the extended block device (XBD) facility for a a standard I/O interface between the file system and device drivers. This standard interface allows you to write your own file system for VxWorks, and freely mix file systems and device drivers.

File systems used for removable devices make use of the file system monitor for automatic detection of device insertion and instantiation of the appropriate file system on the device.

The relationship between applications, file systems, I/O facilities, device drivers and hardware devices is illustrated in Figure 7-1. Note that this illustration is relevant for the HRFS, dosFs, rawFs, and cdromFs file systems. The dotted line indicates the elements that need to be configured and instantiated to create a specific, functional run-time file system.

Figure 7-1 **File Systems in a VxWorks System**



This chapter discusses the following VxWorks file systems and how they are used:

- **HRFS**

  A transactional file system designed for real-time use of block devices (disks) and POSIX compliant. Can be used on flash memory inconjuntion with TrueFFS and the XBD block wrapper component.

  See *7.3 Highly Reliable File System: HRFS*, p.259.

- **dosFs**

  Designed for real-time use of block devices (disks), and compatible with the MS-DOS file system. Can be used with flash memory in conjunction with the TrueFFS. Can also be used with the transaction-based reliable file system (TRFS) facility. See *7.4 MS-DOS-Compatible File System: dosFs*, p.265.

- **rawFS**

  Provides a simple raw file system that treats an entire disk as a single large file. See *7.5 Raw File System: rawFs*, p.278.

- **cdromFs**

  Allows applications to read data from CD-ROMs formatted according to the ISO 9660 standard file system. See *7.6 CD-ROM File System: cdromFs*, p.280.

- **ROMFS**

  Designed for bundling applications and other files with a VxWorks system image. No storage media is required beyond that used for the VxWorks boot image. See *7.7 Read-Only Memory File System: ROMFS*, p.284.

- **TSFS**

  Uses the host target server to provide the target with access to files on the host system. See *7.8 Target Server File System: TSFS*, p.286.

For information about the file system monitor, see the *VxWorks Kernel Programmer's Guide: Local File Systems*. For information about the XBD facility, see the *VxWorks Kernel Programmer's Guide: I/O System*.

File Systems and Flash Memory

VxWorks can be configured with file-system support for flash memory devices using TrueFFS and the dosFs or HRFS file system. For more information, see *7.4 MS-DOS-Compatible File System: dosFs*, p.265 and the *VxWorks Kernel Programmer's Guide: Flash File System Support with TrueFFS*.

NOTE: This chapter provides information about facilities available for real-time processes. For information about creating file systems, and file system facilities available in the kernel, see the *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.2 File System Monitor

The file system monitor provides for automatic detection of device insertion, and instantiation of the appropriate file system on the device. The monitor is required for all file systems that are used with the extended block device (XBD) I/O facility. It is provided with the **INCLUDE_FS_MONITOR** component.

The file systems that require both the XBD and the file system monitor components are HRFS, dosFs, rawFs, and cdromFs.

For detailed information about how the file system monitor works, see the *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.3 Highly Reliable File System: HRFS

The Highly Reliable File System (HRFS) is a transactional file system for real-time systems. The primary features of the file system are:

- Fault tolerance. The file system is never in an inconsistent state, and is therefore able to recover quickly from unexpected loses of power.
- Transactional operations on a file basis, rather than the whole disk.
- Hierarchical file and directory system, allowing for efficient organization of files on a volume.
- Compatibility with a widely available storage devices.
- POSIX conformance.

For more information about the HRFS libraries see the VxWorks API references for **hrfsFormatLib**, **hrFsLib**, and **hrfsChkDskLib**.

HRFS and Flash Memory

For information about using HRFS with flash memory, see the *VxWorks Kernel Programmer's Guide: Flash File System Support with TrueFFS*.

7.3.1 Configuring VxWorks for HRFS

To include HRFS support in VxWorks, configure the kernel with the appropriate required and optional components.

Required Components

Either the **INCLUDE_HRFS** or the **INCLUDE_HRFS_READONLY** component is required. As its name indicates, the latter is a read-only version of the main HRFS component. The libraries it provides are smaller as it provides no facilities for disk modifications.

In addition, you need to include the appropriate component for your block device; for example, **INCLUDE_SCSI** or **INCLUDE_ATA**.

Optional HRFS Components

The **INCLUDE_HRFS_FORMAT** component (HRFS formatter) and the **INCLUDE_HRFS_CHKDSK** (HRFS consistency checker) are optional components.

Optional XBD Components

Optional XBD components are:

INCLUDE_XBD_PART_LIB	disk partitioning facilities
INCLUDE_XBD_BLK_DEV	XBD wrapper component for device drivers that have not been ported to XBD.
INCLUDE_XBD_RAMDRV	RAM disk facility

CAUTION: If you are using a device for which the driver has not been ported to XBD, you must use the **INCLUDE_XBD_BLK_DEV** wrapper component in addition to **INCLUDE_XBD**. See the VxWorks Kernel Programmer's Guide: I/O System for more information.

For information about the XBD facility, see the *VxWorks Kernel Programmer's Guide: I/O System*.

7.3.2 Creating an HRFS File System

For information about creating an HRFS file system, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.3.3 Transactionality

HRFS is a transactional based file system. It is transactional on a file or directory basis. This is unlike TRFS where the whole disk is considred.

Transactions are committed to disk automatically when modifying or deleting a file or directory. That is, upon successful completion of a function that modifies the disk means that the modifications are committed. There is no need for application interaction to commit.

Example functions that cause modifications to disk:

- **write( )**
- **remove( )**
- **delete( )**
- **mkdir( )**
- **rmdir( )**
- **link( )**
- **unlink( )**
- **truncate( )**
- **truncated( )**
- **ioctl( )** where the supplied command requires modifying the disk.

7.3.4 Maximum Number of Files and Directories

Files and directories are stored on disk in data structures called inodes. During formatting the maximum number of inodes is specified as a parameter to the formatter. See API reference for more details. This means that the combination of files and directories can never be more than there are inodes. It is fixed at the time of formatting. Trying to create a file or directory when all the inodes are exhausted will generate an error. Deleting a file or directory returns frees its corresponding inode.

7.3.5 Working with Directories

This section discusses creating and removing directories, and reading directory entries.

Creating Subdirectories

You can create as many subdirectories as there are inodes. Subdirectories can be created in the following ways

1. Using **open( )**: To create a directory, the **O_CREAT** option must be set in the flags parameter and the **S_IFDIR** or **FSTAT_DIR** option must be set in the mode parameter. The **open( )** calls returns a file descriptor that describes the new directory. The file descriptor can only be used for reading only and should be closed when no longer needed.
2. Use **mkdir( )**, **usrFsLib**.

When creating a directory using any of the above methods, the new directory name must be specified. This name can be either a full pathname or a pathname relative to the current working directory.

Removing Subdirectories

A directory that is to be deleted must be empty (except for the "**.**" and "**..**" entries). The root directory can never be deleted. Subdirectories can be removed in the following ways:

- Using **ioctl( )** 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.
- Using the **remove( )** function, specifying the name of the directory.
- Use **rmdir( )**, **usrFsLib**.

Reading Directory Entries

You can programmatically search directories on HRFS volumes using the **opendir( )**, **readdir( )**, **rewinddir( )**, and **closedir( )** routines.

To obtain more detailed information about a specific file, use the **fstat( )** or **stat( )** routine. 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 API reference for **dirLib**.

7.3.6 Working with Files

This section discusses file I/O and file attributes.

File I/O Routines

Files on an HRFS file system device are created, deleted, written, and read using the standard VxWorks I/O routines: **creat( )**, **remove( )**, **write( )**, and **read( )**. For more information, see *6.3 Basic I/O*, p.229, and the **ioLib** API references.

Note that **delete( )** and **remove( )** are synonymous with **unlink( )** for HRFS.

File Linking and Unlinking

When a link is created an inode is not used. Another directory entry is created at the location specified by the parameter to **link( )**. In addition, a reference count to the linked file is stored in the file's corresponding inode. When unlinking a file, this reference count is decremented. If the reference count is zero when **unlink( )** is called, the file is deleted except if there are open file descriptors open on the file. In this case the directory entry is removed but the file still exists on the disk. This prevents tasks and processes (RTPs) from opening the file. When the final open file descriptor is closed the file is fully deleted freeing its inode.

Note that you cannot create a link to a subdirectory only to a regular file.

File Permissions

Unlike dosfs, files on HRFS do not have attributes. They instead have POSIX style permission bits. You can change these bits using the **chmod( )** and **fchmod( )** routines. See the API references for more information.

7.3.7 Crash Recovery and Volume Consistency

For detailed information about crash recovery and volume consistence, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.3.8 I/O Control Functions Supported by HRFS

The HRFS file system supports the **ioctl( )** functions. These functions are defined in the header file **ioLib.h** along with their associated constants.

For more information, see the API reference for for **ioctl( )** in **ioLib.**

Table 7-1 **I/O Control Functions Supported by HRFS**

Function	Decimal Value	Description
FIODISKCHANGE	13	Announces a media change.
FIODISKFORMAT	5	Formats the disk (device driver function).
FIODISKINIT	6	Initializes a file system on a disk volume.
FIOFLUSH	2	Flushes the file output buffer.
FIOFSTATGET	38	Gets file status information (directory entry data).
FIOGETNAME	18	Gets the filename of the *fd*.
FIOMOVE	47	Moves a file (does not rename the file).
FIONFREE	30	Gets the number of free bytes on the volume.
FIONREAD	1	Gets the number of unread bytes in a file.
FIOREADDIR	37	Reads the next directory entry.
FIORENAME	10	Renames a file or directory.
FIORMDIR	32	Removes a directory.
FIOSEEK	7	Sets the current byte offset in a file.
FIOSYNC	21	Same as **FIOFLUSH**, but also re-reads buffered file data.
FIOTRUNC	42	Truncates a file to a specified length.
FIOUNMOUNT	39	Un-mounts a disk volume.

Table 7-1 **I/O Control Functions Supported by HRFS** (cont'd)

Function	Decimal Value	Description
FIOWHERE	8	Returns the current byte position in a file.
FIONCONTIG64	50	Gets the maximum contiguous disk space into a 64-bit integer.
FIONFREE64	51	Gets the number of free bytes into a 64-bit integer.
FIONREAD64	52	Gets the number of unread bytes in a file into a 64-bit integer.
FIOSEEK64	53	Sets the current byte offset in a file from a 64-bit integer.
FIOWHERE64	54	Gets the current byte position in a file into a 64-bit integer.
FIOTRUNC64	55	Set the file's size from a 64-bit integer.

7.4 MS-DOS-Compatible File System: dosFs

The dosFs file system is an MS-DOS-compatible file system that offers considerable flexibility appropriate to the multiple demands of real-time applications. The primary features are:

- Hierarchical files and directories, allowing efficient organization and an arbitrary number of files to be created on a volume.
- A choice of contiguous or non-contiguous files on a per-file basis.
- Compatible with widely available storage and retrieval media (diskettes, hard drives, and so on).
- The ability to boot VxWorks from a dosFs file system.
- Support for VFAT (Microsoft VFAT long file names)
- Support for FAT12, FAT16, and FAT32 file allocation table types.

For information about dosFs libraries, see the VxWorks API references for **dosFsLib** and **dosFsFmtLib**.

For information about the MS-DOS file system, please see the Microsoft documentation.

NOTE: The discussion in this chapter of the dosFs file system uses the term *sector* to refer to the minimum addressable unit on a *disk*. This definition of the term follows most MS-DOS documentation. However, in VxWorks, these units on the disk are normally referred to as *blocks*, and a disk device is called a *block device*.

dosFs and Flash Memory

For information about using dosFs with flash memory, see the *VxWorks Kernel Programmer's Guide: Flash File System Support with TrueFFS*.

dosFs and the Transaction-Based Reliable File System Facility

For information about using dosFs with the transaction-based reliable file system (TRFS) facility, see *6.8 Transaction-Based Reliable File System Facility: TRFS*, p.252.

7.4.1 Configuring VxWorks for dosFs

To include dosFs support in VxWorks, configure the kernel with the appropriate required and optional components.

Required Components

The following components are required:

INCLUDE_DOSFS_MAIN	**dosFsLib**
INCLUDE_DOSFS_FAT	dosFs FAT12/16/32 FAT handler
INCLUDE_XBD	XBD component

And, either one or both of the following components are required:

INCLUDE_DOSFS_DIR_VFAT	Microsoft VFAT direct handler
INCLUDE_DOSFS_DIR_FIXED	Strict 8.3 & VxLongNames directory handler

In addition, you need to include the appropriate component for your block device; for example, **INCLUDE_SCSI** or **INCLUDE_ATA**.

Note that you can use **INCLUDE_DOSFS** to automatically include the following components:

- **INCLUDE_DOSFS_MAIN**
- **INCLUDE_DOSFS_DIR_VFAT**
- **INCLUDE_DOSFS_DIR_FIXED**
- **INCLUDE_DOSFS_FAT**
- **INCLUDE_DOSFS_CHKDSK**
- **INCLUDE_DOSFS_FMT**

Optional dosFs Components

The optional dosFs components are:

INCLUDE_DOSFS_CACHE	disk cache facility (for rotational media)
INCLUDE_DOSFS_FMT	dosFs file system formatting module
INCLUDE_DOSFS_CHKDSK	file system integrity checking
INCLUDE_DISK_UTIL	standard file system operations, such as **ls**, **cd**, **mkdir**, **xcopy**, and so on
INCLUDE_TAR	the **tar** utility

Optional XBD Components

Optional XBD components are:

INCLUDE_XBD_PART_LIB	disk partitioning facilities
INCLUDE_XBD_BLK_DEV	XBD wrapper component for device drivers that have not been ported to XBD.
INCLUDE_XBD_TRANS	TRFS support facility
INCLUDE_XBD_RAMDRV	RAM disk facility

CAUTION: If you are using a device for which the driver has not been ported to XBD, you must use the **INCLUDE_XBD_BLK_DEV** wrapper component in addition to **INCLUDE_XBD**. See the VxWorks Kernel Programmer's Guide: I/O System for more information.

For information about the XBD facility, see the *VxWorks Kernel Programmer's Guide: I/O System*.

7.4.2 Creating a dosFs File System

For information about creating a dosFs file system, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.4.3 Working with Volumes and Disks

This section discusses accessing volume configuration information and synchronizing volumes. For information about **ioctl( )** support functions, see *7.4.8 I/O Control Functions Supported by dosFsLib*, p.276.

Accessing Volume Configuration Information

The **dosFsShow( )** routine can be used to display volume configuration information from the shell. The **dosFsVolDescGet( )** routine can be used programmatically obtain or verify a pointer to the **DOS_VOLUME_DESC** structure. For more information, see the API references for these routines.

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, a disk should be synchronized before it is removed. For more information, see the API references for **close( )** and **dosFsVolUnmount( )**.

7.4.4 Working with Directories

This section discusses creating and removing directories, and reading directory entries.

Creating Subdirectories

For FAT32, subdirectories can be created in any directory at any time. For FAT12 and FAT16, subdirectories can be created in any directory at any time, except in the root directory once it reaches its maximum entry count. Subdirectories can be created in the following ways:

1. Using **ioctl( )** with the **FIOMKDIR** function: The name of the directory to be created is passed as a parameter to **ioctl( )**.
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.

3. Use **mkdir( )**, **usrFsLib**.

When creating a directory using any of the above methods, the new directory name must be specified. This name can be either a full pathname or a pathname relative to the current working directory.

Removing Subdirectories

A directory that is to be deleted must be empty (except for the "**.**" and "**..**" entries). The root directory can never be deleted. Subdirectories can be removed in the following ways:

- Using **ioctl( )** 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.
- Using the **remove( )** function, specifying the name of the directory.
- Use **rmdir( )**, **usrFsLib**.

Reading Directory Entries

You can programmatically search directories on dosFs volumes using the **opendir( )**, **readdir( )**, **rewinddir( )**, and **closedir( )** routines.

To obtain more detailed information about a specific file, use the **fstat( )** or **stat( )** routine. 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 API reference for **dirLib**.

7.4.5 Working with Files

This section discusses file I/O and file attributes.

File I/O Routines

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( )**. For more information, see *6.3 Basic I/O*, p.229, and the **ioLib** API references.

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 7-2.

Table 7-2 **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
If this flag is set, files accessed with **open( )** cannot be written to. If the **O_WRONLY** or **O_RDWR** flags are set, **open( )** returns **ERROR**, setting **errno** to **S_dosFsLib_READ_ONLY**.

DOS_ATTR_HIDDEN
This flag is ignored by **dosFsLib** and produces no special handling. For example, entries with this flag are reported when searching directories.

DOS_ATTR_SYSTEM
This flag is ignored by **dosFsLib** and produces no special handling. For example, entries with this flag are reported when searching directories.

DOS_ATTR_VOL_LABEL
This is a volume label flag, which 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.

DOS_ATTR_DIRECTORY
This is a directory flag, which indicates that this entry is a subdirectory, and not a regular file.

DOS_ATTR_ARCHIVE
This is an archive flag, which 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 7-1 **Setting DosFs File Attributes**

This example makes a dosFs file read-only, and leaves other attributes intact.

```
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);
return (OK);
}
```

NOTE: You can also use the **attrib( )** routine to change file attributes. For more information, see the entry in **usrFsLib**.

7.4.6 Disk Space Allocation Options

The dosFs file system allocates disk space using one of the following methods. The first two methods are selected based upon the size of the write operation. The last method must be manually specified.

- **single cluster allocation**

  Single cluster allocation uses a single cluster, which is the minimum allocation unit. This method is automatically used when the write operation is smaller than the size of a single cluster.

- **cluster group allocation (nearly contiguous)**

  Cluster group allocation uses adjacent (contiguous) groups of clusters, called *extents*. Cluster group allocation is nearly contiguous allocation and is the default method used when files are written in units larger than the size of a disk's cluster.

- **absolutely contiguous allocation**

  Absolutely contiguous allocation uses only absolutely contiguous clusters. Because this type of allocation is dependent upon the existence of such space, it is specified under only two conditions: immediately after a new file is created and when reading from a file assumed to have been allocated to a contiguous space. Using this method risks disk fragmentation.

For any allocation method, you can deallocate unused reserved bytes by using the POSIX-compatible routine **ftruncate( )** or the **ioctl( )** function **FIOTRUNC**.

Choosing an Allocation Method

Under most circumstances, cluster group allocation is preferred to absolutely contiguous file access. Because it is nearly contiguous file access, it achieves a nearly optimal access speed. Cluster group allocation also significantly minimizes the risk of fragmentation posed by absolutely contiguous allocation.

Absolutely contiguous allocation attains raw disk throughput levels, however this speed is only slightly faster than nearly contiguous file access. Moreover, fragmentation is likely to occur over time. This is because after a disk has been in use for some period of time, it becomes impossible to allocate contiguous space. Thus, there is no guarantee that new data, appended to a file created or opened with absolutely continuous allocation, will be contiguous to the initially written data segment.

It is recommended that for a performance-sensitive operation, the application regulate disk space utilization, limiting it to 90% of the total disk space. Fragmentation is unavoidable when filling in the last free space on a disk, which has a serious impact on performance.

Using Cluster Group Allocation

The dosFs file system defines the size of a cluster group based on the media's physical characteristics. That size is fixed for each particular media. Since seek operations are an overhead that reduces performance, it is desirable to arrange files so that sequential portions of a file are located in physically contiguous disk clusters. Cluster group allocation occurs when the cluster group size is considered sufficiently large so that the seek time is negligible compared to the **read**/**write** time. This technique is sometimes referred to as *nearly contiguous* file access because seek time between consecutive cluster groups is significantly reduced.

Because all large files on a volume are expected to have been written as a group of extents, removing them frees a number of extents to be used for new files subsequently created. Therefore, as long as free space is available for subsequent file storage, there are always extents available for use. Thus, cluster group allocation effectively prevents *fragmentation* (where a file is allocated in small units spread across distant locations on the disk). Access to fragmented files can be extremely slow, depending upon the degree of fragmentation.

Using Absolutely Contiguous Allocation

A contiguous file is made up of a series of consecutive disk sectors. Absolutely contiguous allocation is intended to allocate contiguous space to a specified file (or directory) and, by so doing, optimize access to that file. You can specify absolutely contiguous allocation either when creating a file, or when opening a file previously created in this manner.

For more information on the **ioctl( )** functions, see *7.4.8 I/O Control Functions Supported by dosFsLib*, p.276.

Allocating Contiguous Space for a File

To allocate a contiguous area to a newly created file, follow these steps:

1. First, create the file in the normal fashion using **open( )** or **creat( )**.
2. Then, call **ioctl( )**. Use the file descriptor returned from **open( )** or **creat( )** as the file descriptor argument. Specify **FIOCONTIG** as the function code argument and the size of the requested contiguous area, in bytes, as the third argument.

The FAT is then searched for a suitable section of the disk. If found, this space is assigned to the new file. The file can then be closed, or it can be used for further I/O operations. The file descriptor used for calling **ioctl( )** should be the only descriptor open to the file. Always perform the **ioctl( ) FIOCONTIG** operation before writing any data to the file.

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);
```

Allocating Space for Subdirectories

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 subsequently 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.

Opening and Using a Contiguous File

Fragmented files require following cluster chains in the FAT. However, if a file is recognized as contiguous, the system can use an enhanced method that improves performance. This applies to all contiguous files, whether or not they were explicitly created using **FIOCONTIG**. Whenever a file is opened, it is checked for contiguity. If it is found to be contiguous, the file system registers the necessary information about that file to avoid the need for subsequent access to the FAT table. This enhances performance when working with the file by eliminating seek operations.

When you are opening a contiguous file, you can explicitly indicate that the file is contiguous by specifying the **DOS_O_CONTIG_CHK** flag with **open( )**. This prompts the file system to retrieve the section of contiguous space, allocated for this file, from the FAT table.

To find the maximum contiguous area on a device, you can use the **ioctl( )** function **FIONCONTIG**. This information can also be displayed by **dosFsConfigShow( )**.

Example 7-2 **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*).

```
STATUS contigTest
    (
    void                    /* no argument */
    )
    {
    int count;              /* size of maximum contiguous area in bytes */
    int fd;                 /* file descriptor */

    /* 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);
    return (OK);
    }
```

7.4.7 Crash Recovery and Volume Consistency

For information about crash recovery and volume consistence, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.4.8 I/O Control Functions Supported by dosFsLib

The dosFs file system supports the **ioctl( )** functions. These functions are defined in the header file **ioLib.h** along with their associated constants.

For more information, see the API references for **dosFsLib** and for **ioctl( )** in **ioLib.**

Table 7-3 **I/O Control Functions Supported by dosFsLib**

Function	Decimal Value	Description
FIOATTRIBSET	35	Sets the file-attribute byte in the dosFs directory entry.
FIOCONTIG	36	Allocates contiguous disk space for a file or directory.
FIODISKCHANGE	13	Announces a media change.
FIODISKFORMAT	5	Formats the disk (device driver function).
FIODISKINIT	6	Initializes a dosFs file system on a disk volume.
FIOFLUSH	2	Flushes the file output buffer.
FIOFSTATGET	38	Gets file status information (directory entry data).
FIOGETNAME	18	Gets the filename of the *fd*.
FIOLABELGET	33	Gets the volume label.
FIOLABELSET	34	Sets the volume label.
FIOMKDIR	31	Creates a new directory.
FIOMOVE	47	Moves a file (does not rename the file).
FIONCONTIG	41	Gets the size of the maximum contiguous area on a device.
FIONFREE	30	Gets the number of free bytes on the volume.

Table 7-3 **I/O Control Functions Supported by dosFsLib** (cont'd)

Function	Decimal Value	Description
FIONREAD	1	Gets the number of unread bytes in a file.
FIOREADDIR	37	Reads the next directory entry.
FIORENAME	10	Renames a file or directory.
FIORMDIR	32	Removes a directory.
FIOSEEK	7	Sets the current byte offset in a file.
FIOSYNC	21	Same as **FIOFLUSH**, but also re-reads buffered file data.
FIOTRUNC	42	Truncates a file to a specified length.
FIOUNMOUNT	39	Un-mounts a disk volume.
FIOWHERE	8	Returns the current byte position in a file.
FIOCONTIG64	49	Allocates contiguous disk space using a 64-bit size.
FIONCONTIG64	50	Gets the maximum contiguous disk space into a 64-bit integer.
FIONFREE64	51	Gets the number of free bytes into a 64-bit integer.
FIONREAD64	52	Gets the number of unread bytes in a file into a 64-bit integer.
FIOSEEK64	53	Sets the current byte offset in a file from a 64-bit integer.
FIOWHERE64	54	Gets the current byte position in a file into a 64-bit integer.
FIOTRUNC64	55	Set the file's size from a 64-bit integer.

7.4.9 Booting from a Local dosFs File System Using SCSI

For information about booting from a local dosFs file system using SCSI, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.5 Raw File System: rawFs

VxWorks provides a *raw file system* (rawFs) for use in systems that require only the most basic disk I/O functions. The rawFs file system, implemented with **rawFsLib**, treats the entire disk volume much like a single large file.

Although the dosFs file system provides this ability to varying degrees, the rawFs file system offers advantages in size and performance if more complex functions are not required.

The rawFs file system imposes no organization of the data on the disk. It maintains no directory information; and there is therefore no division of the disk area into specific files. All **open( )** operations on rawFs devices specify only the device name; no additional filenames are possible.

The entire disk area is treated as a single file and 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.

A rawFs file system is created by default if inserted media does not contain a recognizable file system.

7.5.1 Configuring VxWorks for rawFs

To use the rawFs file system, configure VxWorks with the **INCLUDE_RAWFS** and **INCLUDE_XBD** components.

CAUTION: If you are using a device for which the driver has not been ported to XBD, you must use the **INCLUDE_XBD_BLK_DEV** wrapper component in addition to **INCLUDE_XBD**. See the VxWorks Kernel Programmer's Guide: I/O System for more information.

Set the **NUM_RAWFS_FILES** parameter of the **INCLUDE_RAWFS** component to the desired maximum open file descriptor count. For information about using multiple file descriptors with what is essentially a single large file, see *7.5.4 rawFs File I/O*, p.279.

7.5.2 Creating a rawFs File System

For information about creating a rawFs file system, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.5.3 Mounting rawFs 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.

⚠ **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 or unexpected results may occur.

7.5.4 rawFs File I/O

To begin I/O operations upon a rawFs device, first open the device using the standard **open( )** routine (or the **creat( )** routine). Data on the rawFs device is written and read using the standard I/O routines **write( )** and **read( )**. For more information, see *6.3 Basic I/O*, p.229.

The character pointer associated with a file descriptor (that is, the byte offset where the read and write operations 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.

7.5.5 I/O Control Functions Supported by rawFsLib

The rawFs file system supports the **ioctl( )** functions shown in Table 7-4. The functions listed are defined in the header file **ioLib.h**. For more information, see the API references for **rawFsLib** and for **ioctl( )** in **ioLib**.

Table 7-4 **I/O Control Functions Supported by rawFsLib**

Function	Decimal Value	Description
FIODISKCHANGE	13	Announces a media change.
FIODISKFORMAT	5	Formats the disk (device driver function).

Table 7-4 **I/O Control Functions Supported by rawFsLib** (cont'd)

Function	Decimal Value	Description
FIOFLUSH	2	Same as **FIOSYNC**.
FIOGETNAME	18	Gets the device name of the *fd*.
FIONREAD	1	Gets the number of unread bytes on the device.
FIOSEEK	7	Sets the current byte offset on the device.
FIOSYNC	21	Writes out all modified file descriptor buffers.
FIOUNMOUNT	39	Un-mounts a disk volume.
FIOWHERE	8	Returns the current byte position on the device.

7.6 CD-ROM File System: cdromFs

The VxWorks CD-ROM file system, cdromFs allows applications to read data from CDs formatted according to the ISO 9660 standard file system with or without the Joliet extensions. This section describes how cdromFs is organized, configured, and used.

The cdromFs library, **cdromFsLib**, lets applications read any CD-ROMs, CD-Rs, or CD-RWs (collectively called CDs) that are formatted in accordance with the ISO 9660 file system standard, with or without the Joliet extensions. ISO 9660 interchange level 3, implementation level 2, is supported. Note that multi-extent files, interleaved files, and files with extended attribute records are supported.

The following CD features and ISO 9660 features are not supported:

- Multi-volume sets
- Record format files
- CDs with a sector size that is not a power of two[1]
- Multi-session CD-R or CD-RW[2]

1. Therefore, mode 2/form 2 sectors are not supported, as they have 2324 bytes of user data per sector. Both mode 1/form 1 and mode 2/form 1 sectors are supported, as they have 2048 bytes of user data per sector.

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 forward slashes (/) and back slashes (\) as path delimiters. However, the backslash is not recommended because it might not be supported in future releases.

cdromFs provides access to CD file systems using any standard **BLK_DEV** structure. The basic initialization sequence is similar to installing a dosFs file system on a SCSI or ATA device, with a few significant differences: Create the CD file system device directly on the **BLK_DEV**. CBIO drivers are not used.

After you have created the CD file system device (*7.6.2 Creating and Using cdromFs*, p.282), use **ioctl( )** to set file system options. The files system options are described below:

CDROMFS_DIR_MODE_SET/GET
These options set and get the directory mode. The directory mode controls whether a file is opened with the Joliet extensions, or without them. The directory mode can be set to any of the following:

MODE_ISO9660
Do not use the Joliet extensions.

MODE_JOLIET
Use the Joliet extensions.

MODE_AUTO
Try opening the directory first without Joliet, and then with Joliet.

CAUTION: Changing the directory mode un-mounts the file system. Therefore, any open file descriptors are marked as obsolete.

CDROMFS_STRIP_SEMICOLON
This option sets the **readdir( )** strip semicolon setting to **FALSE** if *arg* is 0, and to **TRUE** otherwise. If **TRUE**, **readdir( )** removes the semicolon and following version number from the directory entries retrieved.

CDROMFS_GET_VOL_DESC
This option returns, in *arg*, the primary or supplementary volume descriptor by which the volume is mounted. *arg* must be of type **T_ISO_PVD_SVD_ID**, as

2. The first session (that is, the earliest session) is always read. The most commonly desired behavior is to read the last session (that is, the latest session).

defined in **cdromFsLib.h**. The result is the volume descriptor, adjusted for the endianness of the processor (not the raw volume descriptor from the CD). This result can be used directly by the processor. The result also includes some information not in the volume descriptor, such as which volume descriptor is in use.

For information on using **cdromFs( )**, see the API reference for **cdromFsLib**.

7.6.1 Configuring VxWorks for cdromFs

To configure VxWorks with cdromFs, add the **INCLUDE_CDROMFS** and **INCLUDE_XBD** components to the kernel. Add other required components (such as SCSI or ATA) depending on the type of device).

⚠ **CAUTION:** If you are using a device for which the driver has not been ported to XBD, you must use the **INCLUDE_XBD_BLK_DEV** wrapper component in addition to **INCLUDE_XBD**. See the VxWorks Kernel Programmer's Guide: I/O System for more information.

If you are using an ATAPI device, make appropriate modifications to the **ataDrv**, **ataResources[ ]** structure array (if needed). This must be configured appropriately for your hardware platform.

7.6.2 Creating and Using cdromFs

For information about creating and using a CD block device, see *VxWorks Kernel Programmer's Guide: Local File Systems*.

7.6.3 I/O Control Functions Supported by cdromFsLib

The cdromFs file system supports the **ioctl( )** functions. These functions, and their associated constants, are defined in the header files **ioLib.h** and **cdromFsLib.h**.

Table 7-5 describes the **ioctl( )** functions that **cdromFsLib** supports. For more information, see the API references for **cdromFsLib** and for **ioctl( )** in **ioLib**.

Table 7-5 **ioctl( ) Functions Supported by cdromFsLib**

Function Constant	Decimal	Description
CDROMFS_DIR_MODE_GET	7602176	Gets the volume descriptor(s) used to open files.
CDROMFS_DIR_MODE_SET	7602177	Sets the volume descriptor(s) used to open files.
CDROMFS_GET_VOL_DESC	7602179	Gets the volume descriptor that is currently in use.
CDROMFS_STRIP_SEMICOLON	7602178	Sets the **readdir( )** strip version number setting.
FIOFSTATGET	38	Gets file status information (directory entry data).
FIOGETNAME	18	Gets the filename of the file descriptor.
FIOLABELGET	33	Gets the volume label.
FIONREAD	1	Gets the number of unread bytes in a file.
FIONREAD64	52	Gets the number of unread bytes in a file (64-bit version).
FIOREADDIR	37	Reads the next directory entry.
FIOSEEK	7	Sets the current byte offset in a file.
FIOSEEK64	53	Sets the current byte offset in a file (64-bit version).
FIOUNMOUNT	39	Un-mounts a disk volume.
FIOWHERE	8	Returns the current byte position in a file.
FIOWHERE64	54	Returns the current byte position in a file (64-bit version).

7.6.4 Version Numbers

cdromFsLib has a 4-byte version number. The version number is composed of four parts, from most significant byte to least significant byte:

- major number
- minor number
- patch level
- build

The version number is returned by **cdromFsVersionNumGet( )** and displayed by **cdromFsVersionNumDisplay( )**.

7.7 Read-Only Memory File System: ROMFS

ROMFS is a simple, read-only file system that represents and stores files and directories in a linear way (similar to the tar utility). It is installed in RAM with the VxWorks system image at boot time. The name ROMFS stands for *Read Only Memory File System*; it does not imply any particular relationship to ROM media.

ROMFS provides the ability to bundle VxWorks applications—or any other files for that matter—with the operating system. No local disk or network connection to a remote disk is required for executables or other files. When VxWorks is configured with the ROMFS component, files of any type can be included in the operating system image simply by adding them to a ROMFS directory on the host system, and then rebuilding VxWorks. The build produces a single system image that includes both the VxWorks and the files in the ROMFS directory.

When VxWorks is booted with this image, the ROMFS file system and the files it holds are loaded with the kernel itself. ROMFS allows you to deploy files and operating system as a unit. In addition, process-based applications can be coupled with an automated startup facility so that they run automatically at boot time. ROMFS thereby provides the ability to create fully autonomous, multi-process systems.

ROMFS can also be used to store applications that are run interactively for diagnostic purposes, or for applications that are started by other applications under specific conditions (errors, and so on).

7.7.1 Configuring VxWorks with ROMFS

VxWorks must be configured with the **INCLUDE_ROMFS** component to provide ROMFS facilities.

7.7.2 Building a System With ROMFS and Files

Configuring VxWorks with ROMFS and applications involves several simple steps:

1. A ROMFS directory must be created in the project directory on the host system, using the name **/romfs**.
2. Application files must be copied into the directory.
3. VxWorks must be rebuilt.

For example, adding a process-based application called **myVxApp.vxe** from the command line would look like this:

```
cd c:\myInstallDir\vxworks-6.1\target\proj\wrSbc8260_diab
mkdir romfs
copy c:\allMyVxApps\myVxApp.vxe romfs
make TOOL=diab
```

The contents of the **romfs** directory are automatically built into a ROMFS file system and combined with the VxWorks image.

The ROMFS directory does not need to be created in the VxWorks project directory. It can also be created in any location on (or accessible from) the host system, and the **make** utility's **ROMFS_DIR** macro used to identify where it is in the build command. For example:

```
make TOOL=diab ROMFS_DIR="c:\allMyVxApps"
```

Note that any files located in the **romfs** directory are included in the system image, regardless of whether or not they are application executables.

7.7.3 Accessing Files in ROMFS

At runtime, the ROMFS file system is accessed as **/romfs**. The content of the ROMFS directory can be browsed using the **ls** and **cd** shell commands, and accessed programmatically with standard file system routines, such as **open( )** and **read( )**.

For example, if the directory *installDir*/**vxworks-6.***x*/**target/proj/wrSbc8260_diab/romfs** has been created on the host, the file **foo** copied to it, and the system rebuilt and booted; then using **cd** and **ls** from the shell (with the command interpreter) looks like this:

```
[vxWorks *]# cd /romfs
[vxWorks *]# ls
.
..
foo
[vxWorks *]#
```

And **foo** can also be accessed at runtime as **/romfs/foo** by any applications running on the target.

7.7.4 Using ROMFS to Start Applications Automatically

ROMFS can be used with various startup mechanisms to start process-based applications automatically when VxWorks boots.

See *2.8.4 Using ROMFS to Start Applications Automatically*, p.73 for more information.

7.8 Target Server File System: TSFS

The Target Server File System (TSFS) is designed for development and diagnostic purposes. It is a full-featured VxWorks file system, but the files are actually located on the host system.

The TSFS provides all of the I/O features of the network driver for remote file access (**netDrv**; see *6.7.5 Non-NFS Network Devices*, p.250), without requiring any target resources—except those required for communication between the target system and the target server on the host. The TSFS uses a WDB target agent driver to transfer requests from the VxWorks I/O system to the target server. The target server reads the request and executes it using the host file system. When you open a file with TSFS, the file being opened is actually on the host. Subsequent **read( )** and **write( )** calls on the file descriptor obtained from the **open( )** call read from and write to the opened host file.

The TSFS VIO driver is oriented toward file I/O rather than toward console operations. 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 filename to routines such as **ld( )** and **copy( )**.

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, see the API reference for **wdbTsfsDrv**.

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. The **ioctl( )** usage specific to TSFS sockets is discussed in the API reference for **wdbTsfsDrv**. This socket configuration allows VxWorks 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**.

Configuring VxWorks for TSFS Use

To use TSFS, configure VxWorks with the **INCLUDE_WDB_TSFS** component. This creates the **/tgtsvr** file system on the target.

The target server on the host system must also be configured for TSFS. This involves assigning a root directory on your host to TSFS (see the discussion of the target server **-R** option in *Security Considerations*, p.288). For example, on a PC host you could set the TSFS root to **c:\myTarget\logs**.

Having done so, opening the file **/tgtsvr/logFoo** on the target causes **c:\myTarget\logs\logFoo** 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.

Security Considerations

While TSFS has much in common with **netDrv**, the security considerations are different (also see *6.7.5 Non-NFS Network Devices*, p.250). 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. By default, any host 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. However, the target server can be locked (with the **-L** option) to restrict access to the TSFS.

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 filenames 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 modifications are allowed.

NOTE: For more information about the target server and the TSFS, see the **tgtsvr** command reference. For information about specifying target server options from the IDE, see the host development environment documentation.

Using the TSFS to Boot a Target

For information about using the TSFS to boot a targets, see *VxWorks Kernel Programmer's Guide: Kernel*.

8

Error Detection and Reporting

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8.1 Introduction

VxWorks provides an error detection and reporting facility to help debug software faults. It does so by recording software exceptions in a specially designated area of memory that is not cleared between warm reboots. The facility also allows for selecting system responses to fatal errors, with alternate strategies for development and deployed systems.

The key features of the error detection and reporting facility are:

- A persistent memory region in RAM used to retain error records across warm reboots.
- Mechanisms for recording various types of error records.
- Error records that provide detailed information about runtime errors and the conditions under which they occur.
- The ability to display error records and clear the error log from the shell.
- Alternative error-handing options for the system's response to fatal errors.
- Macros for implementing error reporting in user code.

For more information about error detection and reporting routines in addition to that provided in this chapter, see the API reference for **edrLib**. Also see the *VxWorks Kernel Programmer's Guide: Error Detection and Reporting* for information about facilities available only in the kernel.

For information about related facilities, see *5.5 Memory Error Detection*, p.212.

NOTE: This chapter provides information about facilities available for real-time processes. For information about facilities available in the VxWorks kernel, see the corresponding chapter in the *VxWorks Kernel Programmer's Guide*.

8.2 Configuring Error Detection and Reporting Facilities

To use the error detection and reporting facilities:

- VxWorks must be configured with the appropriate components.
- A persistent RAM memory region must be configured, and it must be sufficiently large to hold the error records.
- Optionally, users can change the system's default response to fatal errors.

8.2.1 Configuring VxWorks

To use the error detection and reporting facility, the kernel must be configured with the following components:

- **INCLUDE_EDR_PM**
- **INCLUDE_EDR_ERRLOG**
- **INCLUDE_EDR_SHOW**
- **INCLUDE_EDR_SYSDBG_FLAG**

8.2.2 Configuring the Persistent Memory Region

The persistent-memory region is an area of RAM at the top of system memory specifically reserved for an error records. It is protected by the MMU and the VxWorks **vmLib** facilities. The memory is not cleared by warm reboots, provided a VxWorks 6.*x* boot loader is used.

A cold reboot always clears the persistent memory region. The **pmInvalidate( )** routine can also be used to explicitly destroy the region (making it unusable) so that it is recreated during the next warm reboot.

The persistent-memory area is write-protected when the target system includes an MMU and VxWorks has been configured with MMU support.

The size of the persistent memory region is defined by the **PM_RESERVED_MEM** configuration parameter. By default the size is set to six pages of memory.

By default, the error detection and reporting facility uses one-half of whatever persistent memory is available. If no other applications require persistent memory, the component may be configured to use almost all of it. This can be accomplished by defining **EDR_ERRLOG_SIZE** to be the size of **PM_RESERVED_MEM** less the size of one page of memory.

If you increase the size of the persistent memory region beyond the default, you must create a new boot loader with the same **PM_RESERVED_MEM** value. The memory area between **RAM_HIGH_ADRS** and **sysMemTop( )** must be big enough to copy the VxWorks boot loader. If it exceeds the **sysMemTop( )** limit, the boot loader may corrupt the area of persistent memory reserved for core dump storage when it loads VxWorks. The boot loader, must therefore be rebuilt with a lower **RAM_HIGH_ADRS** value.

WARNING: If the boot loader is not properly configured (as described above), this could lead into corruption of the persistent memory region when the system boots.

The **EDR_RECORD_SIZE** parameter can be used to change the default size of error records. Note that for performance reasons, all records are necessarily the same size.

The **pmShow( )** shell command (for the C interpreter) can be used to display the amount of allocated and free persistent memory.

For more information about persistent memory, see the *VxWorks Kernel Programmer's Guide: Memory Management*, and the **pmLib** API reference.

WARNING: A VxWorks 6.*x* boot loader must be used to ensure that the persistent memory region is not cleared between warm reboots. Prior versions of the boot loader may clear this area.

8.2.3 Configuring Responses to Fatal Errors

The error detection and reporting facilities provide for two sets of responses to fatal errors. See *8.5 Fatal Error Handling Options*, p.297 for information about these responses, and various ways to select one for a runtime system.

8.3 Error Records

Error records are generated automatically when the system experiences specific kinds of faults. The records are stored in the persistent memory region of RAM in a circular buffer. Newer records overwrite older records when the persistent memory buffer is full.

The records are classified according to two basic criteria:

- event type
- severity level

The event type identifies the context in which the error occurred (during system initialization, or in a process, and so on).

The severity level indicates the seriousness of the error. In the case of fatal errors, the severity level is also associated with alternative system's responses to the error (see *8.5 Fatal Error Handling Options*, p.297).

The event types are defined in Table 8-1, and the severity levels in Table 8-2.

Table 8-1 **Event Types**

Type	Description
INIT	System initialization events.
BOOT	System boot events.
REBOOT	System reboot (warm boot) events.
KERNEL	VxWorks kernel events.
INTERRUPT	Interrupt handler events.
RTP	Process environment events.
USER	Custom events (user defined).

Table 8-2 **Severity Levels**

Severity Level	Description
FATAL	Fatal event.
NONFATAL	Non-fatal event.
WARNING	Warning event.
INFO	Informational event.

The information collected depends on the type of events that occurs. In general, a complete fault record is recorded. For some events, however, portions of the

record are excluded for clarity. For example, the record for boot and reboot events exclude the register portion of the record.

Error records hold detailed information about the system at the time of the event. Each record includes the following generic information:

- date and time the record was generated
- type and severity
- operating system version
- task ID
- process ID, if the failing task in a process
- task name
- process name, if the failing task is in a process
- source file and line number where the record was created
- a free form text message

It also optionally includes the following architecture-specific information:

- memory map
- exception information
- processor registers
- disassembly listing (surrounding the faulting address)
- stack trace

8.4 Displaying and Clearing Error Records

The **edrShow** library provides a set of commands for the shell's C interpreter that are used for displaying the error records created since the persistent memory region was last cleared. See Table 8-3.

Table 8-3 **Shell Commands for Displaying Error Records**

Command	Action
edrShow( )	Show all records.
edrFatalShow( )	Show only **FATAL** severity level records.
edrInfoShow( )	Show only **INFO** severity level records.
edrKernelShow( )	Show only **KERNEL** event type records.

Table 8-3 **Shell Commands for Displaying Error Records** (cont'd)

Command	Action
edrRtpShow( )	Show only **RTP** (process) event type records.
edrUserShow( )	Show only **USER** event type records.
edrIntShow( )	Show only **INTERRUPT** event type records.
edrInitShow( )	Show only **INIT** event type records.
edrBootShow( )	Show only **BOOT** event type records.
edrRebootShow( )	Show only **REBOOT** event type records.

The shell's command interpreter provides comparable commands. See the API references for the shell, or use the **help edr** command.

In addition to displaying error records, each of the show commands also displays the following general information about the error log:

- total size of the log
- size of each record
- maximum number of records in the log
- the CPU type
- a count of records missed due to no free records
- the number of active records in the log
- the number of reboots since the log was created

See the **edrShow** API reference for more information.

8.5 Fatal Error Handling Options

In addition to generating error records, the error detection and reporting facility provides for two modes of system response to fatal errors for each event type:

- debug mode, for lab systems (development)
- deployed mode, for production systems (field)

The difference between these modes is in their response to fatal errors in processes (RTP events). In debug mode, a fatal error in a process results in the process being

stopped. In deployed mode, as fatal error in a process results in the process being terminated.

The operative error handling mode is determined by the system debug flag (see *8.5.2 Setting the System Debug Flag*, p.299). The default is deployed mode.

Table 8-4 describes the responses in each mode for each of the event types. It also lists the routines that are called when fatal records are created.

The error handling routines are called response to certain fatal errors. Only fatal errors—and no other event types—have handlers associated with them. These handlers are defined in *installDir*/**vxworks-6.***x*/**target/config/comps/src/edrStub.c**. Developers can modify the routines in this file to implement different system responses to fatal errors. The names of the routines, however, cannot be changed.

Table 8-4 **FATAL Error-Handling Options**

Event Type	Debug Mode	Deployed Mode (default)	Error Handling Routine
INIT	Reboot	Reboot	**edrInitFatalPolicyHandler( )**
KERNEL	Stop failed task	Stop failed task	**edrKernelFatalPolicyHandler( )**
INTERRUPT	Reboot	Reboot	**edrInterruptFatalPolicyHandler( )**
RTP	Stop process	Delete process	**edrRtpFatalPolicyHandler( )**

Note that when the debugger is attached to the target, it gains control of the system before the error-handling option is invoked, thus allowing the system to be debugged even if the error-handling option calls for a reboot.

8.5.1 Configuring VxWorks with Error Handling Options

In order to provide the option of debug mode error handling for fatal errors, VxWorks must be configured with the **INCLUDE_EDR_SYSDBG_FLAG** component, which it is by default. The component allows a system debug flag to be used to select debug mode, as well as reset to deployed mode (see *8.5.2 Setting the System Debug Flag*, p.299). If **INCLUDE_EDR_SYSDBG_FLAG** is removed from VxWorks, the system defaults to deployed mode (see Table 8-4).

8.5.2 Setting the System Debug Flag

How the error detection and reporting facility responds to fatal errors, beyond merely recording the error, depends on the setting of the system debug flag. When the system is configured with the **INCLUDE_EDR_SYSDBG_FLAG** component, the flag can be used to set the handling of fatal errors to either debug mode or deployed mode (the default).

For systems undergoing development, it is obviously desirable to leave the system in a state that can be more easily debugged; while in deployed systems, the aim is to have them recover as best as possible from fatal errors and continue operation.

The debug flag can be set in any of the following ways:

- Statically, with boot loader configuration.
- Interactively, at boot time.

When a system boots, the banner displayed on the console displays information about the mode defined by the system debug flag. For example:

```
ED&R Policy Mode: Deployed
```

The modes are identified as **Debug**, **Deployed**, or **Permanently Deployed**. The latter indicates that the **INCLUDE_EDR_SYSDBG_FLAG** component is not included in the system, which means that the mode is deployed and that it cannot be changed to debug.

Setting the Debug Flag Statically

The system can be set to either debug mode or deployed mode with the **f** boot loader parameter when a boot loader is configured and built. The value of 0x000 is used to select deployed mode. The value of 0x400 is used to select debug mode. By default, it is set to deployed mode.

To change the default behavior when configuring a new system, change the **f** parameter in the **DEFAULT_BOOT_LINE** definition in *installDir***/target/config/***bspName***/config.h**, which looks like this:

```
#define DEFAULT_BOOT_LINE BOOT_DEV_NAME \
"(0,0)wrSbc8260:vxworks " \
"e=192.168.100.51 " \
"h=192.168.100.155 " \
"g=0.0.0.0 " \
"u=anonymous pw=user " \
"f=0x00 tn=wrSbc8260"
```

For information about configuring and building boot loaders, see the *VxWorks Kernel Programmer's Guide: Kerne*l.

Setting the Debug Flag Interactively

To change the system debug flag interactively, stop the system when it boots. Then use the **c** command at the boot-loader command prompt. Change the value of the the **f** parameter: use 0x000 for deployed mode (the default) or to 0x400 for debug mode.

8.6 Other Error Handling Options for Processes

By default, any faults generated by a process are handled by the error detection and reporting facility.

A process can, however, handle its own faults by installing an appropriate signal handler in the process. If a signal handler is installed (for example, **SIGSEGV** or **SIGBUS**), the signal handler is run instead of an error record being created and an error handler being called. The signal handler may pass control to the facility if it chooses to by using the **edrErrorInject( )** system call.

For more information about signals, see *3.3.10 Signals*, p.143.

8.7 Using Error Reporting APIs in Application Code

The **edrLib.h** file provides a set of convenient macros that developers can use in their source code to generate error messages (and responses by the system to fatal errors) under conditions of the developers choosing.

The macros have no effect if VxWorks has not been configured with error detection and reporting facilities. Code does not, therefore, need to be conditionally compiled to make use of these facilities.

The **edrLib.h** file is in *installDir*/**vxworks-6.***x*/**target/usr/h**

The following macros are provided:

EDR_USER_INFO_INJECT (trace, msg)
Creates a record in the error log with an event type of USER and a severity of INFO.

EDR_USER_WARNING_INJECT (trace, msg)
Creates a record in the error log with event type of USER and a severity of WARNING.

EDR_USER_FATAL_INJECT (trace, msg)
Creates a record in the error log with event type of USER and a severity of FATAL.

All the macros use the same parameters. The *trace* parameter is a boolean value indicating whether or not a traceback should be generated for the record. The *msg* parameter is a string that is added to the record.

8.8 Sample Error Record

The following is an example of a record generated by a failed process task:

```
==[1/1]============================================================
Severity/Facility:   FATAL/RTP
Boot Cycle:          1
OS Version:          6.0.0
Time:                THU JAN 01 05:21:16 1970 (ticks = 1156617)
Task:                "tInitTask" (0x006f4010)
RTP:                 "edrdemo.vxe" (0x00634048)
RTP Address Space:   0x10226000 -> 0x10254000
Injection Point:     rtpSigLib.c:4893

Default Signal Handling : Abnormal termination of RTP edrdemo.vxe (0x634048)

<<<<<Memory Map>>>>>

0x00100000 -> 0x002a48dc: kernel
0x10226000 -> 0x10254000: RTP

<<<<<Registers>>>>>

r0         = 0x10226210   sp         = 0x10242f70   r2         = 0x10238e30
r3         = 0x00000037   r4         = 0x102440e8   r5         = 0x10244128
r6         = 0x00000000   r7         = 0x10231314   r8         = 0x00000000
r9         = 0x10226275   r10        = 0x0000000c   r11        = 0x0000000c
r12        = 0x00000000   r13        = 0x10239470   r14        = 0x00000000
r15        = 0x00000000   r16        = 0x00000000   r17        = 0x00000000
r18        = 0x00000000   r19        = 0x00000000   r20        = 0x00000000
r21        = 0x00000000   r22        = 0x00000000   r23        = 0x00000000
r24        = 0x00000000   r25        = 0x00000000   r26        = 0x00000000
r27        = 0x00000002   r28        = 0x10242f9c   r29        = 0x10242fa8
r30        = 0x10242fac   r31        = 0x50000000   msr        = 0x0000f032
lr         = 0x10226210   ctr        = 0x0024046c   pc         = 0x10226214
cr         = 0x80000080   xer        = 0x20000000   pgTblPtr   = 0x00740000
scSrTblPtr = 0x0064ad04   srTblPtr   = 0x0064acc4

<<<<<Disassembly>>>>>

 0x102261f4  48003559    bl          0x1022974c # strtoul
 0x102261f8  3be30000    addi        r31,r3,0x0 # 0
 0x102261fc  3c601022    lis         r3,0x1022 # 4130
 0x10226200  38636244    addi        r3,r3,0x6244 # 25156
 0x10226204  389f0000    addi        r4,r31,0x0 # 0
 0x10226208  4cc63182    crxor       crb6,crb6,crb6
 0x1022620c  48002249    bl          0x10228454 # printf
 0x10226210  39800000    li          r12,0x0 # 0
*0x10226214  999f0000    stb         r12,0(r31)
 0x10226218  48000014    b           0x1022622c # 0x1022622c
 0x1022621c  3c601022    lis         r3,0x1022 # 4130
 0x10226220  38636278    addi        r3,r3,0x6278 # 25208
 0x10226224  4cc63182    crxor       crb6,crb6,crb6
 0x10226228  4800222d    bl          0x10228454 # printf
 0x1022622c  80010014    lwz         r0,20(r1)
 0x10226230  83e1000c    lwz         r31,12(r1)

<<<<<Traceback>>>>>

0x102261cc _start       +0x4c : main ()
```

9 C++ Development

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9.1 Introduction

This chapter provides information about C++ development for VxWorks using the Wind River and GNU toolchains.

WARNING: Wind River Compiler C++ and GNU C++ binary files are not compatible.

NOTE: This chapter provides information about facilities available for real-time processes. For information about facilities available in the VxWorks kernel, see the corresponding chapter in the *VxWorks Kernel Programmer's Guide*.

9.2 C++ Code Requirements

Any VxWorks task that uses C++ must be spawned with the **VX_FP_TASK** option. By default, tasks spawned from host tools (such as the Wind Shell) automatically have **VX_FP_TASK** enabled.

WARNING: Failure to use the **VX_FP_TASK** option when spawning a task that uses C++ can result in hard-to-debug, unpredictable floating-point register corruption at run-time.

If you reference a (non-overloaded, global) C++ symbol from your C code you must 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.

9.3 C++ Compiler Differences

The Wind River C++ Compiler uses the Edison Design Group (EDG) C++ front end. It fully complies with the ANSI C++ Standard. For complete documentation on the Wind River Compiler and associated tools, see the *Wind River C/C++ Compiler User's Guide*.

The GNU compilers provided with the host tools and IDE support most of the language features described in the *ANSI C++ Standard*. In particular, they provide support for template instantiation, exception handling, run-time type information, and namespaces. For complete documentation on the GNU compiler and on the associated tools, see the *GNU ToolKit User's Guide*.

The following sections briefly describe the differences in compiler support for template instantiation, exception handling, and run-time type information.

9.3.1 Template Instantiation

In C, every function and variable used by a program must be defined in exactly one place (more precisely one *translation unit*). However, in C++ there are entities which have no clear point of definition but for which a definition is nevertheless required. These include template specializations (specific instances of a generic template; for example, **std::vector** *int*), out-of-line bodies for inline functions, and virtual function tables for classes without a non-inline virtual function. For such entities a source code definition typically appears in a header file and is included in multiple translation units.

To handle this situation, both the Wind River Compiler and the GNU compiler generate a definition in every file that needs it and put each such definition in its own section. The Wind River compiler uses *COMDAT* sections for this purpose, while the GNU compiler uses *linkonce* sections. In each case the linker removes duplicate sections, with the effect that the final executable contains exactly one copy of each needed entity.

It is highly recommended that you use the default settings for template instantiation, since these combine ease-of-use with minimal code size. However it is possible to change the template instantiation algorithm; see the compiler documentation for details.

Wind River Compiler

The Wind River Compiler C++ options controlling multiple instantiation of templates are:

-Xcomdat
: This option is the default. When templates are instantiated implicitly, the generated **code** or **data** section are marked as **comdat**. The linker then collapses identical instances marked as such, into a single instance in memory.

-Xcomdat-off
: Generate template instantiations and **inline** functions as static entities in the resulting object file. Can result in multiple instances of static member-function or class variables.

For greater control of template instantiation, the **-Ximplicit-templates-off** option tells the compiler to instantiate templates only where explicitly called for in source code; for example:

```
template class A<int>;   // Instantiate A<int> and all member functions.
template int f1(int);    // Instantiate function int f1{int).
```

GNU Compiler

The GNU C++ compiler options controlling multiple instantiation of templates are:

-fimplicit-templates
This option is the default. Template instantiations and out-of-line copies of **inline** functions are put into special *linkonce* sections. Duplicate sections are merged by the linker, so that each instantiated template appears only once in the output file.

-fno-implicit-templates
This is the option for explicit instantiation. Using this strategy explicitly instantiates any templates that you require.

9.3.2 Exception Handling

Both compilers support thread-safe exception handling by default.

Wind River Compiler

To turn off support for exception handling, use the **-Xexceptions-off** compiler flag.

The Wind River Compiler exception handling model is table driven and requires little run-time overhead if a given exception is not thrown. Exception handling does, however, involve a size increase.

GNU Compiler

To turn off support for exception handling, use the **-fno-exceptions** compiler flag.

Unhandled Exceptions

As required by the *ANSI C++ Standard*, an unhandled exception ultimately calls **terminate( )**. The default behavior of this routine is to suspend the offending task and to send a warning message to the console. You can install your own termination handler by calling **set_terminate( )**, which is defined in the header file **exception**.

9.3.3 Run-Time Type Information

Both compilers support Run-time Type Information (RTTI), and the feature is enabled by default. This feature adds a small overhead to any C++ program containing classes with virtual functions.

For the Wind River Compiler, the RTTI language feature can be disabled with the **-Xrtti-off** flag.

For the GNU compiler, the RTTI language feature can be disabled with the **-fno-rtti** flag.

9.4 Namespaces

Both the Wind River and GNU C++ compilers supports namespaces. You can use namespaces for your own code, according to the C++ standard.

The C++ standard also defines names from system header files in a *namespace* called **std**. The standard requires that you specify which names in a standard header file you will be using.

The following code is technically invalid under the latest standard, and will not work with this release. It compiled with a previous release of the GNU compiler, but will not compile under the current releases of either the Wind River or GNU C++ compilers:

```
#include <iostream.h>
int main()
    {
        cout << "Hello, world!" << endl;
    }
```

The following examples provide three correct alternatives illustrating how the C++ standard would now represent this code. The examples compile with either the Wind River or the GNU C++ compiler:

```
// Example 1
    #include <iostream>
    int main()
        {
            std::cout << "Hello, world!" << std::endl;
        }
```

```
// Example 2
    #include <iostream>
    using std::cout;
    using std::endl;
    int main()
        {
            cout << "Hello, world!" << endl;
        }

// Example 3
    #include <iostream>
    using namespace std;
    int main()
        {
            cout << "Hello, world!" << endl;
        }
```

9.5 C++ Demo Example

For a sample C++ application, see *installDir*/**vxworks-6.***x*/**target/usr/apps/samples/cplusplus/factory**.

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