QNX® Neutrino® RTOS

Programmer's Guide

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About the QNX Neutrino Programmer's Guide

The QNX Neutrino *Programmer's Guide* covers a variety of topics that might interest developers who are building applications that will run under the QNX Neutrino RTOS.

For an introduction to programming in QNX Neutrino, see *Getting Started with QNX Neutrino*. Depending on the nature of your application and target platform, you may also need to refer to *Building Embedded Systems*. If you're using the Integrated Development Environment, see the IDE *User's Guide*.

This table may help you find what you need in the *Programmer's Guide*:

When you want to:	Go to:
Get started with a "Hello, world!" program	*Compiling and Debugging*
Get an overview of the QNX Neutrino process model and scheduling methods	*Programming Overview*
Create and terminate processes	*Processes*
Write programs for multicore systems	*Multicore Processing*
Manipulate the access control lists for files and directories	*Working with ACLs*
Understand the inaccuracies in times	*Understanding the Microkernel's Concept of Time*
Use native networking	*Transparent Distributed Processing Using Qnet*
Learn about ISRs in QNX Neutrino	*Writing an Interrupt Handler*
Learn about programming for differently sized architectures	*32- and 64-Bit Architectures*
Analyze and detect problems related to dynamic memory management	*Heap Analysis*
Deal with non-x86 issues (e.g., big-endian vs little-endian)	*Freedom from Hardware and Platform Dependencies*
Understand our **Makefile** methodology	*Conventions for Recursive Makefiles and Directories*
Learn how to use the GDB debugger	*Using GDB*
Look up terms used in the QNX Neutrino documentation	*Glossary*

We assume that you've already installed QNX Neutrino and that you're familiar with its architecture. For a detailed overview, see the *System Architecture* manual.

For the most part, the information that's documented in the *Programmer's Guide* is specific to QNX. For more general information, we recommend the following books:

Threads:

- Butenhof, David R. 1997. *Programming with POSIX Threads*. Reading, MA: Addison-Wesley Publishing Company. ISBN 0-201-63392-2.

TCP/IP programming (note that some of the advanced API features mentioned in the following books might not be supported):

- Hunt, Craig. 2002. *TCP/IP Network Administration*. Sebastopol, CA: O'Reilly & Associates. ISBN 0-596-00297-1.
- Stevens, W. Richard. 1997. *Unix Network Programming: Networking APIs: Sockets and XTI*. Upper Saddle River, NJ: Prentice-Hall PTR. ISBN 0-13-490012-X.
- Stevens, W. Richard. 1993. *TCP/IP Illustrated, Volume 1 The Protocols*. Reading, MA: Addison-Wesley Publishing Company. ISBN 0-201-63346-9.
- Stevens, W. Richard. 1995. *TCP/IP Illustrated, Volume 2 The Implementation*. Reading, MA: Addison-Wesley Publishing Company. ISBN 0-201-63354-X.

Typographical conventions

Throughout this manual, we use certain typographical conventions to distinguish technical terms. In general, the conventions we use conform to those found in IEEE POSIX publications.

The following table summarizes our conventions:

Reference	Example
Code examples	`if( stream == NULL)`
Command options	`-lR`
Commands	`make`
Constants	NULL
Data types	`unsigned short`
Environment variables	*PATH*
File and pathnames	**/dev/null**
Function names	*exit()*
Keyboard chords	**Ctrl–Alt–Delete**
Keyboard input	`Username`
Keyboard keys	**Enter**
Program output	`login:`
Variable names	*stdin*
Parameters	*parm1*
User-interface components	**Navigator**
Window title	**Options**

We use an arrow in directions for accessing menu items, like this:

You'll find the Other... menu item under **Perspective** → **Show View**.

We use notes, cautions, and warnings to highlight important messages:

Notes point out something important or useful.

CAUTION: Cautions tell you about commands or procedures that may have unwanted or undesirable side effects.

DANGER: Warnings tell you about commands or procedures that could be dangerous to your files, your hardware, or even yourself.

Note to Windows users

In our documentation, we typically use a forward slash (/) as a delimiter in pathnames, including those pointing to Windows files. We also generally follow POSIX/UNIX filesystem conventions.

Technical support

Technical assistance is available for all supported products.

To obtain technical support for any QNX product, visit the Support area on our website (*www.qnx.com*). You'll find a wide range of support options, including community forums.

Chapter 1
Compiling and Debugging

Let's start by looking at some things you should consider when you start to write a program for the QNX Neutrino RTOS.

Choosing the version of the OS

You can install and work with multiple versions of QNX Neutrino. Whether you're using the command line or the IDE, you can choose which version of the OS to build programs for.

QNX Neutrino uses these environment variables to locate files on the *host* machine:

QNX_CONFIGURATION_EXCLUSIVE

The location of the configuration files for the installed versions of QNX Neutrino 7.0 or later.

You need to set this variable only when the configuration files are located in a directory other than ***$HOME*/.qnx** or *QNX_CONFIGURATION*.

QNX_CONFIGURATION

The location of the configuration files for the installed versions of QNX Neutrino 6.6 or earlier.

QNX_HOST

The location of host-specific files.

QNX_TARGET

The location of target backends on the host machine.

In QNX SDP 6.5, a system profile sets up these environment variables; for later releases, you need to run a script:

- On Windows, run:

  base_directory`\qnx`*nnn*`-env.bat`

- On Linux or Mac, run:

  `source` *base_directory*`/qnx`*nnn*`-env.sh`

where *base_directory* is where you installed QNX SDP. The name of the script depends on the release and the development host:

Release	Windows	Linux	Mac
QNX SDP 6.6	`qnx660-env.bat`	`qnx660-env.sh`	Not supported
QNX SDP 7.0	`qnxsdp-env.bat`	`qnxsdp-env.sh`	`qnxsdp-env.sh`

In QNX SDP 6.6 or later, you need to set up the environment in every command-prompt window that you want to run the tools in.

For the command-line tools, how you choose which version of the OS to build programs for depends on how you installed QNX SDP:

- If you installed QNX SDP so that it uses the same *QNX_CONFIGURATION* directory as an earlier version of QNX SDP, use the `qconfig` utility.
- If you didn't use the same *QNX_CONFIGURATION* directory:
  - To choose 6.5.0, use its version of `qconfig`. On Windows you can also use `QWinCfg`, a graphical front end for `qconfig`; for example, choose **QNX Software Development Platform 6.5.0** → **Configuration** from the Start menu.
  - To choose 6.6 or later, use the **qnx.*-env.bat** or **qnx.*-env.sh** command as described above to set up the environment. QNX SDP 6.6 or later includes `qconfig`, but you can't use it to select the version of the OS unless you used the same *QNX_CONFIGURATION* directory as for 6.5.

Here's what `qconfig` does:

- If you run it without any options, `qconfig` lists the versions that are installed on your machine.
- If you use the `-e` option, you can use `qconfig` to set up the environment for building software for a specific version of the OS. For example, if you're using the Korn shell (`ksh`), you can configure your machine like this:

```
eval `qconfig -n "QNX Software Development Platform 7.0.0" -e`
```

To start the IDE:

- In QNX SDP 7.0:
  - on Windows, choose **QNX** → **QNX Momentics IDE** from the Start menu, or use the desktop icon
  - on Linux, run ***base_directory*/qnxmomentics/qde**
  - on macOS, click the icon labelled **QNX Momentics IDE** from the launchpad
- In QNX SDP 6.6, run *base_directory*`\run-qde.vbs` on Windows, or *base_directory*`/run-qde.sh` on Linux or macOS. These programs set up the environment and then start the IDE.
- In QNX SDP 6.5, use the desktop icon or run *$QNX_HOST*`\usr\qde\eclipse\qde.exe` on Windows, or run *$QNX_HOST*`/usr/qde/eclipse/qde` on Linux. Run these commands in a shell that's set up for the QNX SDP 6.5 environment.

You can also choose the build target if you're using the IDE; see “Switching between SDKs” in the Reference chapter of the IDE *User's Guide*.

Making your code more portable

To help you create portable applications, the QNX Neutrino RTOS lets you compile for specific standards and include OS-specific code.

Conforming to standards

The header files supplied with the C library provide the proper declarations for the functions and for the number and types of arguments used with them. Constant values used in conjunction with the functions are also declared. The files can usually be included in any order, although individual function descriptions show the preferred order for specific headers.

When you use the `-ansi` option, `qcc` compiles strict ANSI code. Use this option when you're creating an application that must conform to the ANSI standard. The effect on the inclusion of ANSI- and POSIX-defined header files is that certain portions of the header files are omitted:

- for ANSI header files, these are the portions that go beyond the ANSI standard
- for POSIX header files, these are the portions that go beyond the POSIX standard

You can then use the `qcc -D` option to define *feature-test macros* to select those portions that are omitted. Here are the most commonly used feature-test macros:

_POSIX_C_SOURCE=*version*

Include those portions of the header files that relate to the given POSIX standard. For example, _POSIX_C_SOURCE=199506 specifies the *IEEE Standard Portable Operating System Interface for Computer Environments - POSIX 1003.1*, 1996.

_FILE_OFFSET_BITS=64

Make the libraries use 64-bit file offsets.

_LARGEFILE64_SOURCE

Include declarations for the functions that support large files (those whose names end with `64`).

_QNX_SOURCE

Include everything defined in the header files. This is the default.

Feature-test macros may be defined on the command line, or in the source file before any header files are included. The latter is illustrated in the following example, in which an ANSI- and POSIX-conforming application is being developed.

```
#define _POSIX_C_SOURCE=199506
#include <limits.h>
#include <stdio.h>
   …
#if defined(_QNX_SOURCE)
  #include "non_POSIX_header1.h"
  #include "non_POSIX_header2.h"
  #include "non_POSIX_header3.h"
#endif
```

You'd then compile the source code using the `-ansi` option.

You can also set the *POSIXLY_CORRECT* environment variable to 1. This environment variable is used by Unix-style operating systems to alter behavior to comply with POSIX where it's different from the OS's default behavior. It's a *de facto* standard that isn't defined by POSIX.

For example, if *POSIXLY_CORRECT* is set, functions that check the length of a pathname do so *before* removing any redundant **.** and **..** components. If *POSIXLY_CORRECT* isn't set, the functions check the length *after* removing any redundant components.

Including OS-specific code

If you need to include OS-specific code in your application, you can wrap it in an `#ifdef` to make the program more portable.

The `qcc` utility defines these preprocessor symbols (or *manifest constants*):

__QNX__

The target is a QNX operating system (QNX 4 or QNX Neutrino).

__QNXNTO__

The target is the QNX Neutrino RTOS.

For example:

```
#if defined(__QNX__)
   /* QNX-specific (any flavor) code here */

   #if defined(__QNXNTO__)
      /* QNX Neutrino-specific code here */
   #else
      /* QNX 4-specific code here */
   #endif
#endif
```

For information about other preprocessor symbols that you might find useful, see the Manifests chapter of the QNX Neutrino *C Library Reference*.

Cross-development

In this section, we'll describe how to compile and debug a QNX Neutrino system. Your QNX Neutrino system might be anything from a deeply embedded turnkey system to a powerful multiprocessor server. You'll develop the code to implement your system using development tools running on a supported cross-development platform.

QNX Neutrino supports *cross-development*, where you develop on your host system and then transfer and debug the executable on your target hardware.

You can choose how you wish to compile and link your programs: you can use tools with a command-line interface (via the `qcc` command) or you can use our Integrated Development Environment (see the IDE *User's Guide*). Our samples here illustrate the command-line method.

Let's look at the spectrum of methods available to you to run your executable:

If your environment is:	Then you can:
Cross-development, network filesystem link	Compile and link, load over a network filesystem, and then run on the target
Cross-development, debugger link	Compile and link, use a debugger to transfer the executable to the target, and then run on the target
Cross-development, rebuilding the image	Compile and link, rebuild the entire image, and then reboot the target.

Which method you use depends on what's available to you. All the methods share the same initial step—write the code, then compile and link it for QNX Neutrino on the platform that you wish to run the program on.

Let's go through the steps necessary to build a simple QNX Neutrino program that displays the text "Hello, world!"—the classic first C program. The program itself is very simple:

```
#include <stdio.h>

int
main (void)
{
    printf ("Hello, world!\n");
    return (0);
}
```

You compile it for ARMv7 (little-endian) with the single line:

```
qcc -V gcc_ntoarmv7le hello.c -o hello
```

This executes the C compiler with a special cross-compilation flag, `-V gcc_ntoarmv7le`, that tells the compiler to use the `gcc` compiler, QNX Neutrino-specific includes, libraries, and options to create an ARMv7 (little-endian) executable using the GCC compiler. At this point, you should have an executable called **hello**.

To see a list of compilers and platforms supported, simply execute the command:

```
qcc -V
```

Cross-development with network filesystem

If you're using a network filesystem, let's assume you've already set up the filesystem on both ends.

For information on setting this up, see “TCP/IP with network filesystem” in the Sample Buildfiles appendix in *Building Embedded Systems*.

Using a network filesystem is a rich cross-development method, because you have access to remotely mounted filesystems. This is useful for a number of reasons:

- Your embedded system requires only a network connection; no disks (and disk controllers) are required.
- You can access all the shipped and custom-developed QNX Neutrino utilities—they don't need to be present on your (limited) embedded system.
- Multiple developers can share the same filesystem server.

For a network filesystem, you'll need to ensure that the shell's *PATH* environment variable includes the path to your executable via the network-mounted filesystem, or that you specify the full path to the executable. At this point, you can just type the name of the executable at the target's command-line prompt (if you're running a shell on the target):

```
hello
```

Cross-development with debugger

Once the debug agent is running, and you've established connectivity between the host and the target, you can use the debugger to upload the executable to the target, and then run and interact with it.

When the debug agent is connected to the host debugger, you can transfer files between the host and target systems. Note that this is a general-purpose file transfer facility—it's not limited to transferring only executables to the target.

In order for QNX Neutrino to execute a program on the target, the program must be available for loading from some type of filesystem. This means that when you transfer executables to the target, you must write them to a filesystem. Even if you don't have a conventional filesystem on your target, there's a writable “filesystem” present under QNX Neutrino—the **/dev/shmem** filesystem. This serves as a convenient RAM-disk for uploading the executables to.

Cross-development, deeply embedded

If your system is deeply embedded and you have no connectivity to the host system, or you wish to build a system “from scratch,” you'll have to perform the following steps (in addition to the common step of creating the executables, as described above):

1. Build a QNX Neutrino OS image that includes your executables.
2. Transfer the OS image to the target.
3. Boot the target from this OS image.

For more information, see *Building Embedded Systems* and the documentation for your Board Support Package.

Using libraries

When you're developing code, you almost always make use of a *library*, a collection of code modules that you or someone else has already developed (and hopefully debugged).

Under QNX Neutrino, we have three different ways of using libraries:

Static linking

You can combine your modules with the modules from the library to form a single executable that's entirely self-contained. We call this *static linking*. The word "static" implies that it's not going to change—*all* the required modules are already combined into one executable.

Dynamic linking

Rather than build a self-contained executable ahead of time, you can take your modules and link them in such a way that the Process Manager links them to the library modules before your program runs. We call this *dynamic linking*. The word "dynamic" here means that the association between your program and the library modules that it uses is done *at load time*, not at link time (as was the case with the static version).

Runtime loading

There's a variation on the theme of dynamic linking called *runtime loading*. In this case, the program decides *while it's actually running* that it wishes to load a particular function from a library.

Static and dynamic libraries

To support the two major kinds of linking described above, QNX Neutrino has two kinds of libraries: *static* and *dynamic*:

Static libraries

A static library is usually identified by a **.a** (for "archive") suffix (e.g., **libc.a**). The library contains the modules you want to include in your program and is formatted as a collection of ELF object modules that the linker can then extract (as required by your program) and *bind* with your program at link time.

This "binding" operation literally copies the object module from the library and incorporates it into your "finished" executable. The major advantage of this approach is that when the executable is created, it's entirely self-sufficient—it doesn't require any other object modules to be present on the target system. This advantage is usually outweighed by two principal disadvantages, however:

- *Every* executable created in this manner has its own private copy of the library's object modules, resulting in large executable sizes (and possibly slower loading times, depending on the medium).
- You must *relink the executable* in order to upgrade the library modules that it's using.

Dynamic libraries

A dynamic library is usually identified by a **.so** (for "shared object") suffix (e.g., **libc.so**).

Like a static library, this kind of library also contains the modules that you want to include in your program, but these modules are *not* bound to your program at link time. Instead, your program is linked in such a way that the Process Manager causes your program to be bound to the shared objects at load time.

The Process Manager performs this binding by looking at the program to see if it references any shared objects (**.so** files). If it does, then the Process Manager looks to see if those particular shared objects are already present in memory. If they're not, it loads them into memory. Then the Process Manager patches your program to be able to use the shared objects. Finally, the Process Manager starts your program.

Note that from your program's perspective, it isn't even aware that it's running with a shared object versus being statically linked—that happened before the first line of your program ran!

The main advantage of dynamic linking is that the programs in the system reference only a particular set of objects—they don't contain them. As a result, programs are smaller. This also means that you can upgrade the shared objects *without relinking the programs*. This is especially handy when you don't have access to the source code for some of the programs.

dlopen()

If you want to “augment” your program with additional code at runtime, you can call *dlopen()*.

This function call tells the system that it should find the shared object referenced by the *dlopen()* function and create a binding between the program and the shared object. Again, if the shared object isn't present in memory already, the system loads it. The main advantage of this approach is that the program can determine, at runtime, which objects it needs to have access to.

Note that there's no *real* difference between a library of shared objects that you link against and a library of shared objects that you load at runtime. Both modules are of the exact same format. The only difference is in how they get used.

By convention, therefore, we place libraries that you link against (whether statically or dynamically) into the **lib** directory, and shared objects that you load at runtime into the **lib/dll** (for “dynamically loaded libraries”) directory.

Note that this is just a convention—there's nothing stopping you from linking against a shared object in the **lib/dll** directory or from using the *dlopen()* function call on a shared object in the **lib** directory.

Platform-specific library locations

The development tools have been designed to work out of their processor directories (**x86**, **armle-v7**, etc.). This means you can use the same toolset for any target platform.

If you have development libraries for a certain platform, then put them into the platform-specific library directory (e.g., **/x86/lib**), which is where the compiler and tools look.

You can use the `-L` option to `qcc` to explicitly provide a library path.

Linking your modules

To link your application against a library, use the `-l` option to `qcc`, omitting the `lib` prefix and any extension from the library's name. For example, to link against **libsocket**, specify `-l socket`.

You can specify more than one `-l` option. The `qcc` configuration files might specify some libraries for you; for example, `qcc` usually links against **libc**. The description of each function in the QNX Neutrino *C Library Reference* tells you which library to link against.

The QNX Neutrino linker is a single-pass linker, so you must list all libraries after all objects (**.o** files) on the link line. If one library (say, **lib1.a**) has functions that call functions in another library (say, **lib2.a**), then put **lib1.a** before **lib2.a**) on the link command line.

By default, the tool chain links dynamically. We do this because of all the benefits mentioned above.

If you want to link *everything* statically, specify the `-static` option to `qcc`, which causes the link stage to look in the library directory *only* for static libraries (identified by a **.a** extension).

For this release of QNX Neutrino, you can't use the floating point emulator (`fpemu.so`) in statically linked executables.

Although we generally discourage linking statically, it does have this advantage: in an environment with tight configuration management and software QA, the very same executable can be regenerated at link time and known to be complete at runtime.

To link dynamically (the default), you don't have to do anything.

To link statically *and* dynamically (some libraries linked one way, other libraries linked the other way), the two keywords `-Bstatic` and `-Bdynamic` are positional parameters that can be specified to `qcc`. All libraries specified after the particular `-B` option are linked in the specified manner. You can have multiple `-B` options:

```
qcc ... -Bdynamic -l1 -l2 -Bstatic -l3 -l4 -Bdynamic -l5
```

This causes libraries **lib1**, **lib2**, and **lib5** to be dynamically linked (i.e., `qcc` links against the files **lib1.so**, **lib2.so** and **lib5.so**), and libraries **lib3** and **lib4** to be statically linked (i.e., `qcc` links against the files **lib3.a** and **lib4.a**).

You may see the extension **.1** appended to the name of the shared object (e.g., **libc.so.1**). This is a version number. Use the extension **.1** for your first revision, and increment the revision number if required.

You may wish to use the above “mixed-mode” linking because some of the libraries you're using are needed by only one executable or because the libraries are small (less than 4 KB), in which case you'd be wasting memory to use them as shared libraries. Note that shared libraries are typically mapped in 4-KB pages and require at least one page for the “`text`” section and possibly one page for the “`data`” section.

When you specify `-Bstatic` or `-Bdynamic`, *all* subsequent libraries are linked in the specified manner.

Creating shared objects

To create a shared object suitable for linking against:

1. Compile the source files for the library using the `-shared` option to `qcc`.
2. To create the library from the individual object modules, simply combine them with the linker (this is done via the `qcc` compiler driver as well, also using the `-shared` command-line option).

Make sure that all objects and "static" libs that are pulled into a **.so** are position-independent as well (i.e., also compiled with `-shared`).

If you make a shared library that has to static-link against an existing library, you can't static-link against the **.a** version (because those libraries themselves aren't compiled in a position-independent manner). Instead, there's a special version of the libraries that has a capital "S" just before the **.a** extension. For example, instead of linking against **libsocket.a**, you'd link against **libsocketS.a**. We recommend that you don't static-link, but rather link against the **.so** shared object version.

Specifying an internal name

When you're building a shared object, you can specify the following option to `qcc`:

"-Wl,-h*name*"

(You might need the quotes to pass the option through to the linker intact, depending on the shell.)

This option sets the internal name of the shared object (SONAME) to *name* instead of to the object's pathname, so you'd use *name* to access the object when dynamically linking. The internal name must end with a version number (e.g., **lib*xx*.so.*n*** and not merely **lib*xx*.so**).

You might find this useful when doing cross-development (e.g., from a Windows system to a QNX Neutrino target). If several versions of a library provide the same interface, they'd have the same SONAME; if another version of the library is incompatible with earlier versions, its SONAME would be different.

For example, you might have several versions of the C library, and **libc.so** could be a symbolic link to the most recent version:

```
# ls -l libc.so*
lrwxrwxrwx  1 root      root             9 Oct 28 11:59 libc.so -> libc.so.4
-rwxr-xr-x  1 root      root         28902 Jul 09  2010 libc.so.2
-rwxr-xr-x  1 root      root        645784 Jun 20  2012 libc.so.3
-rwxrwxr-x  1 root      root        904512 Oct 20 21:01 libc.so.4
# objdump -x libc.so.4 | grep SONAME
  SONAME               libc.so.4
# objdump -x libc.so.3 | grep SONAME
  SONAME               libc.so.3
# objdump -x libc.so.2 | grep SONAME
  SONAME               libc.so.2
# objdump -x libc.so | grep SONAME
  SONAME               libc.so.4
```


If you link against **libc.so** when it's a link to version 3, you won't be able to execute your program on a system that has only version 4 of the library.

Optimizing the runtime linker

The runtime linker supports the following features that you can use to optimize the way it resolves and relocates symbols:

- *Lazy binding*
- RTLD_LAZY
- *Lazy loading*

The term "lazy" in all of them can cause confusion, so let's compare them briefly before looking at them in detail:

- Lazy binding is the process by which symbol resolution is deferred until a symbol is actually used.
- RTLD_LAZY indicates to the runtime linker that an a loaded object might have unresolved symbols that it shouldn't worry about resolving. It's up to the developer to load the objects that define the symbols before calling any functions that use the symbols.
- Lazy loading modifies the lookup scope and avoids loading objects (or even looking them up) before the linker needs to search them for a symbol.

RTLD_LAZY doesn't imply anything about whether dependencies are loaded; it says where a symbol is looked up. It allows the looking up of symbols that are subsequently opened with the RTLD_GLOBAL flag, when looking up a symbol in an RTLD_LAZY-opened object and its resolution scope fails. The term "resolution scope" is intentional since we don't know what it is by just looking at RTLD_LAZY; it differs depending on whether you specify RTLD_WORLD, RTLD_LAZYLOAD, or both.

Lazy binding

Lazy binding (also known as lazy linking or on-demand symbol resolution) is the process by which symbol resolution isn't done until a symbol is actually used. Functions can be bound on-demand, but data references can't.

All dynamically resolved functions are called via a Procedure Linkage Table (PLT) stub. A PLT stub uses relative addressing, using the Global Offset Table (GOT) to retrieve the offset. The PLT knows where the GOT is, and uses the offset to this table (determined at program linking time) to read the destination function's address and make a jump to it.

To be able to do that, the GOT must be populated with the appropriate addresses. Lazy binding is implemented by providing some stub code that gets called the first time a function call to a lazy-resolved symbol is made. This stub is responsible for setting up the necessary information for a binding function that the runtime linker provides. The stub code then jumps to it.

The binding function sets up the arguments for the resolving function, calls it, and then jumps to the address returned from resolving function. The next time that user code calls this function, the PLT stub jumps directly to the resolved address, since the resolved value is now in the GOT. (The GOT is initially populated with the address of this special stub; the runtime linker does only a simple relocation for the load base.)

The semantics of lazy-bound (on-demand) and now-bound (at load time) programs are the same:

- In the bind-now case, the application fails to load if a symbol couldn't be resolved.

- In the lazy-bound case, it doesn't fail right away (since it didn't check to see if it could resolve all the symbols) but still fails on the first call to an unresolved symbol. This doesn't change even if the application later calls *dlopen()* to load an object that defines that symbol, because the application can't change the resolution scope. The only exceptions to this rule are objects loaded using *dlopen()* with the RTLD_LAZY flag (see below).

Lazy binding is controlled by the `-z` option to the linker, `ld`. This option takes keywords as an argument; the keywords include (among others):

`lazy`

When generating an executable or shared library, mark it to tell the runtime linker to defer function-call resolution to the point when the function is called (lazy binding), rather than at load time.

`now`

When generating an executable or shared library, mark it to tell the runtime linker to resolve all symbols when the program is started, or when the shared library is linked to using *dlopen()*, instead of deferring function-call resolution to the point when the function is first called.

In QNX Neutrino 7.0 or later, "now" binding is the default because it's more secure than lazy binding. If you're using `qcc` (as we recommend), use the `-W` option to pass the `-z` option to `ld`. For example, specify `-Wl,-zlazy` or `-Wl,-znow`.

To see if a binary was built with `-znow`, use the appropriate variant of `readelf`. For example:

`ntox86-readelf -d` *my_binary*

The output includes the `BIND_NOW` dynamic tag if `-znow` was used when linking.

You can use the *DL_DEBUG* environment variable to get the runtime linker to display some debugging information. For more information, see "*Diagnostics and debugging*" and "*Environment variables*," later in this chapter.

Applications with many symbols—typically C++ applications—benefit the most from lazy binding. For many C applications, the difference is negligible.

Lazy binding does introduce some overhead; it takes longer to resolve *N* symbols using lazy binding than with immediate resolution. There are two aspects that potentially save time or at least improve the user's perception of system performance:

- When you start an application, the runtime linker doesn't resolve all symbols, so you may expect to see the initial screen sooner, providing your initialization prior to displaying the screen doesn't end up calling most of the symbols anyway.
- When the application is running, many symbols won't be used and thus they aren't looked up.

Both of the above are typically true for C++ applications.

Lazy binding could affect realtime performance because there's a delay the first time you access each unresolved symbol, but this delay isn't likely to be significant, especially on fast machines. If this delay is a problem, use `-znow`

It isn't sufficient to use `-znow` on the shared object that has a function definition for handling something critical; the whole process must be resolved "now". For example, you should probably link driver executables with `-znow` or run drivers with *LD_BIND_NOW*.

RTLD_LAZY

RTLD_LAZY is a flag that you can pass to *dlopen()* when you load a shared object.

Even though the word "lazy" in the name suggests that it's about lazy binding as described above in "*Lazy binding*," it has different semantics. It makes (semantically) no difference whether a *program* is lazy- or now- bound, but for objects that you load with *dlopen()*, RTLD_LAZY means "there may be symbols that can't be resolved; don't try to resolve them until they're used." This flag currently applies only to function symbols, not data symbols.

What does it practically mean? To explain that, consider a system that comprises an executable X, and shared objects P (primary) and S (secondary). X uses *dlopen()* to load P, and P loads S. Let's assume that P has a reference to *some_function()*, and S has the definition of *some_function()*.

If X opens P without RTLD_LAZY binding, the symbol *some_function()* doesn't get resolved—not at the load time, nor later by opening S. However, if P is loaded with `RTLD_LAZY | RTLD_WORLD`, the runtime linker doesn't try to resolve the symbol *some_function()*, and there's an opportunity for us to call `dlopen("S", RTLD_GLOBAL)` before calling *some_function()*. This way, the *some_function()* reference in P is satisfied by the definition of *some_function()* in S.

There are several programming models made possible by RTLD_LAZY:

- X uses *dlopen()* to load P and calls a function in P; P determines its own requirements and loads the object with the appropriate implementation. For that, P needs to be opened with RTLD_LAZY. For example, the X server opens a video driver (P), and the video driver opens its own dependencies.
- X uses *dlopen()* to load P, and then determines the implementation that P needs to use (e.g., P is a user interface, and S is the "skin" implementation).

Lazy loading

Lazy dependency loading (or on-demand dependency loading) is a method of loading the required objects when they're actually required.

The most important effect of lazy loading is that the resolution scope is different for a lazyload dependency. While in a "normal" dependency, the resolution scope contains immediate dependencies followed by their dependencies sorted in breadth-first order, for a lazy-loaded object, the resolution scope ends with its first-level dependencies. Therefore, all of the lazy-loaded symbols must be satisfied by definitions in its first level dependencies.

Due to this difference, you must carefully consider whether lazy-load dependencies are suitable for your application.

Each dynamic object can have multiple dependencies. dependencies can be *immediate* or *implicit*:

- Immediate dependencies are those that directly satisfy all external references of the object.
- Implicit dependencies are those that satisfy dependencies of the object's dependencies.

The ultimate dependent object is the executable binary itself, but we consider any object that needs to resolve its external symbols to be dependent. When referring to immediate or implicit dependencies, we always view them from the point of view of the dependent object.

Here are some other terms:

Lazy-load dependency

Dependencies that aren't immediately loaded are referred to as *lazy-load dependencies*.

Lookup scope/resolution scope

A list of objects where a symbol is looked for. The lookup scope is determined at the object's load time.

Immediate and lazy symbol resolution

All symbolic references must be resolved. Some symbol resolutions need to be performed immediately, such as symbolic references to global data. Another type of symbolic references can be resolved on first use: external function calls. The first type of symbolic references are referred to as *immediate*, and the second as *lazy*.

To use lazy loading, specify the RTLD_LAZYLOAD flag when you call *dlopen()*.

The runtime linker creates the link map for the executable in the usual way, by creating links for each DT_NEEDED object. Lazy dependencies are represented by a special link, a placeholder that doesn't refer to actual object yet. It does, however, contain enough information for the runtime linker to look up the object and load it on demand.

The lookup scope for the dependent object and its regular dependencies is the link map, while for each lazy dependency symbol, the lookup scope gets determined on-demand, when the object is actually loaded. Its lookup scope is defined in the same way that we define the lookup scope for an object loaded with `dlopen(RTLD_GROUP)` (it's important that RTLD_WORLD not be specified, or else we'd be including all RTLD_GLOBAL objects in the lookup scope).

When a call to an external function is made from dependent object, by using the lazy binding mechanism we traverse its scope of resolution in the usual way. If we find the definition, we're done. If, however, we reach a link that refers to a not-yet-loaded dependency, we load the dependency and then look it up for the definition. We repeat this process until either a definition is found, or we've traversed the entire dependency list. We don't traverse any of the implicit dependencies.

The same mechanism applies to resolving immediate relocations. If a dependent object has a reference to global data, and we don't find the definition of it in the currently loaded objects, we proceed to load the lazy dependencies, the same way as described above for resolving a function symbol. The difference is that this happens at the load time of the dependent object, not on first reference.

This approach preserves the symbol-overriding mechanisms provided by *LD_PRELOAD*.

Another important thing to note is that lazy-loaded dependencies change their own lookup scope; therefore, when resolving a function call from a lazy-loaded dependency, the lookup scope is different than if the dependency was a normal dependency. As a consequence, lazy loading can't be transparent as, for example, lazy binding is (lazy binding doesn't change the lookup scope, only the time of the symbol lookup).

Diagnostics and debugging

When you're developing a complex application, it may become difficult to understand how the runtime linker lays out the internal link maps and scopes of resolution. To help determine what exactly the runtime linker is doing, you can use the *DL_DEBUG* environment variable to make the linker display diagnostic messages.

Diagnostic messages are categorized, and the value of *DL_DEBUG* determines which categories are displayed. The special category `help` doesn't produce diagnostics messages, but rather displays a help message and then terminates the application.

To redirect diagnostic messages to a file, set the *LD_DEBUG_OUTPUT* environment variable to the full path of the output file.

For security reasons, the runtime linker unsets *DL_DEBUG* and *LD_DEBUG_OUTPUT* if the binary has the setuid bit set.

Environment variables

The following environment variables affect the operation of the runtime linker:

For security reasons, the runtime linker unsets *DL_DEBUG*, *LD_DEBUG*, *LD_DEBUG_OUTPUT*, *LD_LIBRARY_PATH*, and *LD_PRELOAD* if the binary has the setuid bit set.

DL_DEBUG

Display diagnostic messages. The value can be a comma-separated list of the following:

- `all` — display all debug messages.
- `help` — display a help message, and then exit.
- `reloc` — display relocation processing messages.
- `libs` — display information about shared objects being opened.
- `statistics` — display runtime linker statistics.
- `lazyload` — print lazy-load debug messages.
- `debug` — print various runtime linker debug messages.

A value of 1 (one) is the same as `all`.

LD_BIND_NOW

Affects lazy-load dependencies due to full symbol resolution. Typically, it forces the loading of all lazy-load dependencies (until all symbols have been resolved).

LD_DEBUG

A synonym for *DL_DEBUG*; if you set both variables, *DL_DEBUG* takes precedence.

LD_DEBUG_OUTPUT

The name of a file in which the runtime linker writes its output. By default, output is written to *stderr*.

LD_LIBRARY_PATH

A colon-separated list of paths that the runtime linker uses to search for shared libraries.

LD_PRELOAD

A colon-separated list of full paths to the shared libraries on an ELF system that you want to load before loading other libraries. You can use this environment variable to add or change functionality when you run a program.

LD_TRAP_ON_ERROR

If this environment variable is set, the runtime linker faults instead of exiting on fatal errors, so that you can examine the core file that's generated.

Debugging in a cross-development environment

The debugger can run on one platform to debug executables on another:

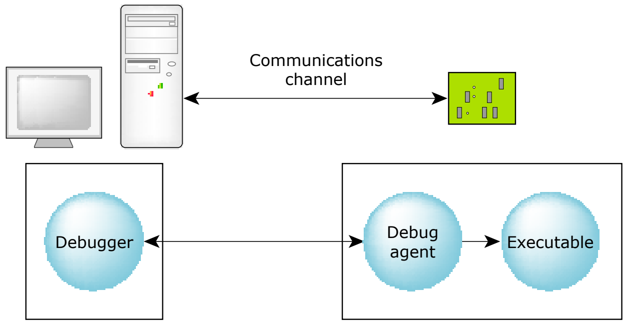


Figure 1: Debugging in a cross-development environment.

In a cross-development environment, the host and the target systems must be connected via some form of communications channel.

The two components, the debugger and the debug agent, perform different functions. The debugger is responsible for presenting a user interface and for communicating over some communications channel to the debug agent. The debug agent is responsible for controlling (via the **/proc** filesystem) the process being debugged.

All debug information and source remains on the host system. This combination of a small target agent and a full-featured host debugger allows for full symbolic debugging, even in the memory-constrained environments of small targets.

In order to debug your programs with full source using the symbolic debugger, you'll need to use the `-g` to tell the C compiler and linker to include symbolic information in the object and executable files. For details, see the `qcc` docs in the *Utilities Reference*. Without this symbolic information, the debugger can provide only assembly-language-level debugging.

The GNU debugger (gdb)

The GNU debugger is a command-line program that provides a very rich set of options.

You'll find a tutorial-style doc called "*Using GDB*" as an appendix in this manual.

You can invoke `gdb` by using the following variants, which correspond to your target platform:

For this target:	Use this command:
AArch64	`ntoaarch64-gdb`
ARMv7	`ntoarmv7-gdb`
x86	`ntox86-gdb`
x86 64-bit	`ntox86_64-gdb`

For more information, see the `gdb` entry in the *Utilities Reference*.

The process-level debug agent

When a breakpoint is encountered and the process-level debug agent `pdebug` is in control, the process being debugged and all its threads are stopped. All other processes continue to run and interrupts remain enabled.

To use the `pdebug` agent, you must set up pty support (via `devc-pty`) on your target.

When the process's threads are stopped and the debugger is in control, you may examine the state of any thread within the process. For more info on examining thread states, see the `gdb` docs.

The `pdebug` agent may either be included in the image and started in the image startup script or started later from any available filesystem that contains `pdebug`. The `pdebug` command-line invocation specifies which device is used.

You can start `pdebug` in one of three ways, reflecting the nature of the connection between the debugger and the debug agent:

- serial connection
- TCP/IP static port connection
- TCP/IP dynamic port connection

Serial connection

If the host and target systems are connected via a serial port, then you should start the debug agent (`pdebug`) with the following command:

`pdebug` *devicename* [**,** *baud*]

This indicates the target's communications channel (*devicename*) and specifies the baud rate (*baud*).

For example, if the target has a **/dev/ser2** connection to the host, and we want the link to be 115,200 baud, we would specify:

```
pdebug /dev/ser2,115200
```

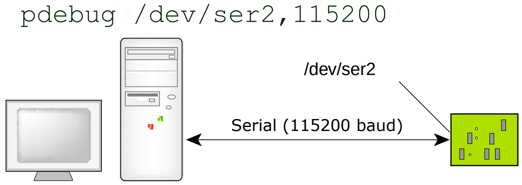


Figure 2: Running the process debug agent with a serial link at 115200 baud.

The QNX Neutrino target requires a supported serial port. The target is connected to the host using either a null-modem cable, which allows two identical serial ports to be directly connected, or a straight-through cable, depending on the particular serial port provided on the target. The null-modem cable crosses the Tx/Rx data and handshaking lines. Most computer stores stock both types of cables.

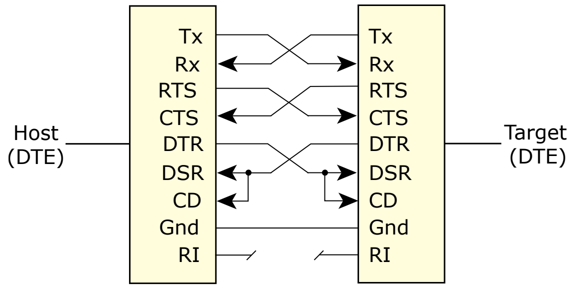


Figure 3: Null-modem cable pinout.

TCP/IP connection

If the host and the target are connected via some form of TCP/IP connection, the debugger and agent can use that connection as well. Two types of TCP/IP communications are possible with the debugger and agent: static port and dynamic port connections (see below).

The QNX Neutrino target must have a supported Ethernet controller. Note that since the debug agent requires the TCP/IP manager to be running on the target, this requires more memory.

This need for extra memory is offset by the advantage of being able to run multiple debuggers with multiple debug sessions over the single network cable. In a networked development environment, developers on different network hosts could independently debug programs on a single common target.

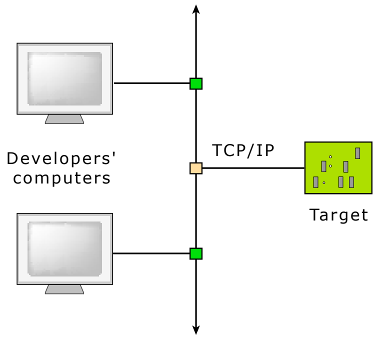


Figure 4: Several developers can debug a single target system.

TCP/IP static port connection

For a static port connection, the debug agent is assigned a TCP/IP port number and listens for communications on that port only. For example, the `pdebug 1204` command specifies TCP/IP port `1204`:

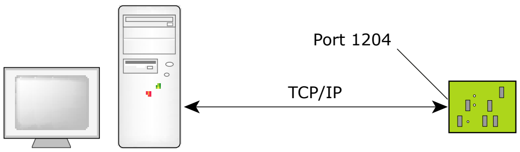


Figure 5: Running the process debug agent with a TCP/IP static port.

If you have multiple developers, each developer could be assigned a specific TCP/IP port number above the reserved ports `0` to `1024`.

TCP/IP dynamic port connection

For a dynamic port connection, the debug agent is started by `inetd` and communicates via standard input/output. The command to run the process debug agent in this case is as follows (from the **inetd.conf** file):

```
pdebug stream tcp nowait root /usr/bin/pdebug pdebug -
```

The `inetd` process fetches the communications port from the configuration file (typically **/etc/services**). For example:

```
pdebug 1234/tcp
```

The host process debugger (`gdb`) connects to the port explicitly, but the debug agent (`pdebug`) has no direct knowledge of the port.

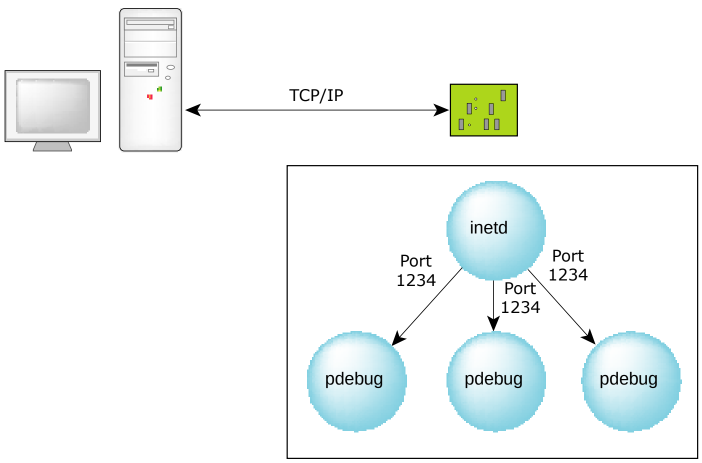


Figure 6: For a TCP/IP dynamic port connection, the `inetd` process manages the port.

Note that this method is also suitable for one or more developers. It's effectively what the `qconn` daemon does to provide support to remote IDE components; `qconn` listens to a port and spawns `pdebug` on a new, dynamically determined port.

Sample buildfile for dynamic port sessions

The following buildfile supports multiple sessions specifying the same port. Although the port for each session on the `pdebug` side is the same, `inetd` causes unique ports to be used on the debugger side. This ensures a unique socket pair for each session.

Note that `inetd` should be included and started in your boot image. The `pdebug` program should also be in your boot image (or available from a mounted filesystem).

The config files could be built into your boot image (as in this sample buildfile) or linked in from a remote filesystem using the `[type=link]` command:

```
[type=link] /etc/services=/mount_point/services
[type=link] /etc/inetd.conf=/mount_point/inetd.conf
```

Here's the buildfile:

```
[virtual=x86,bios +compress] boot = {
    startup-x86 -N node428
    PATH=/proc/boot:/bin:/apk/bin_nto:./ procnto
```

```
}

[+script] startup-script = {
# explicitly running in edited mode for the console link
    devc-ser8250 -e -b115200 &
    reopen
    display_msg Welcome to QNX Neutrino on a PC-compatible BIOS system
# tcp/ip with a fictitious ABC100 Ethernet adaptor
    io-pkt-v4-hc -d abc100 -ptcpip if=ndi0:10.0.1.172
    waitfor /dev/socket
    inetd &
    pipe
# pdebug needs devc-pty to be running
    devc-pty &
# NFS mount of the QNX Neutrino filesystem
    fs-nfs3 -r 10.89:/x86 /x86 -r 10.89:/home /home &
# CIFS mount of the NT filesystem
    fs-cifs -b //QA:10.0.1.181:/QARoot /QAc apk 123 &
# NT Hyperterm needs this to interpret backspaces correctly
    stty erase=08
    reopen /dev/console
    [+session] esh &
}

[type=link] /usr/lib/ldqnx.so.2=/proc/boot/libc.so
[type=link] /lib=/x86/lib
[type=link] /tmp=/dev/shmem         # tmp points to shared memory
[type=link] /dev/console=/dev/ser2  # no local terminal
[type=link] /bin=/x86/bin           # executables in the path
[type=link] /apk=/home/apk          # home dir

[perms=+r,+x]           # Boot images made under MS-Windows
                        # need to be reminded of permissions.
devnp-abc100.so
libc.so
fpemu.so
libsocket.so

[data=copy]             # All executables that can be restarted
                        # go below.
devc-ser8250
io-pkt-v4-hc
pipe
devc-pty
fs-nfs3
fs-cifs
inetd
esh
stty
ping
ls
                        # Data files are created in the named
                        # directory.
/etc/hosts = {
```



```
127.0.0.1    localhost
10.89        node89
10.222       node222
10.326       node326
10.0.1.181   QA node437
10.241       APP_ENG_1
}

/etc/services = {
ftp           21/tcp
telnet        23/tcp
pdebug        8000/tcp
}

/etc/inetd.conf = {
ftp     stream    tcp    nowait    root    /bin/fdtpd       fdtpd
telnet  stream    tcp    nowait    root    /bin/telnetd     telnetd
pdebug  stream    tcp    nowait    root    /usr/bin/pdebug  pdebug -
}
```

A simple debug session

In this example, we'll be debugging our “Hello, world!” program via a TCP/IP link. We go through the following steps:

- configuring the target
- compiling for debugging
- starting the debug session
- using basic debugging commands

The buildfile for the image follows these sections.

Configure the target

Let's assume an x86 target using a basic TCP/IP configuration. The following lines (from the sample buildfile below) show what's needed to host the sample session:

```
io-pkt-v4-hc -d abc100 -ptcpip if=ndi0:10.0.1.172
devc-pty &
[+session] pdebug 8000 &
```

The above specifies that the host IP address is 10.0.1.172. The `pdebug` program is configured to use port 8000.

Compile for debugging

We'll be using the x86 compiler. Note the `-g` option, which makes the compiler include debugging information:

```
$ qcc -V gcc_ntox86 -g -o hello hello.c
```

Start the debug session

For this simple example, the source can be found in our working directory. First, let's start the session; to reduce document clutter, we'll run the debugger in quiet mode:

```
ntox86-gdb -quiet
```

The `gdb` debugger provides its own shell; by default its prompt is `(gdb)`. Specify the target IP address and the port used by pdebug:

```
(gdb) target qnx 10.0.1.172:8000
Remote debugging using 10.0.1.172:8000
0x0 in ?? ()
```

Upload the debug executable to the target. (This can be a slow operation. If the executable is large, you may prefer to build the executable into your target image.) Note that the file has to be in the target system's pathname space, so we can get the executable via a network filesystem, `ftp`, or, if no filesystem is present, via the upload command:

```
(gdb) upload hello /tmp/hello
```


Load the symbolic debug information from the current working directory (in this case, **hello** must reside on the host system):

```
(gdb) sym hello
Reading symbols from hello...done.
```

Start the program:

```
(gdb) run /tmp/hello
Starting program:  /tmp/hello
Trying to find symbol file for ldqnx.so.2
Retrying dynamic interpreter in libc.so.4
```

Set a breakpoint on *main()*:

```
(gdb) break main
Breakpoint 1 at 0x80483ae: file hello.c, line 8.
```

Allow the program to continue to the breakpoint found at *main()*:

```
(gdb) c
Continuing.
Breakpoint 1, main () at hello.c:8
8       gettimeofday (&when, NULL);
```

We're now ready to start the debug session:

```
(gdb)
```

Basic debugger commands

While you're in a debug session, you can use any of the following commands as the next action for starting the actual debugging of the project:

n

Step through the program, proceeding through subroutine calls.

l

List the specified function or line.

break

Set a breakpoint on the specified function or line.

help

Get the help main menu.

help data

Get the help data menu.

help inspect

Get help for the `inspect` command.

inspect *y*

Inspect the contents of variable *y*.

set y=3

Assign a value to variable *y*.

bt

Get a back trace.

For more information about these commands and their arguments, see the *Using GDB* appendix in this guide, or use the `help` *cmd* command in `gdb`.

Let's see how to use some of these basic commands. First, here's the `list` command:

```
(gdb) l
3
4   main () {
5       struct timeval when;
6       int x,y,z;
7
8       gettimeofday (&when, NULL);
9       printf ("Hi ya!\n");
10
11      x=3;
12      y=2;
```

Press **Enter** to repeat the last command:

```
(gdb) <enter>
13      z=3*2;
14
15      exit (0);
16
17  }
```

Break on line 11:

```
(gdb) break 11
Breakpoint 2 at 0x80483c7: file hello.c, line 11.
```

Continue until the first breakpoint:

```
(gdb) c
Continuing.
Hi ya!

Breakpoint 2, main () at hello.c:11
11      x=3;
```

Notice that the above command went past the *printf()* statement at line 9, so the output from the call is displayed on the screen.

Inspect variable *y*, using the short form of the `inspect` command:

```
(gdb) ins y
$1 = -1338755812
```

Get some help on the `step` and `next` commands:

```
(gdb) help s
Step program until it reaches a different source line.
```

```
Argument N means do this N times (or till program stops
for another reason).
(gdb) help n
Step program, proceeding through subroutine calls.
Like the "step" command as long as subroutine calls don't
happen; when they do, the call is treated as one instruction.
Argument N means do this N times (or till program stops
for another reason).
```

Go to the next line of execution:

```
(gdb) n
12      y=2;
(gdb) n
13      z=3*2;
(gdb) inspect z
$2 = 1
(gdb) n
15      exit (0);
(gdb) inspe z
$3 = 6
```

Continue program execution:

```
(gdb) continue
Continuing.

Program exited normally.
```

Quit the debugger session:

```
(gdb) quit
The program is running. Exit anyway? (y or n) y
```

Sample boot image

```
[virtual=x86,bios +compress] boot = {
    startup-x86 -N node428
    PATH=/proc/boot:./ procnto
}

[+script] startup-script = {
# explicitly running in edited mode for the console link
    devc-ser8250 -e -b115200 &
    reopen
    display_msg Welcome to QNX Neutrino on a PC-compatible BIOS system
# tcp/ip with the fictitious ABC100 Ethernet adaptor
    io-pkt-v4-hc -d abc100 -ptcpip if=ndi0:10.0.1.172
    waitfor /dev/socket
    pipe
# pdebug needs devc-pty
    devc-pty &
# Start pdebug on port 8000
    [+session] pdebug 8000 &
}
```

```
[type=link] /usr/lib/ldqnx.so.2=/proc/boot/libc.so.4
[type=link] /tmp=/dev/shmem         # tmp points to shared memory
[type=link] /dev/console=/dev/ser2  # no local terminal

[perms=+r,+x]          # Boot images made under MS-Windows need
                       # to be reminded of permissions.
devnp-abc100.so
libc.so
fpemu.so
libsocket.so

[data=copy]             # All executables that can be restarted
                        # go below.
devc-ser8250
io-pkt-v4-hc
pipe
devc-pty
pdebug
esh
ping
ls
```

Chapter 2
Programming Overview

The QNX Neutrino RTOS architecture consists of the microkernel and some number of cooperating processes. These processes communicate with each other via various forms of interprocess communication (IPC). Message passing is the primary form of IPC in QNX Neutrino.

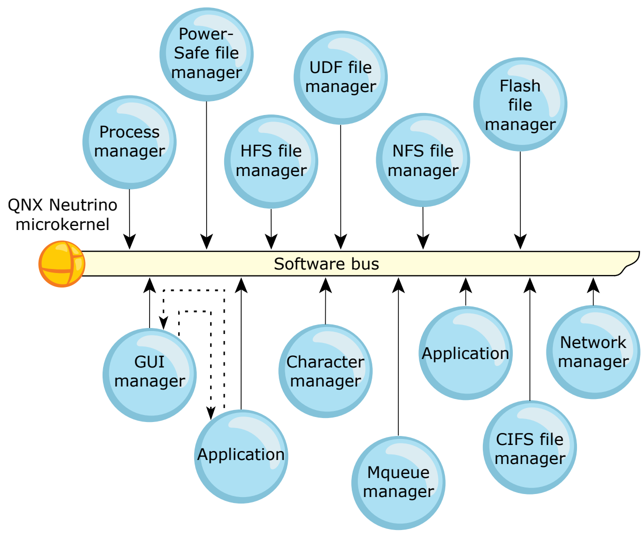


Figure 7: The QNX Neutrino architecture acts as a kind of "software bus" that lets you dynamically plug in/out OS modules.

The above diagram shows an application sending a message to the GUI manager, and the GUI manager responding.

An application as a set of processes

This idea of using a set of cooperating processes isn't limited to the OS "system processes." Your applications should be written in exactly the same way. You might have some driver process that gathers data from some hardware and then needs to pass that data on to other processes, which then act on that data.

Let's use the example of an application that's monitoring the level of water in a reservoir. Should the water level rise too high, then you'll want to alert an operator as well as open some flow-control valve.

In terms of hardware, you'll have some water-level sensor tied to an I/O board in a computer. If the sensor detects some water, it will cause the I/O board to generate an interrupt.

The software consists of a driver process that talks to the I/O board and contains an *interrupt handler* to deal with the board's interrupt. You'll also have a GUI process that will display an alarm window when told to do so by the driver, and finally, another driver process that will open/close the flow-control valve.

Why break this application into multiple processes? Why not have everything done in one process? There are several reasons:

1. Each process lives in its own *protected memory space*. If there's a bug such that a pointer has a value that isn't valid for the process, then when the pointer is next used, the hardware will generate a fault, which the kernel handles (the kernel will set the SIGSEGV signal on the process).

   This approach has two benefits. The first is that a stray pointer won't cause one process to overwrite the memory of another process. The implications are that one process can go bad *while other processes keep running*.

   The second benefit is that the fault will occur precisely when the pointer is used, not when it's overwriting some other process's memory. If a pointer were allowed to overwrite another process's memory, then the problem wouldn't manifest itself until later and would therefore be much harder to debug.
2. It's very easy to add or remove processes from an application as need be. This implies that applications can be made scalable—adding new features is simply a matter of adding processes.
3. Processes can be started and stopped *on the fly*, which comes in handy for dynamic upgrading or simply for stopping an offending process.
4. Processing can be easily distributed across multiple processors in a networked environment.
5. The code for a process is much simpler if it concentrates on doing a single job. For example, a single process that acts as a driver, a GUI front-end, and a data logger would be fairly complex to build and maintain. This complexity would increase the chances of a bug, and any such bug would likely affect all the activities being done by the process.
6. Different programmers can work on different processes without fear of overwriting each other's work.

Some definitions

Different operating systems often have different meanings for terms such as "process," "thread," "task," "program," and so on.

In the QNX Neutrino RTOS, an *application* typically means a collection of processes, although sometimes—especially for UI pieces—it can mean just one process. A *program* is the file generated as the result of a compile and link operation; when you run a program on a QNX target, this creates a *process*; a process is, basically, a particular instance of a running program.

A *thread* is a single flow of execution or control. At the lowest level, this equates to the program counter or instruction pointer register advancing through some machine instructions. Each thread has its own current value for this register.

A *process* is a collection of resources shared by one or more threads. These resources include at least the following:

- all code and data in the process, including all nonlocal (nonstack) variables
- signal handlers (although you typically have one thread that handles signals, and you block them in all the other threads)

  It isn't safe to use floating-point operations in signal handlers.

- signal ignore state
- file descriptors (fds), and their relatives, such as sockets, mqueue descriptors, etc.
- channels
- side-channel connections

Along with ownership of these resources goes cleanup. When a process terminates, all process-owned resources are cleaned up, including terminating all threads, releasing all memory, closing all file descriptors, etc. This happens for both normal termination (e.g., calling exit()) and abnormal termination (e.g., dying due to accessing invalid memory).

Threads don't share such things as stack, values for the various registers, SMP thread-affinity mask, and a few other things.

Two threads residing in two different processes don't share very much. About the only thing they do share is the CPU, and maybe not even that if they're running on a multicore processor. Threads in different processes can share memory, but this takes takes a little setup (see *shm_open()* in the *C Library Reference* for an example).

When you run a program (creating a process), you're automatically running a thread. This thread is called the "main" thread, since the first programmer-provided function that runs in a C program is *main()*. The main thread can then create additional threads if need be.

A few things are special about the main thread. One is that if it returns normally, the code it returns to calls *exit()*. Calling *exit()* terminates the process, meaning that all threads in the process are terminated. So when you return normally from the main thread, the process is terminated. When other threads in the process return normally, the code they return to calls *pthread_exit()*, which terminates just that thread.

Another special thing about the main thread is that if it terminates in such a manner that the process is still around (e.g., it calls *pthread_exit()* and there are other threads in the process), then the memory for the main thread's stack *isn't* freed up. This is because the command-line arguments are on that stack and other threads may need them. If any other thread terminates, then that thread's stack is freed.

Priorities and scheduling

Although there's a good discussion of priorities and scheduling policies in the *System Architecture* manual, it will help to go over that topic here in the context of a programmer's guide.

The QNX Neutrino RTOS provides a priority-driven preemptive architecture. *Priority-driven* means that each thread can be given a priority and will be able to access the CPU based on that priority. If a low-priority thread and a high-priority thread both want to run, then the high-priority thread will be the one that gets to run.

Preemptive means that if a low-priority thread is currently running and then a high-priority thread suddenly wants to run, then the high-priority thread will take over the CPU and run, thereby preempting the low-priority thread.

On a multicore (SMP) system, QNX Neutrino still runs the highest-priority runnable thread on one of the available cores. Additional cores run other threads in the system, though not necessarily the next highest-priority thread or threads.

Priority range

Threads can have a scheduling priority ranging from 1 to 255 (the highest priority), *independent of the scheduling policy*. A thread inherits the priority of its parent thread by default.

Unprivileged threads can have a priority ranging from 1 to 63 (by default); threads with the PROCMGR_AID_PRIORITY ability enabled (see *procmgr_ability()*) are allowed to set priorities above 63. You can change the allowed priority range for unprivileged processes with the `procnto -P` option.

The process manager has a set of special *idle* threads (one per available CPU core) that have priority 0 and are always ready to run. A CPU core is considered to be idle when the idle thread is scheduled to run on that core. At any instant, a core is either idle or busy; only by averaging over time can a CPU be said to be some percent busy (e.g., 75% CPU usage).

A thread has both a *real priority* and an *effective priority*, and is scheduled in accordance with its effective priority. The thread itself can change both its real and effective priority together, but the effective priority may change because of priority inheritance or the scheduling policy. Normally, the effective priority is the same as the real priority.

Interrupt handlers are of higher priority than any thread, but they're not scheduled in the same way as threads. If an interrupt occurs, then:

1. Whatever thread was running loses the CPU on the core that's handling the interrupt. On multicore machines this may vary, due to hardware configuration and BSP setup.
2. The kernel runs some hardware-specific code supplied by the BSP to identify the interrupt.
3. The kernel calls the appropriate interrupt handler or handlers.
4. The kernel runs some hardware-specific code supplied by the BSP to do end-of-interrupt processing.

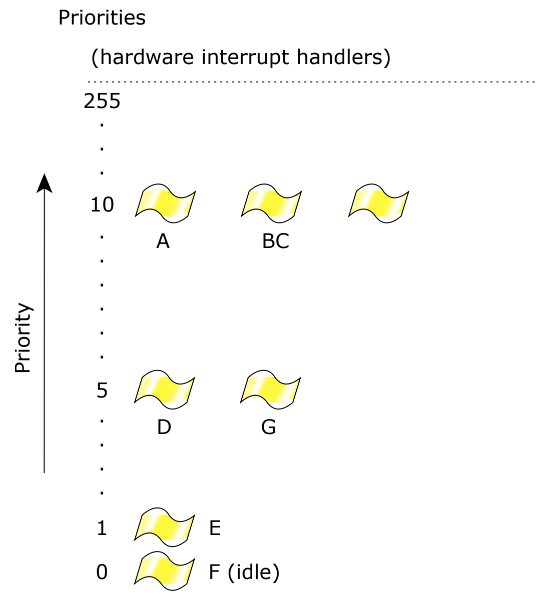


Figure 8: Thread priorities range from 0 (lowest) to 255 (highest).

Although interrupt handlers aren't scheduled in the same way as threads, they're considered to be of a higher priority because an interrupt handler will preempt *any* running thread.

Out-of-range priority requests (QNX Neutrino 6.6 or later)

As an extension to POSIX, when you're setting a priority, you can wrap it in one these macros to specify how to handle out-of-range priority requests:

- *SCHED_PRIO_LIMIT_ERROR(priority)* — indicate an error
- *SCHED_PRIO_LIMIT_SATURATE(priority)* — use the maximum allowed priority (reach a "maximum saturation point")

You can append an `s` or `S` to `procnto`'s `-P` option if you want out-of-range priority requests by default to "saturate" at the maximum allowed value instead of resulting in an error.

BLOCKED and READY states

To fully understand how scheduling works, you must first understand what it means when we say a thread is BLOCKED and when a thread is in the READY state. You must also understand a particular data structure in the kernel called the *ready queue*.

A thread is BLOCKED if it doesn't want the CPU, which might happen for several reasons, such as:

- The thread is sleeping.
- The thread is waiting for a message from another thread.
- The thread is waiting on a mutex that some other thread owns.

When designing an application, you always try to arrange it so that if any thread is waiting for something, make sure it *isn't spinning in a loop using up the CPU*. In general, try to avoid polling. If you do have to poll, then you should try to sleep for some period between polls, thereby giving lower-priority threads the CPU should they want it.

For each type of blocking there is a blocking state. We'll discuss these states briefly as they come up. Examples of some blocking states are REPLY-blocked, RECEIVE-blocked, MUTEX-blocked, INTERRUPT-blocked, and NANOSLEEP-blocked. There's also a STOPPED state, when a thread has been suspended by a SIGSTOP signal and is waiting for a SIGCONT.

A thread is READY if it wants a CPU but something else currently has it. If a thread currently has a CPU, then it's in the RUNNING state. Simply put, a thread that's either READY or RUNNING isn't blocked.

The ready queue

The ready queue is a simplified version of a kernel data structure consisting of a queue with one entry per priority. Each entry in turn consists of another queue of the threads that are READY at the priority. Any threads that aren't READY aren't in any of the queues—but they will be when they become READY.

Let's first consider the ready queue on a single-core system.

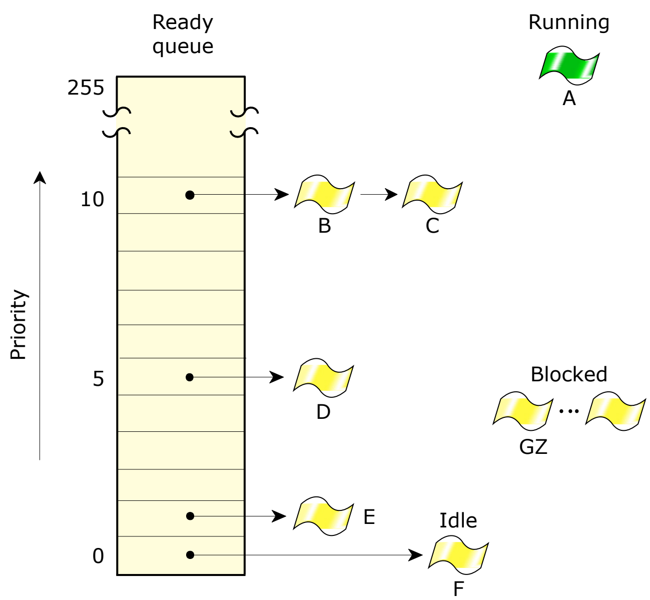


Figure 9: The ready queue for five threads on a single-core system.

In the above diagram, threads B–F are READY. Thread A is currently running. All other threads (G–Z) are BLOCKED. Threads A, B, and C are at the highest priority, so they'll share the processor based on the running thread's scheduling policy.

The *active* thread is the one in the RUNNING state.

Every thread is assigned a priority. The scheduler selects the next thread to run by looking at the priority assigned to every thread in the READY state (i.e., capable of using the CPU). The thread with the highest priority that's at the head of its priority's queue is selected to run. In the above diagram, thread A was formerly at the head of priority 10's queue, so thread A was moved to the RUNNING state.

On a multicore system, this becomes a lot more complex, with issues such as core-affinity optimizations and CPU masks for various threads, making the scheduling decisions more complicated. But the ready queue concept carries over as the primary driver of scheduling decisions for multicore systems as well.

Rescheduling a running thread

The microkernel makes scheduling decisions whenever it's entered as the result of a kernel call, exception, or hardware interrupt.

A scheduling decision is made whenever the execution state of any thread changes—it doesn't matter which processes the threads might reside within. *Threads are scheduled globally across all processes.*

Normally the running thread continues to run, but the scheduler performs a context switch from one thread to another whenever the running thread:

Blocks

The running thread blocks when it must wait for some event to occur (response to an IPC request, wait on a mutex, etc.). The blocked thread is removed from the running array, and another thread is selected to run:

- In the single-core (simple) case, the highest-priority ready thread that's at the head of its priority's queue is chosen and allowed to run.
- In a multicore system, the scheduler has some flexibility in deciding exactly how to schedule the other threads, with an eye towards optimizing cache usage and minimizing thread migration. This could mean that some processors will be running lower-priority threads while a higher-priority thread is waiting to run on the processor it last ran on. The next time a processor that's running a lower-priority thread makes a scheduling decision, it will choose the higher-priority one.

  In any case, the realtime scheduling rules that were in place on a uniprocessor system are guaranteed to be upheld on a multicore system.

When the blocked thread is subsequently unblocked, it's usually placed on the end of the ready queue for its priority level.

Is preempted

The running thread is preempted when a higher-priority thread is placed on the ready queue (it becomes READY as the result of its block condition being resolved). The preempted thread is moved to the start of the ready queue for that priority, and the higher-priority thread runs. When it's time for a thread at that priority level to run again, that thread resumes execution—a preempted thread doesn't lose its place in the queue for its priority level.

Yields

The running thread voluntarily yields the processor (e.g., via `sched_yield`) and is placed on the end of the ready queue for that priority. The highest-priority thread then runs (which may still be the thread that just yielded).

Scheduling policies

To meet the needs of various applications, QNX Neutrino provides these scheduling policies:

- *FIFO scheduling* — SCHED_FIFO
- *Round-robin scheduling* — SCHED_RR
- *Sporadic scheduling* — SCHED_SPORADIC

Another scheduling policy (called "other"—SCHED_OTHER) behaves in the same way as round-robin. We don't recommend using the "other" scheduling policy, because its behavior may change in the future.

Each thread in the system may run using any method. Scheduling methods are effective on a per-thread basis, not on a global basis for all threads and processes on a node.

Remember that these scheduling policies apply only when two or more threads that share the same priority are READY (i.e., the threads are directly competing with each other). If a higher-priority thread becomes READY, it immediately preempts all lower-priority threads.

In the following diagram, three threads of equal priority are READY. If Thread A blocks, Thread B will run.

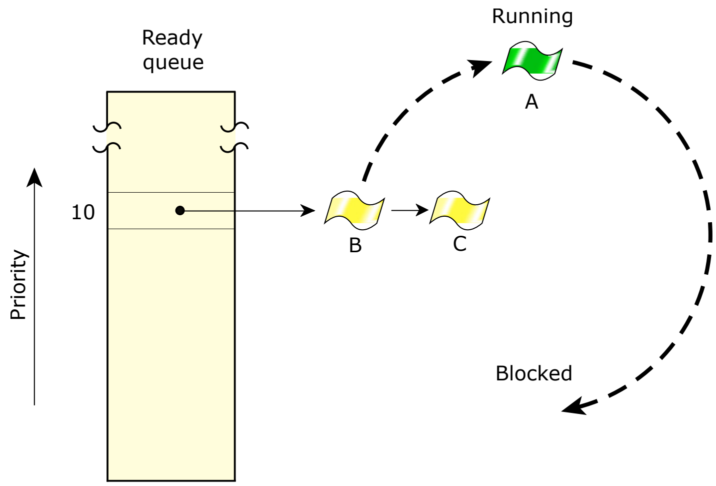


Figure 10: Thread A blocks; Thread B runs.

A thread can call *pthread_attr_setschedparam()* or *pthread_attr_setschedpolicy()* to set the scheduling parameters and policy to use for any threads that it creates.

Although a thread gets its initial priority and scheduling policy from its parent thread (usually by inheritance), the thread can call *pthread_setschedparam()* to request to change the algorithm and priority applied by the kernel, or *pthread_setschedprio()* to change just the priority. A thread can get information about its current algorithm and policy by calling *pthread_getschedparam()*. Both these functions take a thread ID as their first argument; you can call *pthread_self()* to get the calling thread's ID. For example:

```
struct sched_param param;
int policy, retcode;
```

```
/* Get the scheduling parameters. */

retcode = pthread_getschedparam( pthread_self(), &policy, &param);
if (retcode != EOK) {
    printf ("pthread_getschedparam: %s.\n", strerror (retcode));
    return EXIT_FAILURE;
}

printf ("The assigned priority is %d, and the current priority is %d.\n",
        param.sched_priority, param.sched_curpriority);

/* Increase the priority. */

param.sched_priority++;

/* Set the scheduling algorithm to FIFO */

policy = SCHED_FIFO;

retcode = pthread_setschedparam( pthread_self(), policy, &param);
if (retcode != EOK) {
    printf ("pthread_setschedparam: %s.\n", strerror (retcode));
    return EXIT_FAILURE;
}
```

When you get the scheduling parameters, the *sched_priority* member of the `sched_param` structure is set to the assigned priority, and the *sched_curpriority* member is set to the priority that the thread is currently running at (which could be different because of priority inheritance).

Our libraries provide a number of ways to get and set scheduling parameters:

pthread_getschedparam(), ***pthread_setschedparam()***, ***pthread_setschedprio()***

These are your best choice for portability.

SchedGet(), ***SchedSet()***

You can use these to get and set the scheduling priority and policy, but they aren't portable because they're kernel calls.

sched_getparam(), ***sched_setparam()***, ***sched_getscheduler()***, and ***sched_setscheduler()***

These functions are intended for use in single-threaded processes.

Our implementations of these functions don't conform completely to POSIX. In multi-threaded applications, they get or set the parameters for thread 1 in the process *pid*, or for the *calling thread* if *pid* is 0. If you depend on this behavior, your code won't be portable. POSIX 1003.1 says these functions should return -1 and set *errno* to EPERM in a multi-threaded application.

getpriority(), ***setpriority()***

Deprecated; don't use these functions.

FIFO scheduling

In FIFO (SCHED_FIFO) scheduling, a thread selected to run continues executing until it:

- voluntarily relinquishes control (e.g., it blocks)
- is preempted by a higher-priority thread

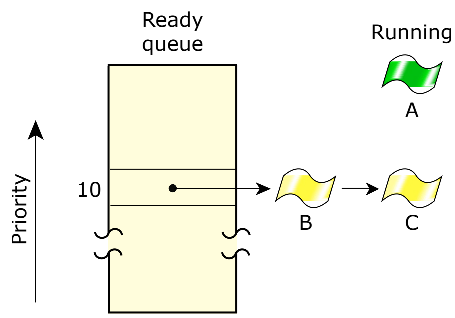


Figure 11: FIFO scheduling. Thread A runs until it blocks.

Round-robin scheduling

In round-robin (SCHED_RR) scheduling, a thread selected to run continues executing until it:

- voluntarily relinquishes control
- is preempted by a higher-priority thread
- consumes its timeslice

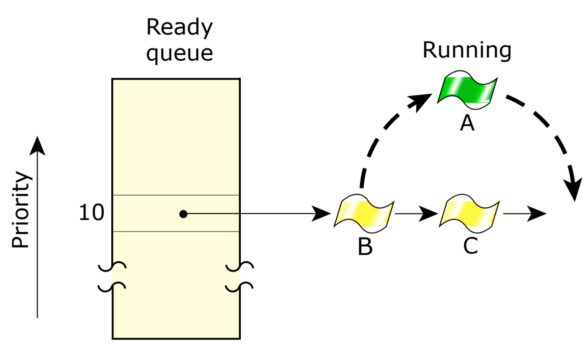


Figure 12: Round-robin scheduling. Thread A ran until it consumed its timeslice; the next READY thread (Thread B) now runs.

A *timeslice* is the unit of time assigned to every process. Once it consumes its timeslice, a thread is put at the end of its queue in the ready queue and the next READY thread at the same priority level is given control.

A timeslice is calculated as:

$4 \times$ *ticksize*

If your processor speed is greater than 40 MHz, then the ticksize defaults to 1 millisecond; otherwise, it defaults to 10 milliseconds. So, the default timeslice is either 4 milliseconds (the default for most CPUs) or 40 milliseconds (the default for slower hardware).

Apart from time-slicing, the round-robin scheduling method is identical to FIFO scheduling.

Sporadic scheduling

The sporadic (SCHED_SPORADIC) scheduling policy is generally used to provide a capped limit on the execution time of a thread *within a given period of time*.

This behavior is essential when Rate Monotonic Analysis (RMA) is being performed on a system that services both periodic and aperiodic events. Essentially, this algorithm allows a thread to service aperiodic events without jeopardizing the hard deadlines of other threads or processes in the system.

Under sporadic scheduling, a thread's priority can oscillate dynamically between a *foreground* or normal priority and a *background* or low priority. For more information, see "Sporadic scheduling" in the QNX Neutrino Microkernel chapter of the *System Architecture* guide.

Why threads?

Now that we know more about priorities, we can talk about why you might want to use threads. We saw many good reasons for breaking things up into separate processes, but what's the purpose of a *multithreaded* process?

The basic purpose of having multiple threads is so you can start something new before finishing something old, that is, something that's already in process.

Let's take the example of a driver. A driver typically has two obligations: one is to talk to the hardware and the other is to talk to other processes. Generally, talking to the hardware is more time-critical than talking to other processes. When an interrupt comes in from the hardware, it needs to be serviced in a relatively small window of time—the driver shouldn't be busy at that moment talking to another process.

One way of fixing this problem is to choose a way of talking to other processes where this situation simply won't arise (e.g., don't send messages to another process such that you have to wait for acknowledgment, don't do any time-consuming processing on behalf of other processes, etc.).

Another way is to use two threads: a higher-priority thread that deals with the hardware and a lower-priority thread that talks to other processes. The lower-priority thread can be talking away to other processes without affecting the time-critical job at all, because when the interrupt occurs, the *higher-priority thread will preempt the lower-priority thread* and then handle the interrupt.

Although this approach does add the complication of controlling access to any common data structures between the two threads, QNX Neutrino provides synchronization tools such as *mutexes* (mutual exclusion locks), which can ensure exclusive access to any data shared between threads.

Talking to hardware

As mentioned earlier in this chapter, writing device drivers is like writing any other program. Only core OS services reside in kernel address space; everything else, including device drivers, resides in process or user address space. This means that a device driver has all the services that are available to regular applications.

Many models are available to driver developers under QNX Neutrino. Generally, the type of driver you're writing will determine the driver model you'll follow. For example, graphics drivers follow one particular model, which allows them to plug into the Screen graphics subsystem, network drivers follow a different model, and so on.

On the other hand, depending on the type of device you're targeting, it may not make sense to follow any existing driver model at all.

This section provides an overview of accessing and controlling device-level hardware in general.

Some hardware operations require I/O privileges; otherwise you'll get a protection fault. To get I/O privileges for a thread, make sure that your process has the PROCMGR_AID_IO ability enabled (see *procmgr_ability()*), and then call *ThreadCtl()*:

```
ret = ThreadCtl(_NTO_TCTL_IO, 0);
if (ret == -1) {
   // An error occurred.
}
```

Probing the hardware

If you're targeting a closed embedded system with a fixed set of hardware, your driver may be able to assume that the hardware it's going to control is present in the system and is configured in a certain way. But if you're targeting more generic systems, you want to first determine whether the device is present. Then you need to figure out how the device is configured (e.g., what memory ranges and interrupt level belong to the device).

For some devices, there's a standard mechanism for determining configuration. Devices that interface to the PCI bus have such a mechanism; each PCI device has a unique vendor and device ID assigned to it. For more information, see the *PCI Server User's Guide*.

Different buses have different mechanisms for determining which resources have been assigned to the device. On some buses, such as the ISA bus, there's no such mechanism. How do you determine whether an ISA device is present in the system and how it's configured? The answer is card-dependent (with the exception of PnP ISA devices).

Accessing the hardware

Once you've determined what resources have been assigned to the device, you're now ready to start communicating with the hardware. How you do this depends on the resources.

I/O resources

In order to perform port I/O, you need to map the I/O base address into your process's address space, using *mmap_device_io()*. For example:

```
uintptr_t iobase;

iobase = mmap_device_io(base_address_size, cpu_base_address);
```

To do the port I/O, use functions such as *in8()*, *in32()*, *out8()*, and so on, adding the register index to *iobase* to address a specific register:

```
out32(iobase + SHUTDOWN_REGISTER, 0xdeadbeef);
```

Note that the call to *mmap_device_io()* isn't necessary on x86 systems, but it's still a good idea to include it for the sake of portability. In the case of some legacy x86 hardware, it may not make sense to call it; for example, a VGA-compatible device has I/O ports at well-known, fixed locations (e.g., 0x3c0, 0x3d4, 0x3d5) with no concept of an I/O base as such. You could access the VGA controller, for example, as follows:

```
out8(0x3d4, 0x11);
out8(0x3d5, in8(0x3d5) & ~0x80);
```

Memory-mapped resources

For some devices, registers are accessed via regular memory operations. To gain access to a device's registers, you need to map them to a pointer in the driver's virtual address space by calling *mmap_device_memory()*. For example:

```
volatile uint32_t *regbase; /* device has 32-bit registers */

regbase = mmap_device_memory(NULL, base_address_size,
             PROT_READ|PROT_WRITE|PROT_NOCACHE, 0, cpu_base_address);
```

Note the following:

- We declared *regbase* with the `volatile` keyword to prevent the compiler from optimizing out accesses to the device's registers.
- We specified the PROT_NOCACHE flag to ensure that the CPU won't defer or omit read/write cycles to the device's registers.

Now you may access the device's memory using the *regbase* pointer. For example:

```
regbase[SHUTDOWN_REGISTER] = 0xdeadbeef;
```

IRQs

You can attach an interrupt handler to the device by calling either *InterruptAttach()* or *InterruptAttachEvent()*. For example:

```
InterruptAttach(_NTO_INTR_CLASS_EXTERNAL | irq,
                handler, NULL, 0, _NTO_INTR_FLAGS_END);
```

> The driver must successfully call `ThreadCtl(_NTO_TCTL_IO, 0)` before it can attach an interrupt.

The essential difference between *InterruptAttach()* and *InterruptAttachEvent()* is the way in which the driver is notified that the device has triggered an interrupt:

- With *InterruptAttach()*, the driver's handler function is called directly by the kernel. Since it's running in kernel space, the handler is severely restricted in what it can do:
  - From within this handler, it isn't safe to call most of the C library functions.
  - If you spend too much time in the handler, other processes and interrupt handlers of a lower or equal priority won't be able to run.
  - Doing too much work in the interrupt handler can negatively affect the system's realtime responsiveness.

  We recommend that you do the bare minimum within the handler (e.g., acknowledge the interrupt at the hardware level) and then deliver an event to the driver. The driver then completes the rest of the work at process level at the driver's normal priority.
- With *InterruptAttachEvent()*, you specify an event to be delivered to the driver when the device triggers an interrupt. The driver then handles the interrupt at the process level.

For more information, see the "*Writing an Interrupt Handler*" chapter in this guide.

Summary

The modular architecture is apparent throughout the entire system: the QNX Neutrino RTOS itself consists of a set of cooperating processes, as does an application.

Each individual process can comprise several cooperating threads. What “keeps everything together” is the priority-based preemptive scheduling in QNX Neutrino, which ensures that time-critical tasks are dealt with by the right thread or process at the right time.

Chapter 3
Processes

As we stated in the Overview chapter, the architecture of the QNX Neutrino RTOS consists of a small microkernel and some number of cooperating *processes*. We also pointed out that your applications should be written the same way—as a set of cooperating processes.

In this chapter, we'll see how to start processes (also known as *creating* processes) from code, how to terminate them, and how to detect their termination when it happens.

For another perspective, see the Processes and Threads and Message Passing chapters of *Getting Started with QNX Neutrino*.

Starting processes: two methods

In embedded applications, there are two typical approaches to starting your processes at boot time.

One approach is to run a *shell script* that contains the command lines for running the processes. There are some useful utilities such as `on` and `nice` for controlling how those processes are started.

The other approach is to have a *starter process* run at boot time. This starter process then starts up all your other processes. This approach has the advantage of giving you more control over how processes are started, whereas the script approach is easier for you (or anyone) to modify quickly.

Process creation

The process manager component of `procnto` is responsible for process creation. If a process wants to create another process, it makes a call to one of the process-creation functions, which then effectively sends a message to the process manager.

Here are the process-creation functions:

- *exec*()* family of functions: *execl()*, *execle()*, *execlp()*, *execlpe()*, *execv()*, *execve()*, *execvp()*, *execvpe()*
- *fork()*
- *forkpty()*
- *popen()*
- *posix_spawn()*
- *spawn*()* family of functions: *spawn()*, *spawnl()*, *spawnle()*, *spawnlp()*, *spawnlpe()*, *spawnp()*, *spawnv()*, *spawnve()*, *spawnvp()*, *spawnvpe()*
- *system()*

It's possible to call *fork()* from a multithreaded process, but it can be very difficult to do so safely, so we recommend that you call it only from single-threaded processes. For more information, see "Using *fork()* in a multithreaded process" in the "Processes and Threads" chapter of *Getting Started with QNX Neutrino*.

There are several versions of *spawn*()* and *exec*()*; the asterisk represents one to three letters, where:

- `l` or `v` (one is required) indicates the way the process parameters are passed
- `p` (optional) indicates that the *PATH* environment variable is searched to locate the program for the process
- `e` (optional) indicates that the environment variables are being passed

For details on each of these functions, see their entries in the QNX Neutrino *C Library Reference*, as well as the "Processes and Threads" chapter of *Getting Started with QNX Neutrino*. Here we'll mention some of the things common to many of them.

When you start a new process, it replaces the existing process if:

- You specify POSIX_SPAWN_EXEC in the extended flags before you call *posix_spawn()*. In spite of the name, this flag is a QNX Neutrino extension.
- You specify P_OVERLAY when calling one of the *spawn** functions.
- You call one of the *exec** routines.

The calling thread in the existing process is suspended while the new process executes (control continues at the point following the place where the new process was started) in the following situations:

- You specify P_WAIT when calling one of the *spawn** functions.
- You call *system()*.

The *system()* function involves a lot of overhead, so you should avoid using it when you just want to create a process. You should use it only when you need a shell that can parse a complex command line, for example, involving pipes or the redirection of file descriptors.

Concurrency

Three possibilities can happen to the creator during process creation:

1. The child process is created and runs concurrently with the parent. In this case, as soon as process creation is successful, the process manager replies to the parent, and the child is made READY. If it's the parent's turn to run, then the first thing it does is return from the process-creation function. This may not be the case if the child process was created at a higher priority than the parent (in which case the child will run before the parent gets to run again).

   This is how *fork()*, *forkpty()*, *popen()*, and *spawn()* work. This is also how the *spawn*()* family of functions work when you specify a mode of P_NOWAIT or P_NOWAITO.

2. The child replaces the parent. In fact, they're not really parent and child, because the image of the given process simply replaces that of the caller. Many things will change, but those things that uniquely identify a process (such as the process ID) will remain the same. This is typically referred to as "execing," since usually the *exec*()* functions are used.

   Many things will remain the same (including the process ID, parent process ID, and file descriptors) with the exception of file descriptors that had the FD_CLOEXEC flag set using *fcntl()*. See the *exec*()* functions for more on what will and will not be the same across the exec.

   The `login` command serves as a good example of execing. Once the login is successful, the `login` command execs into a shell.

   Functions you can use for this type of process creation are the *exec*()* and *spawn*()* families of functions, with mode passed as P_OVERLAY.

3. The calling thread in the parent waits until the child terminates. You can make this happen by passing the mode as P_WAIT when you call one of the *spawn*()* functions.

   Note that what is going on underneath the covers in this case is that *spawn()* is called as in the first possibility above. Then, after it returns, *waitpid()* is called in order to wait for the child to terminate. This means that you can use any of the functions mentioned in our first possibility above to achieve the same thing if you follow them by a call to one of the *wait*()* functions (e.g., *wait()* or *waitpid()*).

Many programmers coming from the Unix world are familiar with the technique of using a call to *fork()* followed by a call to one of the *exec*()* functions in order to create a process that's different from the caller. In QNX Neutrino, you can usually achieve the same thing more efficiently with a single call to one of the *posix_spawn*()* or *spawn*()* functions.

Inheriting file descriptors

The documentation in the QNX Neutrino *C Library Reference* for each function describes in detail what the child inherits from the parent. One thing that we should talk about here, however, is file-descriptor inheritance.

With many of the process-creation functions, the child inherits the file descriptors of the parent. For example, if the parent had file descriptor 5 in use for a particular file when the parent creates the child, the child will also have file descriptor 5 in use for that same file. The child's file descriptor will have been duplicated from the parent's. This means that at the filesystem manager level, the parent and child have the same open control block (OCB) for the file, so if the child seeks to some position in the file, then that changes the parent's seek position as well. It also means that the child can do a `write(5, buf, nbytes)` without having previously called *open()*.

If you don't want the child to inherit a particular file descriptor, then you can use *fcntl()* to prevent it. Note that this won't prevent inheritance of a file descriptor during a *fork()*. The call to *fcntl()* would be:

```
fcntl(fd, F_SETFD, FD_CLOEXEC);
```

If you want the parent to set up exactly which files will be open for the child, then you can use the *fd_count* and *fd_map* parameters with *spawn()*. Note that in this case, only the file descriptors you specify will be inherited. This is especially useful for redirecting the child's standard input (file descriptor 0), standard output (file descriptor 1), and standard error (file descriptor 2) to places where the parent wants them to go.

Alternatively this file descriptor inheritance can also be done through use of *fork()*, one or more calls to *dup()*, *dup2()*, and *close()*, and then *exec*()*. The call to *fork()* creates a child that inherits all the of the parent's file descriptors. *dup()*, *dup2()* and *close()* are then used by the child to rearrange its file descriptors. Lastly, *exec*()* is called to replace the child with the process to be created. Though more complicated, this method of setting up file descriptors is portable whereas the *spawn()* method is not.

Inheriting file descriptors can be a security problem for setuid or setgid processes. For example, a malicious programmer might close *stdin*, *stdout*, or *stderr* before spawning the process. If the process opens a file, it can receive file descriptor 0, 1, or 2. If the process then uses *stdin*, *stdout*, or *stderr*, it might unintentionally corrupt the file. To help prevent such a situation, you can use *set_lowest_fd()* to make sure that your process never gets a file descriptor lower than what you expect.

Process termination

A process can terminate in one of the following basic ways:

- by exiting (i.e., the process terminates itself)
- by being signalled
- by having no running threads (i.e., the thread count goes to 0)

In some operating systems, if a parent process dies, then all of its child processes die too. This isn't the case in QNX Neutrino.

When a process terminates—no matter why—all of its resources are cleaned up:

- Any remaining threads are terminated.
- All file descriptors are closed.
- All channels and side-channel connections are destroyed.
- All memory mappings for the process are unmapped. This includes code, data, heap, hardware mappings, and shared memory.

Process termination from *exit()*

A process can terminate itself by having any thread in the process call *exit()*. Returning from *main()* (i.e., in the main thread) also terminates the process, because the code that's returned to calls *exit()*. This isn't true of threads other than the main thread; returning normally from one of them causes *pthread_exit()* to be called, which terminates only that thread.

The value passed to *exit()* or returned from *main()* is called the *exit status*.

When a process dies by calling *exit()*, “normal exit processing” happens. This includes:

- flushing *stdio* buffers, including *stdout*
- calling at-exit handlers registered by the *atexit()* function

Process termination from signals

A process can be terminated by a signal for a number of reasons. Ultimately, all of these reasons will result in a *signal's being set on the process.* A signal is something that can interrupt the flow of your threads at any time. The default action for most signals is to terminate the process.

- What causes a particular signal to be generated is sometimes processor-dependent.
- The cleanup of the terminated process occurs by default at the priority of the thread that sent the signal. As a QNX Neutrino extension to POSIX functions, if you OR the SIG_TERMER_NOINHERIT flag (defined in **<signal.h>**) into the signal number, the cleanup occurs at the priority of the thread that received the signal.

Here are some of the reasons that a process might be terminated by a signal:

- If any thread in the process tries to use a pointer that doesn't contain a valid virtual address for the process, then the hardware will generate a fault and the kernel will handle the fault by setting the SIGSEGV signal on the process. By default, this will terminate the process.

- A floating-point exception will cause the kernel to set the SIGFPE signal on the process. The default is to terminate the process.
- If you create a shared memory object and then map in more than the size of the object, when you try to write past the size of the object you'll be hit with SIGBUS. In this case, the virtual address used is valid (since the mapping succeeded), but the memory cannot be accessed.
- Another process might explicitly send a signal to your process; for example:

  ```
  kill( pid, SIGTERM );
  ```

When a process dies due to a signal that isn't handled or masked, “normal exit processing” doesn't happen, so this is often called *abnormal* termination of a process.

To get the kernel to display some diagnostics whenever a process terminates abnormally, configure `procnto` with multiple `-v` options. If the process has fd 2 open, then the diagnostics are displayed using (*stderr*); otherwise; you can specify where the diagnostics get displayed by using the `-D` option to your startup. For example, the `-D` as used in this buildfile excerpt will cause the output to go to a serial port:

```
[virtual=x86,bios +compress] .bootstrap = {
    startup-x86 -D 8250..115200
    procnto-smp-instr -vvvv
}
```

You can also have the current state of a terminated process written to a file so that you can later bring up the debugger and examine just what happened. This type of examination is called *postmortem* debugging. This happens only if the process is terminated due to one of these signals:

Signal	Description
SIGABRT	Program-called abort function
SIGBUS	Parity error
SIGEMT	EMT instruction (emulation trap) Note that SIGEMT and SIGDEADLK (mutex deadlock; see *SyncMutexEvent()*) refer to the same signal.
SIGFPE	Floating-point error or division by zero
SIGILL	Illegal instruction executed One possible cause for this signal is trying to perform an operation that requires *I/O privileges*. To request these privileges: **1.** The process must have the PROCMGR_AID_IO ability enabled. For more information, see *procmgr_ability()*. **2.** The thread must call *ThreadCtl()*, specifying the _NTO_TCTL_IO flag: `ThreadCtl( _NTO_TCTL_IO, 0 );`

Signal	Description
SIGQUIT	Quit
SIGSEGV	Segmentation violation
SIGSYS	Bad argument to a system call
SIGTRAP	Trace trap (not reset when caught)
SIGXCPU	Exceeded the CPU limit

The process that dumps the state to a file when the process terminates is called `dumper`, which must be running when the abnormal termination occurs. This is extremely useful, because embedded systems may run unassisted for days or even years before a crash occurs, making it impossible to reproduce the actual circumstances leading up to the crash.

Process termination from thread loss

A process must have one or more threads. If the number of threads in a process goes to 0, the process is terminated.

When a thread calls *pthread_exit()*, that thread is terminated. If any thread but the main thread returns from its thread function, then the wrapping code calls *pthread_exit()*. If the last thread in a process calls *pthread_exit()*, then the process is terminated; in this case, “normal exit processing” doesn't happen.

Detecting process termination

In an embedded application, it's often important to detect if any process terminates prematurely and, if so, to handle it.

Handling it may involve something as simple as restarting the process or as complex as:

1. Notifying other processes that they should put their systems into a safe state.
2. Resetting the hardware.

This is complicated by the fact that some processes call *procmgr_daemon()*. Processes that call this function are referred to as *daemons*. The *procmgr_daemon()* function:

- detaches the caller from the controlling terminal
- puts it in session 1
- optionally, closes all file descriptors except *stdin*, *stdout*, and *stderr*
- optionally, redirects *stdin*, *stdout*, *stderr* to **/dev/null**
- severs the parent-child relationship

As a result of the above, their termination is hard to detect.

Another scenario is where a server process wants to know if any of its clients disappear so that it can clean up any resources it had set aside on their behalf.

Let's look at various ways of detecting process termination.

Using the High Availability Framework

The High Availability Framework provides components not only for detecting when processes terminate, but also for recovering from such terminations.

The main component is a process called the High Availability Manager (`ham`) that acts as a "smart watchdog". Your processes talk to `ham` using the HAM API. With this API you basically set up conditions that `ham` should watch for and take actions when these conditions occur. For example, you can tell `ham` to detect when a process terminates and automatically restart it. The HAM can even detect the termination of daemon processes.

In fact, the High Availability Manager can restart a number of processes, wait between restarts for a process to be ready, and notify the process that this is happening.

The HAM also does *heartbeating*: processes can periodically notify `ham` that they're still functioning correctly; if a process-specified amount of time goes by between notifications, then `ham` can take some action.

The above are just a sample of what's possible with the High Availability Framework. For more information, see the High Availability Framework *Developer's Guide*.

Detecting termination from a starter process

If you've created a set of processes using a starter process, then all those processes are children of that process, with the exception of those that have called *procmgr_daemon()*.

If all you want to do is detect that one of those children has terminated, then a loop that blocks on *wait()* or *sigwaitinfo()* will suffice. Note that when a child process calls *procmgr_daemon()*, both *wait()* and *sigwaitinfo()* behave as if the child process died, although the child is still running.

The *wait()* function will block, waiting until any of the caller's child processes terminate. The other *wait*()* functions include *waitpid()*, which lets you wait for a specific child process, *wait3()*, and *wait4()*. Lastly, there is *waitid()*, which is the lower level of all the *wait*()* functions and returns the most information.

The *wait*()* functions won't always help, however. If a child process was created using one of the *spawn*()* family of functions with the mode passed as P_NOWAITO, then the *wait*()* functions won't be notified of its termination!

What if the child process terminates, but the parent hasn't yet called *wait*()*? This would be the case if one child had already terminated, so *wait*()* returned, but then before the parent got back to the *wait*()*, *a second child terminates*. In that case, some information would have to be stored away about the second child for when the parent does get around to its *wait*()*.

This is in fact the case. The second child's memory will have been freed up, its files will have been closed, and in general the child's resources will have been cleaned up with the exception of a few bytes of memory in the process manager that contain the child's exit status or other reason that it had terminated and its process ID. When the second child is in this state, it's referred to as a *zombie*. The child will remain a zombie until the parent either terminates or finds out about the child's termination (e.g., the parent calls *wait*()*).

What this means is that if a child has terminated and the parent is still alive but doesn't yet know about the terminated child (e.g., hasn't called *wait*()*), then the zombie will be hanging around. If the parent will never care, then you may as well not have the child become a zombie. To prevent the child from becoming a zombie when it terminates, create the child process using one of the *spawn*()* family of functions and pass P_NOWAITO for the *mode*.

Sample parent process using *wait()*

The following sample illustrates the use of *wait()* for waiting for child processes to terminate.

```
/*
 * waitchild.c
 *
 * This is an example of a parent process that creates some child
 * processes and then waits for them to terminate. The waiting is
 * done using wait(). When a child process terminates, the
 * wait() function returns.
*/

#include <spawn.h>
#include <stdio.h>
#include <stdlib.h>
```



```
#include <unistd.h>
#include <sys/wait.h>

main(int argc, char **argv)
{
    char                *args[] = { "child", NULL };
    int                 i, status;
    pid_t               pid;
    struct inheritance  inherit;

    // create 3 child processes
    for (i = 0; i < 3; i++) {
        inherit.flags = 0;
        if ((pid = spawn("child", 0, NULL, &inherit, args, environ)) == -1)
            perror("spawn() failed");
        else
            printf("spawned child, pid = %d\n", pid);
    }

    while (1) {
        if ((pid = wait(&status)) == -1) {
            perror("wait() failed (no more child processes?)");
            exit(EXIT_FAILURE);
        }
        printf("a child terminated, pid = %d\n", pid);

        if (WIFEXITED(status)) {
            printf("child terminated normally, exit status = %d\n",
                WEXITSTATUS(status));
        } else if (WIFSIGNALED(status)) {
            printf("child terminated abnormally by signal = %X\n",
                WTERMSIG(status));
        } // else see documentation for wait() for more macros
    }
}
```

The following is a simple child process to try out with the above parent:

```
#include <stdio.h>
#include <unistd.h>

main(int argc, char **argv)
{
    printf("pausing, terminate me somehow\n");
    pause();
}
```

Sample parent process using *sigwaitinfo()*

The *sigwaitinfo()* function blocks, waiting until any signals that the caller tells it to wait for are set on the caller. If a child process terminates, then the SIGCHLD signal is set on the parent. So all the parent has to do is request that *sigwaitinfo()* return when SIGCHLD arrives.

The following sample illustrates the use of *sigwaitinfo()* for waiting for child processes to terminate:

```
/*
 * sigwaitchild.c
 *
 * This is an example of a parent process that creates some child
 * processes and then waits for them to terminate.  The waiting is
 * done using sigwaitinfo().  When a child process terminates, the
 * SIGCHLD signal is set on the parent.  sigwaitinfo() will return
 * when the signal arrives.
*/

#include <errno.h>
#include <spawn.h>
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/neutrino.h>

void
signal_handler(int signo)
{
    // do nothing
}

int main(void)
{
    char                *args[] = { "child", NULL };
    int                 i;
    pid_t               pid;
    sigset_t            mask;
    siginfo_t           info;
    struct inheritance  inherit;
    struct sigaction    action;

    // mask out the SIGCHLD signal so that it will not interrupt us,
    // (side note: the child inherits the parents mask)
    sigemptyset(&mask);
    sigaddset(&mask, SIGCHLD);
    sigprocmask(SIG_BLOCK, &mask, NULL);

    // by default, SIGCHLD is set to be ignored so unless we happen
    // to be blocked on sigwaitinfo() at the time that SIGCHLD
    // is set on us we will not get it.  To fix this, we simply
    // register a signal handler.  Since we've masked the signal
    // above, it will not affect us.  At the same time we will make
    // it a queued signal so that if more than one are set on us,
    // sigwaitinfo() will get them all.
    action.sa_handler = signal_handler;
    sigemptyset(&action.sa_mask);
    action.sa_flags = SA_SIGINFO; // make it a queued signal
    sigaction(SIGCHLD, &action, NULL);
```

```
    // create 3 child processes
    for (i = 0; i < 3; i++) {
        inherit.flags = 0;
        if ((pid = spawn("child", 0, NULL, &inherit, args, environ)) == -1)
            perror("spawn() failed");
        else
            printf("spawned child, pid = %d\n", pid);
    }

    while (1) {
        if (sigwaitinfo(&mask, &info) == -1) {
            perror("sigwaitinfo() failed");
            continue;
        }
        switch (info.si_signo) {
        case SIGCHLD:
            // info.si_pid is pid of terminated process, it is not POSIX
            printf("A child terminated; pid = %d\n", info.si_pid);
            break;
        default:
            // Should not get here since we asked only for SIGCHLD
            printf("Unexpected signal: %d\n", info.si_signo);
        }
    }
}
```

Detecting dumped processes

As mentioned above, you can run `dumper` so that when a process dies, `dumper` writes the state of the process to a file.

You can also write your own dumper-type process to run instead of, or as well as, `dumper`. This way the terminating process doesn't have to be a child of yours.

To do this, write a resource manager that registers the name, **/proc/dumper** with type _FTYPE_DUMPER. When a process dies due to one of the appropriate signals, the process manager will open **/proc/dumper** and write the pid of the process that died—then it'll wait until you reply to the write with success and then it'll finish terminating the process.

It's possible that more than one process will have **/proc/dumper** registered at the same time, however, the process manager notifies only the process that's at the beginning of its list for that name. Undoubtedly, you want both your resource manager and `dumper` to handle this termination. To do this, request the process manager to put you, instead of `dumper`, at the beginning of the **/proc/dumper** list by passing _RESMGR_FLAG_BEFORE in the *flags* argument to *resmgr_attach()*. You must also open **/proc/dumper** so that you can communicate with `dumper` if it's running. Whenever your *io_write* handler is called, write the pid to `dumper` and do your own handling. Of course this works only when `dumper` is run before your resource manager; otherwise, your open of **/proc/dumper** won't work.

The following is a sample process that demonstrates the above:

```
/*
 *  dumphandler.c
 *
```

```
 *  This demonstrates how you get notified whenever a process
 *  dies due to any of the following signals:
 *
 *  SIGABRT
 *  SIGBUS
 *  SIGEMT
 *  SIGFPE
 *  SIGILL
 *  SIGQUIT
 *  SIGSEGV
 *  SIGSYS
 *  SIGTRAP
 *  SIGXCPU
 *
 *  To do so, register the path, /proc/dumper with type
 *  _FTYPE_DUMPER. When a process dies due to one of the above
 *  signals, the process manager will open /proc/dumper, and
 *  write the pid of the process that died - it will wait until
 *  you reply to the write with success, and then it will finish
 *  terminating the process.
 *
 *  Note that while it is possible for more than one process to
 *  have /proc/dumper registered at the same time, the process
 *  manager will notify only the one that is at the beginning of
 *  its list for that name.
 *
 *  But we want both us and dumper to handle this termination.
 *  To do this, we make sure that we get notified instead of
 *  dumper by asking the process manager to put us at the
 *  beginning of its list for /proc/dumper (done by passing
 *  _RESMGR_FLAG_BEFORE to  resmgr_attach()).  We also open
 *  /proc/dumper so that we can communicate with dumper if it is
 *  running.  Whenever our io_write handler is called, we write
 *  the pid to dumper and do our own handling.  Of course, this
 *  works only if dumper is run before we are, or else our open
 *  will not work.
 *
 */

#include <errno.h>
#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <string.h>
#include <unistd.h>
#include <sys/iofunc.h>
#include <sys/dispatch.h>
#include <sys/neutrino.h>
#include <sys/procfs.h>
#include <sys/stat.h>

int io_write (resmgr_context_t *ctp, io_write_t  *msg,
              RESMGR_OCB_T *ocb);
```

```
static int  dumper_fd;

resmgr_connect_funcs_t  connect_funcs;
resmgr_io_funcs_t       io_funcs;
dispatch_t              *dpp;
resmgr_attr_t           rattr;
dispatch_context_t      *ctp;
iofunc_attr_t           ioattr;

char    *progname = "dumphandler";

main(int argc, char **argv)
{
    /* find dumper so that we can pass any pids on to it */
    dumper_fd = open("/proc/dumper", O_WRONLY);

    dpp = dispatch_create();

    memset(&rattr, 0, sizeof(rattr));
    rattr.msg_max_size = 2048;

    iofunc_func_init(_RESMGR_CONNECT_NFUNCS, &connect_funcs,
                     _RESMGR_IO_NFUNCS, &io_funcs);
    io_funcs.write = io_write;

    iofunc_attr_init(&ioattr, S_IFNAM | 0600, NULL, NULL);

    resmgr_attach(dpp, &rattr, "/proc/dumper", _FTYPE_DUMPER,
                  _RESMGR_FLAG_BEFORE, &connect_funcs,
                  &io_funcs, &ioattr);

    ctp = dispatch_context_alloc(dpp);

    while (1) {
        if ((ctp = dispatch_block(ctp)) == NULL) {
            fprintf(stderr, "%s:  dispatch_block failed: %s\n",
                            progname, strerror(errno));
            exit(1);
        }
        dispatch_handler(ctp);
    }
}

struct dinfo_s {
    procfs_debuginfo    info;
    char                pathbuffer[PATH_MAX]; /* 1st byte is
                                                 info.path[0] */
};

int
display_process_info(pid_t pid)
{
    char            buf[PATH_MAX + 1];
    int             fd, status;
```

```
    struct dinfo_s  dinfo;
    procfs_greg     reg;

    printf("%s: process %d died\n", progname, pid);

    sprintf(buf, "/proc/%d/ctl", pid);

    if ((fd = open(buf, O_RDONLY|O_NONBLOCK)) == -1)
        return errno;

    status = devctl(fd, DCMD_PROC_MAPDEBUG_BASE, &dinfo,
                    sizeof(dinfo), NULL);
    if (status != EOK) {
        close(fd);
        return status;
    }

    printf("%s: name is %s\n", progname, dinfo.info.path);

    /*
     * For getting other type of information, see sys/procfs.h,
     * sys/debug.h, and sys/dcmd_proc.h
     */

    close(fd);
    return EOK;
}

int
io_write(resmgr_context_t *ctp, io_write_t *msg,
         RESMGR_OCB_T *ocb)
{
    char *pstr;
    int status;

    if ((status = iofunc_write_verify(ctp, msg, ocb, NULL))
        != EOK)
        return status;

    if ( (msg->i.xtype & _IO_XTYPE_MASK) != _IO_XTYPE_NONE)
        return ENOSYS;


    if (dumper_fd != -1) {
        /* pass it on to dumper so it can handle it too */

        if (write(dumper_fd, msg+1, msg->i.nbytes) == -1) {
            close(dumper_fd);
            dumper_fd = -1; /* something wrong, no sense in
                               doing it again later */
        }
    }

    /* Proc writes us the pid as a string; get a pointer to the write data */
```

```
    pstr = (char *) (msg+1);

    /* Assume we have room for a null byte at the end of the pid in our
      (default) 1500 byte receive buffer */
    pstr[msg->i.nbytes] = '\0';

    if ((status = display_process_info(atoi(pstr))) != EOK)
        return status;

    _IO_SET_WRITE_NBYTES(ctp, msg->i.nbytes);

    return EOK;
}
```

For more information about getting process information (including using the DCMD_PROC_MAPDEBUG_BASE *devctl()* command), see "*Controlling processes via the /proc filesystem*," later in this chapter.

Detecting the termination of daemons or of *all* processes

What would happen if you've created some processes that subsequently made themselves daemons (i.e., called *procmgr_daemon()*)? As we mentioned above, the *wait*()* functions and *sigwaitinfo()* won't help.

For these you can give the kernel an event, such as one containing a pulse, and have the kernel deliver that pulse to you whenever a daemon terminates. This request for notification is done by calling *procmgr_event_notify()* or *procmgr_event_notify_add()* with PROCMGR_EVENT_DAEMON_DEATH in *flags*.

The difference between these functions is that with *procmgr_event_notify()*, your process can have one notification request; if you call the function again, the request replaces the previous one. With *procmgr_event_notify_add()*, your process can have more than one notification request.

See the documentation for *procmgr_event_notify()* for an example that uses PROCMGR_EVENT_DAEMON_DEATH.

(QNX Neutrino 7.0 or later) The PROCMGR_EVENT_PROCESS_DEATH event type is similar to PROCMGR_EVENT_DAEMON_DEATH, but it requests notification of the death of *all* processes. If you set the SIGEV_FLAG_UPDATEABLE flag in the event, the notification includes the process ID of the process that died. Here's an example:

```
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#include <sys/neutrino.h>
#include <process.h>
#include <sys/procmgr.h>


int main(void)
{
```



```
int chid, coid;
int rcvid;
struct _pulse pulse;
struct sigevent ev;

// Create a channel that's private to this process.
// No other process can connect to it.
chid = ChannelCreate( _NTO_CHF_PRIVATE );
if (-1 == chid)
{
   // Was there an error creating the channel?
   perror("ChannelCreate()"); // Look up the errno code and print
   exit(EXIT_FAILURE);
}

// To ask for pulse delivery, we need a connection to our own channel.
coid = ConnectAttach( 0, 0, chid, _NTO_SIDE_CHANNEL, 0 );
if (-1 == coid)
{
   // Was there an error creating the channel?
   perror("ConnectAttach()"); // Look up the errno code and print
   exit(EXIT_FAILURE);
}

SIGEV_PULSE_INIT( &ev, coid, 10, 1, 0 );
SIGEV_MAKE_UPDATEABLE(&ev);

// Request process death notifications
procmgr_event_notify( PROCMGR_EVENT_PROCESS_DEATH, &ev );

while (1)
{
   rcvid = MsgReceive( chid, &pulse, sizeof pulse, NULL );
   if (-1 == rcvid)
   {
      // Was there an error receiving msg?
      perror("MsgReceive"); // Look up errno code and print
      exit(EXIT_FAILURE); // Give up
   }

   if( pulse.code == 1 )
   {
      printf("Process with pid %d died.\n", pulse.value.sival_int );
```

```
        }
        else
        {
            printf("Unexpected pulse, code: %d\n", pulse.code );
        }
    }
    return 0;
}
```

Detecting client termination

The last scenario is where a server process wants to be notified of any clients that terminate so that it can clean up any resources that it had set aside for them.

This is very easy to do if the server process is written as a *resource manager*, because the resource manager's *io_close_dup()* and *io_close_ocb()* handlers, as well as the *ocb_free()* function, will be called if a client is terminated for any reason. For more information, see *Writing a Resource Manager*.

If the server process isn't a resource manager, it can pass the _NTO_CHF_DISCONNECT flag when it calls *ChannelCreate()*. This tells the kernel to deliver a pulse when a client process disconnects from the server. If the server is using *name_attach()*, that function automatically sets this flag.

Stack allocation

Each thread has its own stack that you can allocate yourself or have the system manage.

The `pthread_attr_t` structure includes members that specify a new thread's stack address and size; *pthread_attr_init()* sets the default values, and you can use *pthread_attr_setstackaddr()* and *pthread_attr_setstacksize()* to override them. The values of the stack address and size members of this structure control the type of stack allocation that occurs when you create a thread:

Stack address	Stack size	Allocation
NULL	0	Automatic (the default)
NULL	Desired size	Partly automatic
Non-NULL	Size of the allocated area	Manual

Let's compare the types of allocation:

Automatic

The process manager allocates a stack in virtual memory. The default size depends on the architecture:

Architecture	Stack size
32-bit x86	128 KB
x86_64	256 KB
32-bit ARM	128 KB
AArch64	512 KB

The stack is followed by a read-only *guard page* that the process manager uses to detect stack overflow. Initially, only part of the stack is allocated in physical memory. This portion contains the thread local storage (TLS) and other system data that's specific to the thread. The process manager allocates additional 4 KB pages of physical memory when required. The guard page exists only in virtual memory; there's no physical memory allocated for it.

When the thread exits, the process manager automatically deallocates the stack.

Partly automatic

The process manager allocates a stack of the size that you specified, rounded up to a multiple of the page size (4 KB). The space is allocated in virtual memory, with a guard page, and the process manager looks after the stack as it does for automatic allocation.

Manual

The process manager uses the stack that you allocated for the thread. It's up to you to allocate enough space for the thread, and no guard page is provided. The process manager doesn't deallocate the stack when the thread exits.

If you specify a stack size (for partly automatic or manual allocation), it should be the size that you want plus PTHREAD_STACK_MIN, which is the amount of space that the thread needs for its thread local storage and other overhead.

A process's main thread starts with an automatically allocated 512 KB stack, but it isn't deleted when the main thread goes away (e.g., calls *pthread_exit()* or is cancelled). The main thread's stack includes the command-line arguments and environment variables, which other threads might still need. To specify the stack size for the main thread, use `qcc`'s `-N` option.

The output of the `pidin mem` command uses an asterisk (`*`) to indicate a stack that isn't automatically returned to the system heap when the thread exits.

Process privileges

In systems where security is important, applications should run with the fewest privileges possible. Doing this helps reduce the impact of possible compromises and can also help lower the privilege escalation attack surface of the device.

The more difficult it is for attackers to elevate an application's privileges, the better; forcing attackers to chain multiple attacks against various applications that each have minimal sets of permissions is ideal.

Services and other system processes usually have to be started as **root** so that they can do privileged things. To improve security, some of these services and processes implement a `-U` command-line option that specifies the user and group IDs to run as.

This option takes one of these forms:

- `-U` *user_name*[,*sup_gid*]*
- `-U` *uid*[`:`*gid*[`,`*sup_gid*]*]

For example, `-U99:98` specifies that the process is to run as user ID 99 and group ID 98. An integration team can assign the appropriate permissions for each user and group.

After the process starts up and carries out any privileged functionality it requires, and possibly obtains capabilities to retain some privileged permissions, it's expected to lower its permission to those specified by the `-U` option.

The **liblogin** library includes a standard helper function called *set_ids_from_arg()* that you can use to do this. In order to use *set_ids_from_arg()*, you have to include the **<login.h>** file and build with the `-llogin` linker option. The following example shows how to handle the `-U` argument simply:

```
case 'U':
    if( set_ids_from_arg( optarg ) != 0 ) {
        // insert appropriate logging and error handling
        log("Invalid user/group specified [%s]", optarg);
        return EXIT_FAILURE;
    }
    break;
```

If your application can't lower privileges as soon as it parses the `-U` option's argument, you should save the argument and pass it to *set_ids_from_arg()* later.

You should lower application privileges as soon as possible, in stages if necessary. For instance, a resource manager typically needs to register a name in the path space by calling *resmgr_attach()*; in order to do this, it requires the PROCMGR_AID_PATHSPACE ability. The service should obtain this ability and immediately drop to the privileges provided by the `-U` option. After registering the name in the path space, the process should drop the ability if it doesn't need to register any more names.

Privilege separation

Privilege separation is a way of designing an application so that its underlying components are divided into a number of processes with differing privileges.

In many applications, services, and drivers, a part of the program will require some amount of elevated privileges to carry out its job. These privileges might be some capability that allows some specific privileged action, some additional groups that allow access to files, and so on. In many designs, these elevated privileges are taken for granted and are simply considered part of the necessary privileges for the entire program. These designs unfortunately usually result in a privileged process's having an unnecessarily large *attack surface*.

The diagram below illustrates a traditional design, with a system service consisting of a single privileged process. In this example, the attack surface exposes the privileged process to all of the clients.

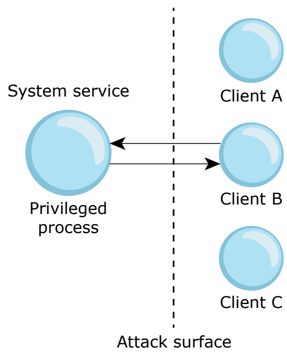


Figure 13: System service with no privilege separation.

For example, a network service that processes incoming packets could be required to carry out some privileged action after processing an incoming packet, requiring the service to have some privileged ability. The processing of all incoming packets, many of which might have nothing to do with running as **root** or some privileged ability, doesn't explicitly require elevated privileges, and therefore the design unnecessarily increases the attack surface of the process.

In this case, you should consider the feasibility of moving the portion of the service that requires special privileges into a separate process with minimal functionality. In this design, a small privileged process can maintain an IPC channel between itself and the network packet processing part of the service. This IPC channel can expose an extremely minimal protocol. This concept is illustrated in the diagram below, which shows two system service processes, and an attack surface exposing only the process with lower privileges.

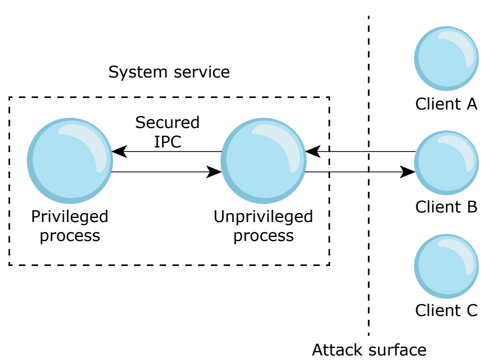


Figure 14: System service with privilege separation.

In the packet-processing scenario, when the nonprivileged part of the application requires some privileged action to take place, it notifies the privileged process, via the IPC channel. This way, any exploited vulnerabilities that manifest from complex operations such as packet processing won't immediately grant an attacker the elevated privileges. The minimal IPC protocol used between the service processes also makes it more difficult for attackers to elevate their privileges by attempting to attack the more privileged process after successfully compromising the less privileged process.

One consideration to keep in mind is the IPC mechanism selected to communicate between the nonprivileged and privileged portions of the service. If you use *fork()* or *spawn()*, followed by *execve()* to start the separated process, then information about the selected IPC mechanism must be transferred because it can't necessarily be inherited easily. In the case of channels and Unix Domain Sockets, the time between when a channel is bound and a child is spawned presents a possible window of attack where the parent process creates the channel and then passes this channel ID to the child process so it can connect. During this window of time, an unauthorized process might be able to connect to the channel. Even if you attempt to enforce UID and GID permissions, there could be another compromised application with the same permissions that might try to connect.

To make sure that the connecting client is in fact the child, we recommend that the implementation verify both the credentials and the process ID (PID) of the channel or UDS client, to make sure that it is in fact the child process connecting. Any other connections should be rejected. In addition, as soon as the connection is established, no further connections should be handled. For a very basic example of how this privilege separation and authentication design might be achieved, see "*An example of privilege separation*."

Note that other widely used Unix services, such as OpenSSH, also carry out this form of privilege separation.

Thread I/O privileges

Some services and drivers have threads that require I/O privileges, which require some special security.

A thread obtains I/O privileges by passing the _NTO_TCTL_IO or _NTO_TCTL_IO_PRIV flag to the *ThreadCtl()* function. In order to do this, the process must have the PROCMGR_AID_IO ability enabled. For more information, see *procmgr_ability()*.

A process containing threads with I/O privileges will represent an extremely likely target of exploitation, and as such must be developed with care. We recommend that you use a privilege separation model when working with I/O privileged threads, where design constraints allow it.

In cases where privilege separation isn't possible and multiple threads must be spawned within one process, only those threads that explicitly require I/O privileges should obtain them.

CAUTION: A thread that has obtained I/O privileges passes those privileges to any thread it spawns.

This inheritance can be problematic in a scenario where you require only one thread to have I/O privileges, and that thread is spawned later on during execution; if you obtain I/O privileges in the main thread, *all the threads it spawns will have I/O privileges*. Obtaining I/O privileges only in the thread explicitly requiring them can make exploitation more difficult by providing an additional obstacle to an attacker who obtains code execution in a non-privileged thread.

Some complications may exist that prevent a process from holding off obtaining I/O privileges; however, these types of issues should be considered and ideally solved during the design phase of the application.

Procmgr abilities

The QNX Neutrino RTOS supports *procmgr abilities*, process-manager settings that govern which operations a particular process is permitted to do.

A privileged process can obtain these abilities before dropping **root** privileges, which lets it retain some functionality that historically would have been restricted to **root**. Furthermore, procmgr abilities can be locked, meaning that even **root** users can't carry out certain actions that they might historically have been able to. This change significantly reduces the attack surface of the system, even when dealing with a **root** process.

We recommend that you use the procmgr ability model wherever possible, retaining specific abilities, and dropping and locking whatever isn't explicitly required. Once you've used the retained abilities, you should drop and lock them if they're no longer necessary. A number of simple examples of ability retention and locking are included in the following sections.

You can adjust procmgr abilities by calling *procmgr_ability()*. This function is typically used by services that start as **root** and need to retain certain capabilities before dropping privileges.

The *procmgr_ability()* function takes as its first argument a process ID, or 0 to indicate the calling process. It's followed by a variable number of arguments, each of which consists of a set of flags that indicate:

- an ability
- the domain (**root** or non-**root**)
- whether or not the ability should be allowed, denied, inheritable, and so on
- whether or not additional arguments are required (e.g., the PROCMGR_AOP_SUBRANGE flag calls for a range to be associated with the ability)

The list of abilities must be terminated by an argument that includes the PROCMGR_AID_EOL flag.

Ability domains

The process manager supports PROCMGR_ADN_ROOT and PROCMGR_ADN_NONROOT flags that indicate which domain an ability applies to.

These flags let a process further limit what actions can be carried out depending on its effective user ID:

PROCMGR_ADN_NONROOT

Modify the ability of the process when it has an effective user ID of 0.

PROCMGR_ADN_ROOT

Modify the ability of the process when it has an effective user ID other than 0.

The following example shows how you can retain a specific ability for your process, before dropping **root** privileges. In the following example, the PROCMGR_AID_PATHSPACE ability is being allowed for non-**root** users:

```
procmgr_ability( 0, PROCMGR_ADN_NONROOT
                    | PROCMGR_AOP_ALLOW
                    | PROCMGR_AID_PATHSPACE,
                  PROCMGR_AID_EOL);
setreuid(new_user, new_user);
setregid(new_group, new_group);
```

Ability ranges

The *procmgr_ability()* function also lets you specify subranges for specific abilities. This is useful for limiting certain abilities to the smallest number of privileges possible.

For example, the PROCMGR_AID_SPAWN_SETUID and PROCMGR_AID_SPAWN_SETGID abilities allow a process to supply specific abilities to a spawned process. Imagine you have a process that needs to spawn child processes that will run with a group other than those of the process. To accomplish this task, the process must obtain one of these abilities. However, the process shouldn't be allowed to simply set arbitrary UIDs and GIDs, or else it might be able to elevate its own privileges. It's possible to supply a subrange that limits what specific user or group identifiers can be supplied.

The following example shows how you can provide a specific subrange to a requested ability:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT           // Non-root domain
                  | PROCMGR_AOP_ALLOW         // Allow the ability
                  | PROCMGR_AOP_SUBRANGE      // Limit ability to a subrange
                  | PROCMGR_AID_SPAWN_SETUID, // Requested ability
                (uint64_t)800, (uint64_t)899, // Subrange for ability
                PROCMGR_AID_EOL               // End of ability list
);
```

In this case, the PROCMGR_AID_SPAWN_SETUID ability is being requested, indicated by the PROCMGR_AOP_ALLOW flag, for user IDs in the range from 800 through 899, as indicated by the PROCMGR_AOP_SUBRANGE flag. The PROCMGR_ADN_NONROOT domain indicates that the process wishes to use this ability when it isn't running as **root**.

We recommend that you limit the subranges requested to as small a set as possible, and include only those values that will explicitly be required.

Locking an ability

An important aspect of procmgr abilities is ability locking, which allows you to force a specific ability to be immutable until the next time the process starts.

This aspect is useful if an ability never needs to be reobtained, especially by a process that is **root**. This also allows non-inheritable abilities to not be subsequently marked as inheritable, and so on. Keep in mind that if you lock an ability and don't mark it as inheritable, then if and when you spawn a new process, that process will not have the ability locked.

The following example demonstrates how to lock a capability by using the PROCMGR_AOP_LOCK flag, effectively preventing it from being changed during the lifetime of the process. The following example specifically adds additional security to the PROCMGR_AOP_SUBRANGE example:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT           // Non-root domain
                  | PROCMGR_AOP_ALLOW         // Allow the ability
                  | PROCMGR_AOP_LOCK          // Prevent further changes
                  | PROCMGR_AOP_SUBRANGE      // Limit ability to a subrange
                  | PROCMGR_AID_SPAWN_SETUID, // Requested ability
                (uint64_t)800, (uint64_t)899, // Subrange for ability
                PROCMGR_AID_EOL               // End of ability list
);
```

Once this call is made, the PROCMGR_AID_SPAWN_SETUID ability can't be modified by anyone. We recommend that you immediately lock all abilities expected to be static after set.

Take care when locking an allowed and inheritable ability. A vulnerability can be introduced if an allowed ability is locked and inheritable and the process then forks or spawns a child that doesn't require the ability or wishes to drop it. Locking should generally be reserved for situations where you are denying an ability. Always check the return code of *procmgr_ability()* and test for an error value of -1 to identify—early in development—these types of problems you may have with dropping abilities.

Dropping an ability

You can drop an ability that your application doesn't need at all, or that it no longer needs.

Here's an example:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT           // Non-root domain
                  | PROCMGR_AOP_DENY          // Drop the ability
                  | PROCMGR_AOP_LOCK          // Prevent further changes
                  | PROCMGR_AID_SPAWN_SETUID, // Specified ability
                PROCMGR_AID_EOL               // End of ability list
);
```

If the application will never again need the ability, you should also specify the PROCMGR_AOP_LOCK flag when you drop it.

If your application has all the abilities that it needs, we recommend that you explicitly deny and lock all other abilities by setting special flags on the PROCMGR_AID_EOL entry that finishes the *procmgr_ability()* parameter list:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT  // Non-root domain
                  | PROCMGR_AOP_DENY // Drop the ability
                  | PROCMGR_AOP_LOCK // Prevent further changes
                  | PROCMGR_AID_EOL  // End of ability list.
);
```

If you OR PROCMGR_AID_EOL with additional flags, *procmgr_ability()* traverses the entire list and applies those flags to any unlocked abilities that you didn't specify in the arguments to the function.

Ability inheritance

By default, procmgr abilities aren't inherited when you create a new process by using *exec*()*, *posix_spawn*()*, or *spawn*()*.

You can modify this setting by specifying the PROCMGR_AOP_INHERIT_YES flag for an ability that a child needs, or PROCMGR_AOP_INHERIT_NO for abilities that a child doesn't need. When children inherit abilities from their parent, make sure that they change the inheritability of any abilities that *their* children shouldn't receive. For example:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT // Non-root domain
                  | PROCMGR_AOP_ALLOW // Allow the ability
                  | PROCMGR_AOP_INHERIT_NO // Prevent inheritance
                  | PROCMGR_AID_SPAWN_SETUID, // Specified ability
                PROCMGR_AID_EOL // End of ability list.
);
```

We recommend against making allowed abilities inheritable unless absolutely necessary. Not marking an allowed ability as inheritable allows the system to set it back to a safe default when executing a new process. Any abilities that have been explicitly locked, denied, or both that shouldn't be accessible to child processes should be marked as inheritable, to make sure that the locks and deny states persist.

Forking and spawning handle ability inheritance in different ways:

- *fork()* creates a nearly exact copy of the parent process, including the current abilities, even if an ability is marked using PROCMGR_AOP_INHERIT_NO.
- *exec*()*, *posix_spawn*()*, and *spawn*()* honor the inheritance flags. The child process inherits only those abilities that have been explicitly marked using PROCMGR_AOP_INHERIT_YES.

Here's a simple example of potentially insecure inheritance, due to the combination of PROCMGR_AOP_ALLOW and PROCMGR_AOP_INHERIT_YES. If you're required to do this in your program, make sure the child doesn't inherit any abilities that it doesn't really need.

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT // Non-root domain
                  | PROCMGR_AOP_ALLOW // Allow the ability
                  | PROCMGR_AOP_INHERIT_YES // Inheritance
                  | PROCMGR_AID_SPAWN_SETUID, // Specified ability
                PROCMGR_AID_EOL // End of ability list.
);
```

The following code is more secure because the child will inherit the denied setting for the ability, due to the combination of PROCMGR_AOP_DENY and PROCMGR_AOP_INHERIT_YES:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT // Non-root domain
                  | PROCMGR_AOP_DENY // Deny the ability
                  | PROCMGR_AOP_INHERIT_YES // Inheritance
                  | PROCMGR_AID_SPAWN_SETUID, // Specified ability
                PROCMGR_AID_EOL // End of ability list.
);
```

Inheritance of a locked and allowed procmgr ability is almost always a vulnerability, unless that ability has been allowed in a more restricted fashion than it would normally be allowed on the system. The following code is an insecure example of locking and inheriting an allowed procmgr ability, due to the combination of PROCMGR_AOP_ALLOW, PROCMGR_AOP_LOCK, and PROCMGR_AOP_INHERIT_YES:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT // Non-root domain
                  | PROCMGR_AOP_ALLOW // Allow the ability
                  | PROCMGR_AOP_LOCK // Lock the ability
                  | PROCMGR_AOP_INHERIT_YES // Inheritance
                  | PROCMGR_AID_SPAWN_SETUID, // Specified ability
                PROCMGR_AID_EOL // End of ability list.
);
```

The following code is secure and encouraged because the child will inherit the denied setting for the ability and never be able to unlock it, due to the combination of PROCMGR_AOP_DENY, PROCMGR_AOP_LOCK, and PROCMGR_AOP_INHERIT_YES:

```
procmgr_ability(0,
                PROCMGR_ADN_NONROOT // Non-root domain
                  | PROCMGR_AOP_DENY // Deny the ability
                  | PROCMGR_AOP_LOCK // Lock the ability
                  | PROCMGR_AOP_INHERIT_YES // Inheritance
                  | PROCMGR_AID_SPAWN_SETUID, // Specified ability
                PROCMGR_AID_EOL // End of ability list.
);
```

You can use code like this to limit procmgr abilities that are normally allowed in the PROCMGR_ADN_NONROOT domain.

Creating abilities

Not only can servers check that their clients have the appropriate abilities, but they can create custom abilities.

This allows system services to define their own arbitrary abilities, and then securely and efficiently verify that a client possesses a required set of abilities. The kernel doesn't need any special knowledge of particular system services, and a client can be granted particular capabilities before the associated server has initialized them.

Allocating capabilities

The following functions allocate capabilities:

```
int procmgr_ability_lookup(const char * name);
int procmgr_ability_create(const char * name, unsigned flags);
```

A client can call *procmgr_ability_lookup()* to obtain a numeric ability identifier, which can then be used in a call to *procmgr_ability()* or to verify the abilities of a client (described below).

The parameter is a string that uniquely identifies the ability, and should consist of a service identifier followed by a capability identifier (e.g., `"fs-qnx6/some_devctl"`). Calling *procmgr_ability_lookup()* twice with the same string is guaranteed to return the same number. If the ability can't be found in the current list of abilities, the requested ability is added to the list. If the ability can't be added to the list, a negative *errno* value is returned, indicating the nature of the failure.

The server calls *procmgr_ability_create()*, which functions identically to *procmgr_ability_lookup()* but allows the server to use the *flags* parameter to additionally specify the privilege domains (PROCMGR_ADN_ROOT, PROCMGR_ADN_NONROOT) that will have the ability by default (i.e., if the ability is not specifically granted or restricted using *procmgr_ability()*). The default privilege domains for an ability may be set only once; further calls to *procmgr_ability_create()* for the same ability succeed only if they specify the same *flags* argument.

In order to create an ability, the server must possess the PROCMGR_AID_ABLE_CREATE ability.

There's no requirement for a call to *procmgr_ability_create()* to precede calls to *procmgr_ability_lookup()*. This avoids forcing any specific ordering of process initialization, and means that processes don't need to hold on to **root** privileges until they can synchronize with the servers and get the ability identifiers that they need.

Here's an example of how a server could create an ability:

```
my_ability = procmgr_ability_create(name, PROCMGR_ADN_ROOT | PROCMGR_ADN_NONROOT));
if(my_ability == -EALREADY) {

    /*  Some other process or thread already created the ability,
        so just look up the ID. */

    my_ability = procmgr_ability_lookup(name);
}
if(my_ability < 0) {
    /* An error occurred. */
    ...
}
```

Verifying capabilities

The server can use the following functions to verify that a client has the required capabilities:

ConnectClientInfoAble()

This function is similar to *ConnectClientInfoExt()*, but accepts a list of capabilities and sets the _NTO_CI_UNABLE bit in the returned `struct _client_info` if the sending process *doesn't* possess all of the required capabilities:

```
struct _client_able {
    unsigned ability;
    unsigned flags;
    uint64_t range_lo;
    uint64_t range_hi;
};

int ConnectClientInfoAble( int scoid,
                           struct _client_info **info_pp,
                           const int flags,
                           struct _client_able abilities[],
                           const int nable);
```

Each of the required abilities must be from the static set of kernel abilities (PROCMGR_AID_*) or must have been previously created using *procmgr_ability_create()*.

iofunc_client_info_able()

This function is similar to *iofunc_client_info_ext()*, but—like *ConnectClientInfoAble()*—takes an array of abilities to check:

```
int iofunc_client_info_able( resmgr_context_t * const ctp,
                             const int ioflag,
                             struct _client_info **info_pp,
                             const int flags,
                             struct _client_able abilities[],
                             const int nable);
```

The *iofunc_check_access()* function inspects the returned `struct _client_info` and rejects the request if the capability check failed.

When you're finished with the `struct _client_info` structure, call *iofunc_client_info_ext_free()* to free it.

For example, here's how you could use *iofunc_client_info_able()* in your server process to check for an ability:

```
struct  _client_able ability;
struct _client_info * infop;
int ability_count;
int error;
int result;

/*  Determine whether or not the caller has this ability */

ability.ability = my_ability;
ability.flags = 0;
ability.range_hi = INT_MAX;
ability.range_lo = 0;
ability_count = 1;

error = iofunc_client_info_able(ctp, 0, &infop, 0, &ability, ability_count);
if((error != EOK) || (infop == NULL)) {
   /* An error occurred. */
   ...
}

/* The client has the requested ability if _NTO_CI_UNABLE isn't set
   in the info flags. */

result = !(infop->flags & _NTO_CI_UNABLE);

/* Free the _client_info structure. */

(void)iofunc_client_info_ext_free(&infop);
```


An example of privilege separation

Here's a basic example of privilege separation consisting of a low-privileged client and a high-privileged server. The example can easily be adapted to various design paradigms.

Note the use of *fork()* followed by *execve()*, which causes the more privileged process to have its own unique address space and stack cookies.

```
include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/neutrino.h>
#include <sys/types.h>
#include <sys/procmgr.h>
#include <login.h>

/* Example credential values */
#define SERVER_UID 88
#define SERVER_GID 88
#define CLIENT_UID 99
#define CLIENT_GID 99

static char *set_ids_arg = NULL;

void
run_server(int chid, pid_t child)
{
    int     rcvid;
    char    msg[10];
    struct _msg_info    info;
    struct _client_info * cinfo;

    /* Retain sample capabilities, and deny and lock all the rest */
    procmgr_ability(0,
      PROCMGR_ADN_NONROOT|PROCMGR_AOP_ALLOW|PROCMGR_AID_PATHSPACE,
      PROCMGR_ADN_NONROOT|PROCMGR_AOP_ALLOW|PROCMGR_AID_SETUID,
      PROCMGR_ADN_NONROOT|PROCMGR_AOP_DENY|PROCMGR_AOP_LOCK|PROCMGR_AID_EOL
     );

    /* drop privileges */
    if (set_ids_arg) {
        if( set_ids_from_arg(set_ids_arg) != 0 ) {
            fprintf(stderr, "set_ids_from_arg failed: errno=%d\n", errno);
            exit(EXIT_FAILURE);
        }
    }
    else {

         /* Note that the server side verifies that the process connecting
            to the channel is indeed its child by comparing the incoming
            process ID to the known child ID. */

        if ( setregid(SERVER_GID, SERVER_GID) != 0 ) {
```

```
            fprintf(stderr, "setregid failed: errno=%d\n", errno);
            exit(EXIT_FAILURE);
        }
        if ( setreuid(SERVER_UID, SERVER_UID) != 0 ) {
            fprintf(stderr, "setreuid failed: errno=%d\n", errno);
            exit(EXIT_FAILURE);
        }
    }

    for ( ; ; ) {
        rcvid = MsgReceive(chid, &msg, sizeof(msg), &info);
        if (rcvid == -1) {
            perror("MsgReceive");
            /* handle errors */
        }
        else if (rcvid == 0) {
            /* handle pulses */
        }
        if (ConnectClientInfoExt(info.scoid, &cinfo,
            _NTO_CLIENTINFO_GETGROUPS) == -1) {
            perror("ConnectClientInfo()");
            exit(EXIT_FAILURE);
        }
        if (cinfo->cred.euid == CLIENT_UID &&
            cinfo->cred.egid == CLIENT_GID &&
            info.pid == child) {
            printf("PID %d: Message from legitimate child\n", getpid());
            /* handle legitimate child request */
            MsgReply(rcvid, 0x1337, NULL, 0);
        }
        free(cinfo);
    }

    exit(EXIT_SUCCESS);
}

void
run_client(int chid)
{
    long    err;
    int     connd;
    char    send_msg[10];
    char    reply_msg[10];

    /* drop privileges. no capabilities retained */
    setregid(CLIENT_GID, CLIENT_GID);
    setreuid(CLIENT_UID, CLIENT_UID);

    connd = ConnectAttach(0, getppid(), chid, _NTO_SIDE_CHANNEL,
                          _NTO_COF_CLOEXEC);
    if (connd == -1) {
        perror("connd");
        exit(EXIT_FAILURE);
    }
```

```
    for ( ; ; ) {
        /* typical functionality with large attack surface here */
        memset(send_msg, 0x41, sizeof(send_msg));
        memset(reply_msg, 0x41, sizeof(reply_msg));
        err = MsgSend(connd, send_msg, sizeof(send_msg), reply_msg,
                      sizeof(reply_msg));
        if (err == -1) {
            perror("MsgSend");
            exit(EXIT_FAILURE);
        }
        printf("PID %d: Got message response!\n", getpid());
    }

    exit(EXIT_SUCCESS);
}

int
main(int argc, char **argv)
{
    int     c;
    int     chid;
    int     connd;
    int     is_client;
    pid_t   pid;

    is_client = 0;
    while ((c = getopt(argc, argv, "c:")) != -1) {
        switch(c) {
            /* only used during re-execution */
            case 'c':
                chid = atoi(optarg);
                is_client = 1;
                break;

            /* add a -U case */
            case 'U':
                set_ids_arg = optarg;
                break;

            default:
                //usage();
                exit(EXIT_FAILURE);
                break;
        }
    }

    if (is_client) {
        run_client(chid);
        return 1; // Unreachable code: run_client() calls exit()
    }

    /* Create channel */
    chid = ChannelCreate(_NTO_CHF_DISCONNECT);
```

```
    if (chid == -1) {
        perror("ChannelCreate");
        exit(EXIT_FAILURE);
    }

    pid = fork(); // alternatively use spawn()
    if (pid == -1) {
        perror("fork");
        exit(EXIT_FAILURE);
    }
    /* parent */
    if (pid) {

       /* Note that the channel identifier is provided to the
          client process, using the command line, so it knows
          where to connect. */

        run_server(chid, pid);
    }
    /* child */
    else {
        unsigned int i;
        char buf[32];   // enough to hold channel id digits
        char ** new_args;
        new_args = malloc((argc+2) * sizeof(char *));
        if (new_args == NULL) {
            perror("malloc");
            exit(EXIT_FAILURE);
        }
        for (i = 0; i < argc; i++) {
            new_args[i] = argv[i];
        }
        new_args[i++] = "-c";
        memset(buf, 0, sizeof(buf));
        if (snprintf(buf, sizeof(buf), "%d", chid) == -1) {
            perror("snprintf");
            exit(EXIT_FAILURE);
        }
        new_args[i++] = buf;
        new_args[i] = NULL;
        execve(new_args[0], new_args, NULL);
    }

    return 0;
}
```

Resource constraint thresholds

In many systems, it's important to guard against clumsy or malicious applications that attempt to exhaust global resources.

A system likely has a “core” or “critical” part that consists of essential services and has some bounded (but not necessarily constant) resource consumption. The rest of the system could have unbounded resource consumption, either because it's designed to handle problems with inherently unbounded resource usage, or because the processes can't be relied upon to bound their resource usage.

Resource constraints ensure that the core can operate even if the extended system is maximizing its resource usage. The core system might have a monitoring capability that allows it to reset the extended system in some way, but that's not essential. The most obvious such resource is system RAM, but the same considerations apply to process table entries, and to resource manager connections (scoids).

A certain level of protection is provided by RLIMIT_FREEMEM (see *setrlimit()*), which prevents applications from allocating memory once the system drops below a certain amount of free memory. Most programs will give up once *malloc()* starts failing, so this provides a reasonable protection againt inadvertent exhaustion, but this solution isn't complete:

- It doesn't reserve other types of resources, such as process IDs and service connection IDs (scoids).
- It doesn't restrict allocations by proxy, where a process induces a resource manager or the kernel to allocate memory (or other resources) on its behalf. This is difficult to resolve, since the kernel and resource managers can't be limited in the same way as applications, because they're required to ensure functioning of the core system in a resource-exhaustion situation.

The idea is to identify the critical processes that form the core system, and give them the ability to allocate as many resources as they need. All other processes are resource-constrained. For each resource that is prone to exhaustion, a threshold is defined, and a constrained process is refused allocation if the amount of free resources is below the threshold. The following system limits specify the constraints (see *sysconf()*):

_SC_RCT_MEM

The minimum amount of memory that the system retains as a resource constraint threshold.

_SC_RCT_SCOID

The minimum number of server connection IDs (scoids) that a server retains as a resource constraint threshold.

The proxy resource-manager case is handled by communicating the client's status to the server using a bit in the `_msg_info` structure. The server can then temporarily constrain itself while handling all or part of a request from a constrained client.

The kernel case is handled by having the kernel consider whether the client is constrained or unconstrained when it's asked to allocate a resource.

The ability PROCMGR_AID_RCONSTRAINT (see *procmgr_ability()*) is given to the critical processes only, and allows them to operate without being subject to resource constraint thresholds. A *ThreadCtl()* command, _NTO_TCTL_RCM_GET_AND_SET, allows a thread to constrain itself or free itself from constraint, but if the thread is a member of a process that lacks the PROCMGR_AID_RCONSTRAINT ability, it's effectively constrained regardless.

To handle resource-constraint modes:

- If the server isn't a critical process (as defined above), it can run in constrained mode, and no special code is required.
- If the server is a critical process, but can service requests from the core system without allocating any resources (directly or indirectly), then it can run in constrained mode, and no special code is required.

- If the server is a critical process and may have to allocate resources in order to handle a request from the core system, it must run in unconstrained mode. This means that the server has the responsibility to ensure that it doesn't allow itself to be used by constrained clients to allocate a resource in excess of the currently defined resource-constraint threshold. Unless the server is actually managing the resource itself, compliance generally means adopting the client's constraint mode when handling a request. This can be accomplished in these ways:
  - Automatically, by setting RESMGR_FLAG_RCM in the `resmgr_attr_t` structure (see the entry for *resmgr_attach()* in the QNX Neutrino *C Library Reference*). This is applicable only to servers using the resource-manager framework:

    ```
    resmgr_attr.flags |= RESMGR_FLAG_RCM;
    resmgr_attach(dpp, &resmgr_attr, name, _FTYPE_ANY, 0, &connect_funcs,
                  &io_funcs, &io_attr))
    ```

  - Manually, by checking for _NTO_MI_CONSTRAINED in the *flags* member of the `_msg_info` structure, available from a call to *MsgReceive()* or *MsgInfo()*. If this bit is set, the message was received from a constrained client. At appropriate moments, a thread that allocates resources on behalf of a constrained client should constrain itself using *ThreadCtl()*:

    ```
    int value = 1; // 1 to constrain, 0 to remove constraint
    ThreadCtl(_NTO_TCTL_RCM_GET_AND_SET, &value); /* swaps current state with value */

    /* Handle the request... */

    ThreadCtl(_NTO_TCTL_RCM_GET_AND_SET, &value); /* restores original state */
    ```

When a server runs as a constrained process, or when it constrains one of its threads, it may find that its resource allocation requests fail when there are still resources available. The server is expected to handle these failures in the same way it would handle a failure caused by complete exhaustion of resources, generally by returning an error to the client. For the sake of overall system stability, it's important for servers that can continue to process messages to do so, even when allocation failures occur.

Controlling processes via the `/proc` filesystem

Implemented by the Process Manager component of `procnto`, the **/proc** virtual filesystem lets you access and control every process and thread running within the system.

The **/proc** filesystem manifests each process currently running on the system as a directory whose name is the numerical process ID (in decimal) of the process. Inside this directory, you'll find the following files:

as

The address space that contains the process's entire memory space.

cmdline

The arguments passed to the process, separated by null characters. For example:

```
# pidin -p 28687 arg
      pid Arguments
    28687 io-pkt-v6-hc -d abc100 mac=96a414016206
# echo `cat /proc/28687/cmdline`
io-pkt-v6-hc-dabc100mac=96a414016206
```

ctl

A file that you can use for *devctl()* commands to access processes and their threads.

exefile

The path of the executable file used to run the process. For example:

```
# echo `cat /proc/28687/exefile`
/sbin/io-pkt-v6-hc
```

mappings

A detailed view of every page in a process's address space.

pmap

A detailed view of the process's mappings.

vmstat

A view of the process's virtual memory.

You can use the following standard functions to access the files in the **/proc** filesystem:

Function	Purpose
open()	Establish a file descriptor to a process
read()	Read data from the process's address space
write()	Write data to the process's address space

Function	Purpose
stat()	Return `struct stat` information
lseek()	Establish a position within the process's address space for further operations
devctl()	Manipulate a process or thread
close()	Release a file descriptor

Ancillary functions (such as *readdir()*, *opendir()*, and so on) are supported on the directory **/proc** itself—this aids in implementing commands such as `ls`.

In QNX Neutrino 7.0 or later, you must open the appropriate file (e.g., **/proc/***pid***/ctl**), not the **/proc/***pid* directory.

When you start `procnto`, you can use the following options to specify the `umask` to use for the **/proc/***pid***/*** files.

`-d`

Controls the umask for **cmdline** and **cctl**. The default is 0022.

`-u`

Controls the umask for **as**, **exefile**, **mappings**, **pmap** and **vmstat**. The default is 0066.

You can use `chmod` to drop permissions on the **as** and **ctl** files, but you can't then regain the permissions.

In order to read or write data from or to the process, you must have opened the file descriptor in the appropriate mode. You must also have appropriate privileges to open the particular process. In QNX Neutrino 7.0.1 or later, access is controlled to a limited extent by POSIX permissions but mainly by abilities (see *procmgr_ability()* in the *C Library Reference*):

- If your process has a different user ID than the target process, and you have only the POSIX permissions, then you can:
  - get limited access to **cmdline**; it shows the target process's first argument only (i.e., it tells you what's running but none of its command-line arguments)
  - get limited access to **ctl**; it supports the DCMD_PROC_INFO, DCMD_PROC_MAPDEBUG_BASE, and DCMD_PROC_TIDSTATUS *devctl()* commands, but the output is sanitized.
  - read `exefile`
- If your process has the same user ID and has POSIX access, then you get unrestricted access to the files.
- Irrespective of the user ID and POSIX permissions:
  - If your process has the PROCMGR_AID_XPROCESS_QUERY ability for the user IDs of the target file (effective, real, and saved), you can get read access to all files except for the **as** file.

  - If your process has PROCMGR_AID_XPROCESS_MEM_READ for the user IDs of the target file (effective, real, and saved), you can get read access to the **as** file.
  - If a process has PROCMGR_AID_XPROCESS_DEBUG for the user IDs of the target file (effective, real, and saved), you can get write access to **as** and **ctl**.

- The **root** user (effective user ID 0), gets unrestricted POSIX access but still needs the abilities.

Only one process can have a **/proc/***pid***/as** or **/proc/***pid***/ctl** file open for writing at a time.

Reading and writing the process's address space

If you have the appropriate permissions, you can access a process's address space. Since threads exist in the context of a process and have access to everything within a process, there's no need to consider threads in this discussion.

You can use the *read()*, *write()*, and *lseek()* functions to access the process's address space. The *read()* function transfers bytes from the current position within the process to the program issuing the *read()*, and *write()* transfers bytes from the program to the process.

The position at which transfer occurs depends on the current offset as set on the file descriptor. In virtual-address systems such as QNX Neutrino, the current offset is taken to be the virtual address *from the process's perspective*. For example, to read 4096 bytes at offset `0x00021000` from process ID number 2259, the following code snippet could be used:

```
int     fd;
char    buf [4096];

fd = open ("/proc/2259/as", O_RDONLY);
lseek (fd, 0x00021000, SEEK_SET);
read (fd, buf, 4096);
```

Of course, you should check the return values in your real code!

If a virtual address process has different chunks of memory mapped into its address space, performing a read or write on a given address may or may not work (or it may not affect the expected number of bytes). This is because the *read()* and *write()* functions affect only *contiguous* memory regions. If you try to read a page of memory that isn't mapped by the process, the read will fail; this is expected.

Manipulating a process or thread

Once you have a file descriptor to a particular process's **/proc/***pid***/ctl** file, you can get information about and control that process and its associated threads.

All of these functions are performed using the *devctl()* call as described in the sections that follow. To be able to use these *devctl()* calls, you'll need at least the following:

```
#include <devctl.h>
#include <sys/procfs.h>
```

There are 32- and 64-bit versions of some of the DCMD_PROC_* commands. For example:

```
#define DCMD_PROC_STATUS32  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status32))
#define DCMD_PROC_STATUS64  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status64))
#define DCMD_PROC_STATUS    (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status))
```

The first two forms are for specific sizes; the generic form (DCMD_PROC_STATUS) maps onto the 64-bit version, whether you compile for a 32- or 64-bit architecture. If you're compiling for a 32-bit architecture, and you want the generic version to map onto the 32-bit command, define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**. If you're compiling for a 64-bit architecture, the generic version always maps onto the 64-bit version of the command.

You can use the *devctl()* commands (described in the sections that follow) to do the following:

- Select a thread for further operations. When you first perform the *open()* to a particular process, by default you're connected to the first thread (the thread that executed the *main()* function). If you wish to switch a different thread, use the DCMD_PROC_CURTHREAD command. To find out how many threads are available in the given process, see the DCMD_PROC_INFO command.
- Start and stop processes and threads:
  - DCMD_PROC_STOP
  - DCMD_PROC_RUN

  You must have opened the file descriptor for writing.
- Set breakpoints:
  - DCMD_PROC_BREAK
  - DCMD_PROC_WAITSTOP
  - DCMD_PROC_GET_BREAKLIST

  You must have opened the file descriptor for writing.
- Examine process and thread attributes:
  - DCMD_PROC_SYSINFO
  - DCMD_PROC_INFO
  - DCMD_PROC_MAPINFO
  - DCMD_PROC_MAPDEBUG
  - DCMD_PROC_MAPDEBUG_BASE
  - DCMD_PROC_SIGNAL
  - DCMD_PROC_STATUS
  - DCMD_PROC_TIDSTATUS
  - DCMD_PROC_GETGREG
  - DCMD_PROC_SETGREG
  - DCMD_PROC_GETFPREG
  - DCMD_PROC_SETFPREG
  - DCMD_PROC_GETREGSET
  - DCMD_PROC_SETREGSET

- DCMD_PROC_EVENT
- DCMD_PROC_SET_FLAG
- DCMD_PROC_CLEAR_FLAG
- DCMD_PROC_PAGEDATA
- DCMD_PROC_PTINFO
- DCMD_PROC_GETALTREG
- DCMD_PROC_SETALTREG
- DCMD_PROC_TIMERS
- DCMD_PROC_IRQS
- DCMD_PROC_THREADCTL
- DCMD_PROC_CHANNELS

Thread information

Several of the *devctl()* commands use a `procfs_status` structure (which is the same as `debug_thread_t`), so let's look at this structure before going into the commands themselves.

- DCMD_PROC_STATUS
- DCMD_PROC_STOP
- DCMD_PROC_TIDSTATUS
- DCMD_PROC_WAITSTOP

The `debug_thread_t` structure is defined for 64-bit architectures as follows in **<sys/debug.h>**:

```
#define BLOCKED_CONNECT_FLAGS_SERVERMON 0x01u

typedef struct _debug_thread_info64 {
    pid_t                       pid;
    pthread_t                   tid;
    uint32_t                    flags;
    uint16_t                    why;
    uint16_t                    what;
    uint64_t                    ip;
    uint64_t                    sp;
    uint64_t                    stkbase;
    uint64_t                    tls;
    uint32_t                    stksize;
    uint32_t                    tid_flags;
    uint8_t                     priority;
    uint8_t                     real_priority;
    uint8_t                     policy;
    uint8_t                     state;
    int16_t                     syscall;
    uint16_t                    last_cpu;
    uint32_t                    timeout;
    int32_t                     last_chid;
    sigset_t                    sig_blocked;
    sigset_t                    sig_pending;
```

```
    __siginfo32_t               __info32;

    union {
        struct {
            pthread_t                   tid;
        }                           join;
        struct {
            intptr64_t                  id;
            uintptr64_t                 sync;
        }                           sync;
        struct {
            uint32_t                    nd;
            pid_t                       pid;
            int32_t                     coid;
            int32_t                     chid;
            int32_t                     scoid;
            uint32_t                    flags;
        }                           connect;
        struct {
            int32_t                     chid;
        }                           channel;
        struct {
            pid_t                       pid;
            uint32_t                    flags;
            uintptr64_t                 vaddr;
        }                           waitpage;
        struct {
            size64_t                    size;
        }                           stack;
        struct {
            pthread_t                   tid;
        }                           thread_event;
        struct {
            pid_t                       child;
        }                           fork_event;
        uint64_t                        filler[4];
    }                           blocked;

    uint64_t                    start_time;
    uint64_t                    sutime;
    uint8_t                     extsched[8];
    uint64_t                    nsec_since_block;

    union {
        __siginfo32_t           info32;
        __siginfo64_t           info64;
        siginfo_t               info;
    };

    uint64_t                    reserved2[4];
}                           debug_thread64_t;
```

> If you ask for information about a specific thread, and the thread no longer exists, the process manager returns information about the one with the next higher thread ID. If there are no threads with a higher ID, *devctl()* returns ESRCH.

The members include:

pid*, *tid

The process and thread IDs.

flags

A combination of the following bits:

- _DEBUG_FLAG_STOPPED — the thread isn't running.
- _DEBUG_FLAG_ISTOP — the thread is stopped at a point of interest.
- _DEBUG_FLAG_IPINVAL — the instruction pointer isn't valid.
- _DEBUG_FLAG_ISSYS — system process.
- _DEBUG_FLAG_SSTEP — stopped because of single-stepping.
- _DEBUG_FLAG_CURTID — the thread is the current thread.
- _DEBUG_FLAG_TRACE_EXEC — stopped because of a breakpoint.
- _DEBUG_FLAG_TRACE_RD — stopped because of read access.
- _DEBUG_FLAG_TRACE_WR — stopped because of write access.
- _DEBUG_FLAG_TRACE_MODIFY — stopped because of modified memory.
- _DEBUG_FLAG_RLC — the Run-on-Last-Close flag is set.
- _DEBUG_FLAG_KLC — the Kill-on-Last-Close flag is set.
- _DEBUG_FLAG_FORK — the child inherits flags (stop on fork or spawn).
- _DEBUG_FLAG_EXEC — (QNX Neutrino 6.6 or later) stop on exec.
- _DEBUG_FLAG_THREAD_EV — (QNX Neutrino 6.6 or later) stop when creating or destroying a thread.
- _DEBUG_FLAG_64BIT — (QNX Neutrino 7.0 or later) the thread is running in a 64-bit architecture.

why*, *what

The *why* field indicates why the process was stopped; the *what* field gives additional information:

why	Description	*what*
_DEBUG_WHY_CHILD	A child process is ready to run; the parent gets a chance to connect to it	The child's process ID
_DEBUG_WHY_EXEC	The process was created by a call to an *exec*()* function	0

why	Description	*what*
_DEBUG_WHY_FAULTED	The thread faulted	The fault number; see `siginfo_t`
_DEBUG_WHY_JOBCONTROL	The thread is under job control	The signal number
_DEBUG_WHY_REQUESTED	The thread was working normally before being stopped by request	0
_DEBUG_WHY_SIGNALLED	The thread received a signal	The signal number
_DEBUG_WHY_TERMINATED	The thread terminated	The process's exit status
_DEBUG_WHY_THREAD	(QNX Neutrino 6.6 or later) A thread was created or destroyed	The thread ID

ip

The current instruction pointer.

sp

The thread's stack pointer.

stkbase

The base address of the thread's stack region.

tls

A pointer to the thread's local storage, which is on the thread's stack. For more information, see `struct _thread_local_storage` in **<sys/storage.h>**.

stksize

The stack size.

tid_flags

The thread flags; see _NTO_TF_* in **<sys/neutrino.h>** and the entry for `pidin` in the *Utilities Reference*.

priority

The priority the thread is actually running at (e.g., its priority may have been boosted).

real_priority

The actual priority the thread would be at with no boosting and so on.

policy

The scheduling policy; one of SCHED_FIFO, SCHED_RR, SCHED_OTHER, or SCHED_SPORADIC.

state

The thread's state. The states themselves are defined in **<sys/states.h>**; for descriptions, see “Thread life cycle” in the QNX Neutrino Microkernel chapter of the *System Architecture* guide. If the thread is waiting for something, the *blocked* member may hold additional information, as described below.

syscall

The last system call; one of the __KER_* values defined in **<sys/kercalls.h>**.

last_cpu

The processor the thread last ran on.

timeout

`_NTO_TF_ACTIVE|_NTO_TF_IMMEDIATE|(1 << state)` — set by *TimerTimeout()*.

last_chid

The ID of the last channel this thread received a message on.

sig_blocked

The set of signals that are blocked for the thread.

sig_pending

The set of signals that are pending for the thread.

blocked

A `union` of the following:

- *join* — if the *state* is STATE_JOIN or STATE_WAITTHREAD, this structure contains *tid*, the ID of the thread that this thread is waiting for.
- *sync* — if the *state* is STATE_CONDVAR, STATE_MUTEX, or STATE_SEM, this structure contains:

  id

  The address of the synchronization object.

  sync

  For a condvar, this is a pointer to the associated mutex; for a mutex, it's a pointer to the mutex.

- *connect* — if the *state* is STATE_SEND or STATE_REPLY, this structure contains:

  nd

  The node descriptor.

pid

The process ID.

coid

The connection ID.

chid

The channel ID.

scoid

The server connection ID that the thread is waiting for.

flags

A bitfield of flags. The BLOCKED_CONNECT_FLAGS_SERVERMON bit is set when the thread has requested server monitor services, and unset either when the thread is unblocked before the server monitor gets to service it or when the server monitor has taken a specified action.

- *channel* — if the *state* is STATE_RECEIVE, this structure contains *chid*, the ID of the channel that the thread is waiting for.
- *waitpage* — if the *state* is STATE_WAITPAGE, this structure contains:

pid

The ID of the process whose address space was active when the page fault occurred.

flags

Internal use only.

vaddr

The virtual address for which the thread is waiting for physical memory to be allocated.

- *stack* — if the *state* is STATE_STACK, this structure contains *size*, the amount of stack that the thread is waiting for to be allocated.
- *thread_event* — if *why* is _DEBUG_WHY_THREAD, this structure contains *tid*, the thread ID of the created or destroyed thread.
- *fork_event* — if *why* is _DEBUG_WHY_CHILD, this structure contains *child*, the process ID of the child.

start_time

The thread's starting time, in nanoseconds.

sutime

The thread's system plus user running time, in nanoseconds.

extsched

Extended scheduling information; a `struct extsched_aps_dbg_thread` structure if the adaptive partitioning thread scheduler is installed.

nsec_since_block

How long the thread has been blocked, in nanoseconds, but to millisecond resolution. 0 for STATE_READY or STATE_RUNNING.

info

A `siginfo_t` structure that contains information about the last signal or fault received.

DCMD_PROC_BREAK

Set or remove a breakpoint in the process that's associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_BREAK32   (__DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 14, procfs_break32))
#define DCMD_PROC_BREAK64   (__DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 14, procfs_break64))
#define DCMD_PROC_BREAK     (__DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 14, procfs_break))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_BREAK
dev_data_ptr	A pointer to a `procfs_break` structure
n_bytes	`sizeof(procfs_break)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_break` structure (see `debug_break_t` in **<sys/debug.h>**) that specifies the breakpoint to be set or removed. For example:

```
procfs_break        brk;

memset(&brk, 0, sizeof brk);
brk.type = _DEBUG_BREAK_EXEC;
brk.addr = acc->break_addr.offset;
brk.size = 0;
devctl(fd, DCMD_PROC_BREAK, &brk, sizeof brk, 0);
```

Use a size of 0 to set a breakpoint, and a size of -1 to delete it.

Breakpoints other than _DEBUG_BREAK_EXEC are highly dependent on the hardware. In many architectures, other types of breakpoints cause the kernel to make the process run in single-step, checking the watchpoints each time, which can be very slow.

DCMD_PROC_CHANNELS

Get information about the channels owned by the specified process.

```
#include <sys/procfs.h>

#define DCMD_PROC_CHANNELS __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 29, procfs_channel)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_CHANNELS
dev_data_ptr	NULL, or an array of `procfs_channel` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer, where the number of channels will be stored

Call this the first time with an argument of NULL to get the number of channels:

```
devctl(fd, DCMD_PROC_CHANNELS, NULL, 0, &n);
```

Next, allocate a buffer that's large enough to hold a `procfs_channel` structure (see `debug_channel_t` in **<sys/debug.h>**) for each channel, and pass it to another *devctl()* call:

```
my_buffer = (procfs_channel *)
               malloc( sizeof(procfs_channel) * n );
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}

devctl( fd, DCMD_PROC_CHANNELS, my_buffer, sizeof(procfs_channel) * n, &dummy);
```

DCMD_PROC_CLEAR_FLAG

Clear specific debug flags with the values provided for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_CLEAR_FLAG  __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 19, uint32_t)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_CLEAR_FLAG
dev_data_ptr	A pointer to a `uint32_t`
n_bytes	`sizeof(uint32_t)`
dev_info_ptr	NULL

The flags that can be cleared are described in **<sys/debug.h>**. The argument is a pointer to an unsigned integer that specifies the debug flags to clear. For example:

```
int flags;

flags = _DEBUG_FLAG_KLC;         /* Kill-on-Last-Close flag */
devctl( fd, DCMD_PROC_CLEAR_FLAG, &flags, sizeof(flags), NULL);
```

To set the flags, use DCMD_PROC_SET_FLAG.

DCMD_PROC_CURTHREAD

Switch to another thread.

```
#include <sys/procfs.h>

#define DCMD_PROC_CURTHREAD  __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 8, pthread_t)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_CURTHREAD
dev_data_ptr	A pointer to a `pthread_t`
n_bytes	`sizeof(pthread_t)`
dev_info_ptr	NULL

The argument to this command is a `pthread_t` value that specifies the thread that you want to be made the current thread. For example:

```
if ((err=devctl( fd, DCMD_PROC_CURTHREAD, &tid,
                 sizeof(tid), NULL)) != EOK) {
  /* An error occurred. */
}
```

DCMD_PROC_EVENT

Define an event to be delivered when the process associated with the file descriptor reaches a point of interest.

```
#include <sys/procfs.h>

#define DCMD_PROC_EVENT32  (__DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 17, struct __sigevent32))
#define DCMD_PROC_EVENT64  (__DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 17, struct __sigevent64))
#define DCMD_PROC_EVENT    (__DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 17, struct sigevent))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_EVENT
dev_data_ptr	A pointer to a `struct sigevent`
n_bytes	`sizeof(struct sigevent)`
dev_info_ptr	NULL

Use the DCMD_PROC_RUN command to set up the point of interest.

The DCMD_PROC_EVENT command won't work unless you've set _DEBUG_RUN_ARM in the *flags* field of the `procfs_run` structure for the DCMD_PROC_RUN command.

Unlike DCMD_PROC_WAITSTOP, the DCMD_PROC_EVENT command doesn't block the calling process.

The argument is a pointer to the `sigevent` that you want to be delivered at the appropriate time. For example:

```
struct sigevent     event;

// Define a sigevent for process stopped notification.
event.sigev_notify = SIGEV_SIGNAL_THREAD;
event.sigev_signo = SIGUSR2;
event.sigev_code = 0;
event.sigev_value.sival_ptr = prp;
event.sigev_priority = -1;
devctl( fd, DCMD_PROC_EVENT, &event, sizeof(event), NULL);
```

DCMD_PROC_GETALTREG

Get the information stored in the alternate register set for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_GETALTREG   __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 21, procfs_fpreg)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_GETALTREG
dev_data_ptr	A pointer to a `procfs_fpreg` structure
n_bytes	`sizeof(procfs_fpreg)`
dev_info_ptr	NULL, or a pointer to an integer where the size of the register set can be stored

The argument is a pointer to a `procfs_fpreg` structure (see `debug_fpreg_t` in **<sys/debug.h>**) that's filled in with the required information on return. If you provide a non-NULL extra argument, it's filled with the actual size of the register set. For example:

```
procfs_fpreg reg;
int regsize;

devctl( fd, DCMD_PROC_GETALTREG, &reg, sizeof(reg), &regsize);
```

If the thread hasn't used the alternate register set (e.g., AltiVec registers), the read may fail.

To set the alternate register set, use DCMD_PROC_SETALTREG.

DCMD_PROC_GETFPREG

Get the information stored in the Floating Point Data registers for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_GETFPREG   __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 12, procfs_fpreg)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_GETFPREG

Argument	Value
dev_data_ptr	A pointer to a `procfs_fpreg` structure
n_bytes	`sizeof(procfs_fpreg)`
dev_info_ptr	NULL, or a pointer to an integer where the size of the data can be stored

The argument is a pointer to a `procfs_fpreg` structure (see `debug_fpreg_t` in **<sys/debug.h>**) that's filled in with the required information on return. If you provide a non-NULL extra argument, it's filled with the size of the data. For example:

```
procfs_fpreg my_fpreg;

devctl( fd, DCMD_PROC_GETFPREG, my_fpreg, sizeof(procfs_fpreg), &size);
```

If the thread hasn't used any floating-point arithmetic, the read may fail because an FPU context has not yet been allocated.

To set the Floating Point Data registers, use DCMD_PROC_SETFPREG.

DCMD_PROC_GETGREG

Get the information stored in the CPU registers based on the current thread of the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_GETGREG   __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 10, procfs_greg)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_GETGREG
dev_data_ptr	A pointer to a `procfs_greg` structure
n_bytes	`sizeof(procfs_greg)`
dev_info_ptr	NULL, or a pointer to an integer where the size of the data can be stored

The argument is a pointer to a `procfs_greg` structure (see `debug_greg_t` in **<sys/debug.h>**) that's filled in with the required information on return. If you provide a non-NULL extra argument, it's filled with the size of the data. For example:

```
procfs_greg my_greg;

devctl( fd, DCMD_PROC_GETGREG, my_greg, sizeof(procfs_greg), &size);
```

To set the CPU registers, use DCMD_PROC_SETGREG.

DCMD_PROC_GETREGSET

Read the given register set.

```
#include <sys/procfs.h>

#define DCMD_PROC_GETREGSET   __DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 25, procfs_regset)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_GETREGSET
dev_data_ptr	A pointer to a `procfs_regset` structure
n_bytes	The number of bytes that you want to get
dev_info_ptr	A pointer to an `int` where the number of bytes retrieved can be stored

The argument is a pointer to a `procfs_regset` structure where the required information can be stored:

```
typedef struct _procfs_regset {
    uint32_t  id;
    char      buf[8192];
} procfs_regset;
```

Set the *id* member to indicate the registers you want to get:

REGSET_ALTREGS

Alternate registers. You can also get and set these registers with the DCMD_PROC_GETALTREG and DCMD_PROC_SETALTREG commands.

REGSET_FPREGS

Floating Point Data registers. You can also get and set these registers with the DCMD_PROC_GETFPREG and DCMD_PROC_SETFPREG commands.

REGSET_GPREGS

CPU registers. You can also get and set these registers with the DCMD_PROC_GETGREG and DCMD_PROC_SETGREG commands.

REGSET_PERFREGS

Performance registers.

For example:

```
procfs_regset regset;
int           returned_length;

regset.id = REGSET_PERFREGS;
devctl( fd, DCMD_PROC_GETREGSET, &regset, sizeof(regset), &returned_length );
```

(QNX Neutrino 7.0.4 or later) The register sets defined in **<sys/debug.h>** include some special values, REGSET_STARTCPU and REGSET_STARTPRIV:

- The range from REGSET_STARTCPU up to but not including REGSET_STARTPRIV is for CPU-specific registers.
- The range from REGSET_STARTPRIV and up is for privileged registers.
- The range from REGSET_STARTPRIV + REGSET_STARTCPU and up is for privileged CPU-specific registers.

In order to get or set registers in the range from REGSET_STARTPRIV and up, your process needs the PROCMGR_AID_PRIVREG ability enabled. See *procmgr_ability()* in the *C Library Reference*.

The target-specific registers include the following:

AARCH64_REGSET_ACTLR

(QNX Neutrino 7.0.4 or later; AArch 64 targets only) Auxiliary Control Register, a privileged 64-bit register that provides implementation-defined configuration and control options for execution at EL1 and EL0.

In order for you to use this register, your startup program needs to set the AARCH64_CPU_ACTLR flag in *cpuinfo.flags* in the system page. For more information, see the “System Page” chapter of *Building Embedded Systems*.

For example:

```
procfs_regset regset;
int           returned_length;

regset.id = AARCH64_REGSET_ACTLR;
*(uint64_t *)&regset.buf[0] = 0;

devctl( fd, DCMD_PROC_GETREGSET, &regset, sizeof(uint32_t) + sizeof(uint64_t),
        &returned_length );
printf ("The value is %llx.\n", *(uint64_t *)&regset.buf[0]);
```

To set a given register set, use DCMD_PROC_SETREGSET.

DCMD_PROC_GET_BREAKLIST

Get a list of the active breakpoints for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_GET_BREAKLIST32  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 28, procfs_break32))
#define DCMD_PROC_GET_BREAKLIST64  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 28, procfs_break64))
#define DCMD_PROC_GET_BREAKLIST    (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 28, procfs_break))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_GET_BREAKLIST
dev_data_ptr	NULL, or an array of `procfs_break` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer where the number of breakpoints can be stored

Call this the first time with an argument of NULL to get the number of breakpoints:

```
devctl( fd, DCMD_PROC_GET_BREAKLIST, NULL, 0, &n);
```

The total number of breakpoints returned is provided as the extra field. Next, allocate a buffer that's large enough to hold a `procfs_break` structure (see `debug_break_t` in **<sys/debug.h>**) for each breakpoint, and pass it to another *devctl()* call:

```
my_buffer = (procfs_break *) malloc( sizeof(procfs_break) * n );
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}
devctl( fd, DCMD_PROC_GET_BREAKLIST, my_buffer,
        sizeof(procfs_break) * n, &dummy);
```

To set or clear breakpoints, use DCMD_PROC_BREAK.

DCMD_PROC_INFO

Obtain information about the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_INFO   __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 1, procfs_info)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_INFO
dev_data_ptr	A pointer to a `procfs_info` structure
n_bytes	`sizeof(procfs_info)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_info` structure (see `debug_process_t` in **<sys/debug.h>**) that's filled in with the required information on return. For example:

```
procfs_info my_info;

devctl( fd, DCMD_PROC_INFO, &my_info, sizeof(my_info), NULL);
```

For more information, see the section on DCMD_PROC_INFO in the appendix about the **/procfs** filesystem in *The QNX Neutrino Cookbook*.

DCMD_PROC_IRQS

Get the interrupt handlers owned by the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_IRQS32   (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 24, procfs_irq32))
#define DCMD_PROC_IRQS64   (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 24, procfs_irq64))
#define DCMD_PROC_IRQS     (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 24, procfs_irq))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_IRQS
dev_data_ptr	NULL, or an array of `procfs_irq` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer where the number of interrupt handlers can be stored

Call this the first time with an argument of NULL to get the number of interrupt handlers:

```
devctl( fd, DCMD_PROC_IRQS, NULL, 0, &n);
```

Next, allocate a buffer that's large enough to hold a `procfs_irq` structure (see `debug_irq_t` in **<sys/debug.h>**) for each handler, and pass it to another *devctl()* call:

```
my_buffer = (procfs_irq *) malloc( sizeof(procfs_irq) * n );
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}

devctl( fd, DCMD_PROC_IRQS, my_buffer, sizeof(procfs_irq) * n,
        &dummy);
```

For more information, see the section on DCMD_PROC_IRQS in the appendix about the **/procfs** filesystem in *The QNX Neutrino Cookbook*.

DCMD_PROC_MAPDEBUG

Get the best guess to the ELF object on the host machine.

```
#include <sys/procfs.h>

#define DCMD_PROC_MAPDEBUG   __DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 3, procfs_debuginfo)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_MAPDEBUG
dev_data_ptr	A pointer to a `procfs_debuginfo` structure
n_bytes	`sizeof(procfs_debuginfo)`
dev_info_ptr	NULL

This is used by debuggers to find the object that contains the symbol information, even though it may have been stripped on the target machine. This call is useful only on MAP_ELF mappings. If any relocation of the ELF object was done, this translation will be undone. This lets you pass in an address within a ELF module, and get in return the address that the original object was linked at so a debugger can find the symbol. (This is an extension from the SYSV interface.)

The argument is a pointer to a `procfs_debuginfo` structure that's filled in with the required information on return. The `procfs_debuginfo` structure can specify the base address of the mapped segment that you're interested in. For example:

```
procfs_debuginfo map;

map.info.vaddr = some_vaddr;
devctl( fd, DCMD_PROC_MAPDEBUG, &map, sizeof map, NULL);
```

DCMD_PROC_MAPDEBUG is useful for non-ELF objects if you need to get the name. Note that the *path* member in `procfs_debuginfo` is a one-byte array; if you want to get the name, you need to allocate more space for it. For example:

```
struct {
    procfs_debuginfo   info;
    char               buff[_POSIX_PATH_MAX];
} map;
```

DCMD_PROC_MAPDEBUG_BASE

Get information pertaining to the path associated with the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_MAPDEBUG_BASE __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 3, procfs_debuginfo)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_MAPDEBUG_BASE
dev_data_ptr	A pointer to a `procfs_debuginfo` structure
n_bytes	`sizeof(procfs_debuginfo)`
dev_info_ptr	NULL

This is a convenience extension; it's equivalent to using DCMD_PROC_INFO, and then DCMD_PROC_MAPDEBUG with the *base_address* field. The base address is the address of the initial executable.

The argument is a pointer to a `procfs_debuginfo` structure, which is filled in with the required information on return. For example:

```
procfs_debuginfo dinfop;

devctl( fd, DCMD_PROC_MAPDEBUG_BASE, &dinfop, sizeof(dinfop),
        NULL);
```

DCMD_PROC_MAPINFO

Obtain segment-specific information about mapped memory segments in the process associated with the file descriptor. This call matches the corresponding *mmap()* calls.

```
#include <sys/procfs.h>

#define DCMD_PROC_MAPINFO  __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 2, procfs_mapinfo)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_MAPINFO
dev_data_ptr	NULL, or an array of `procfs_mapinfo` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer where the number of map entries can be stored

Individual page data isn't returned (i.e., the PG_* flags defined in **<mman.h>** aren't returned). If you need the page attributes, use DCMD_PROC_PAGEDATA instead.

Call this the first time with an argument of NULL to get the number of map entries:

```
devctl( fd, DCMD_PROC_MAPINFO, NULL, 0, &n);
```

Next, allocate a buffer that's large enough to hold a `procfs_mapinfo` structure for each map entry, and pass it to another *devctl()* call:

```
my_buffer = (procfs_mapinfo *)
               malloc( sizeof(procfs_mapinfo) * n );
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}

devctl( fd, DCMD_PROC_MAPINFO, my_buffer,
        sizeof(procfs_mapinfo) * n, &dummy);
```

For more information, see the section on DCMD_PROC_MAPINFO and DCMD_PROC_PAGEDATA in the appendix about the **/procfs** filesystem in *The QNX Neutrino Cookbook*.

DCMD_PROC_PAGEDATA

Obtain page data about mapped memory segments in the process associated with the file descriptor. This call matches the corresponding *mmap()* calls.

```
#include <sys/procfs.h>

#define DCMD_PROC_PAGEDATA    __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 20, procfs_mapinfo)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_PAGEDATA

Argument	Value
dev_data_ptr	NULL, or an array of `procfs_mapinfo` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer where the number of map entries can be stored

If you need the segment-specific attributes, use DCMD_PROC_MAPINFO instead.

Call this the first time with an argument of NULL to get the number of map entries:

```
devctl(fd, DCMD_PROC_PAGEDATA, NULL, 0, &n);
```

Next, allocate a buffer that's large enough to hold a `procfs_mapinfo` structure for each map entry, and pass it to another *devctl()* call:

```
my_buffer = (procfs_mapinfo *)
                malloc( sizeof(procfs_mapinfo) * n );
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}

devctl( fd, DCMD_PROC_PAGEDATA, my_buffer,
        sizeof(procfs_mapinfo) * n, &dummy);
```

For more information, see the section on DCMD_PROC_MAPINFO and DCMD_PROC_PAGEDATA in the appendix about the **/procfs** filesystem in *The QNX Neutrino Cookbook*.

DCMD_PROC_PTINFO

Return the pagetable mapping information for a memory segment

```
#include <sys/procfs.h>

#define DCMD_PROC_PTINFO    __DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 34, procfs_mapinfo)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_PTINFO
dev_data_ptr	An array of at least one `procfs_mapinfo` structure
n_bytes	The size of the array
dev_info_ptr	A pointer to an integer where the number of mappings can be stored

This command returns the pagetable mapping information for the specified memory segment. Call this command with an array of at least one `procfs_mapinfo` structure (defined in **<sys/procfs.h>**). The virtual address you're interested in must be the *vaddr* field of the first `procfs_mapinfo` entry passed in. If the supplied virtual address doesn't match an existing segment, *devctl()* provides information on the next monotonically increasing segment.

The information is based on the current state of the pagetable mappings, and each mapping returned represents a page table entry. This means that while the mapping entry for the pagetable entry has `PROT_READ | PROT_WRITE` protection bits, it may not have been read from or written to, in which case the actual page table entry may indicate PROT_NONE or PROT_READ.

The *size* field indicates the size of the page mapping. The default is 4 KB, but larger mappings are possible on some machines.

The number of mappings returned is the total number of mappings that could be returned, regardless of the size of the buffer passed.

For example:

```
procfs_mapinfo *my_buffer;
int num_mappings;

my_buffer = (procfs_mapinfo *) malloc( sizeof(procfs_mapinfo) * 10 );
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}

if ((err = devctl( fd, DCMD_PROC_PTINFO, my_buffer,
                   sizeof(procfs_mapinfo) * 10,
                   &num_mappings)) != EOK)
{
  /* An error occurred. */
}
```

DCMD_PROC_RUN

Resume the process that's associated with the file descriptor, if it has previously been stopped.

```
#include <sys/procfs.h>

#define DCMD_PROC_RUN32  (__DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 9, procfs_run32))
#define DCMD_PROC_RUN64  (__DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 9, procfs_run64))
#define DCMD_PROC_RUN    (__DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 9, procfs_run))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_RUN
dev_data_ptr	A pointer to a `procfs_run` structure
n_bytes	`sizeof(procfs_run)`
dev_info_ptr	NULL

To stop the process, use DCMD_PROC_STOP. The DCMD_PROC_RUN command also lets you set the "points of interest" (e.g., signals or faults you want to stop on) and other run flags (e.g., instruction pointer or single-step).

The argument is a pointer to a `procfs_run` structure (see `debug_run_t` in **<sys/debug.h>**). This structure is passed on as control information to the process before it resumes. For example:

```
procfs_run      run;

memset( &run, 0, sizeof(run) );
run.flags |= _DEBUG_RUN_CLRFLT | _DEBUG_RUN_CLRSIG;
devctl( fd, DCMD_PROC_RUN, &run, sizeof(run), NULL);
```

The `procfs_run` or `debug_run_t` structure is defined for 64-bit architectures as follows:

```
typedef struct _debug_run64 {
    uint32_t                    flags;
    pthread_t                   tid;
    sigset_t                    trace;
    sigset_t                    hold;
    fltset_t                    fault;
    uintptr32_t                 __ip;
    uintptr64_t                 ip;
} debug_run_t;
```

The members include:

flags

A combination of zero or more of the following bits:

- _DEBUG_RUN_CLRSIG — clear pending signal.
- _DEBUG_RUN_CLRFLT — clear pending fault.
- _DEBUG_RUN_TRACE — the *trace* mask flags interesting signals.
- _DEBUG_RUN_FAULT — the *fault* mask flags interesting faults.
- _DEBUG_RUN_VADDR — change *ip* before running.
- _DEBUG_RUN_STEP — single-step only one thread.
- _DEBUG_RUN_STEP_ALL — single-step one thread; other threads run.

- _DEBUG_RUN_CURTID — change the current thread (target thread) to the one whose thread ID is specified by *tid*.
- _DEBUG_RUN_ARM — deliver an event at the point of interest. Use the DCMD_PROC_EVENT command to define the event.

tid

The ID of the thread that you want to become the current thread, for use with _DEBUG_RUN_CURTID.

trace

A set of signals (SIG*) to trace, for use with _DEBUG_RUN_TRACE.

hold

Not currently used.

fault

A set of faults (FLT*) to trace, for use with _DEBUG_RUN_FAULT.

ip

The new value for the instruction pointer, for use with _DEBUG_RUN_VADDR.

Use *sigemptyset()* and *sigaddset()* to build the set of signals or faults for the *trace*, *hold* and *fault* members.

DCMD_PROC_SETALTREG

Set the alternate register set with the values provided for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_SETALTREG    __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 22, procfs_fpreg)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_SETALTREG
dev_data_ptr	A pointer to a `procfs_fpreg` structure
n_bytes	`sizeof(procfs_fpreg)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_fpreg` structure (see `debug_fpreg_t` in **<sys/debug.h>**) that specifies to set the values of the alternate register set. For example:

```
procfs_fpreg reg;

/* Set the members of reg as required. */
devctl( fd, DCMD_PROC_SETALTREG, &reg, sizeof(reg), NULL);
```

To get the alternate register set, use DCMD_PROC_GETALTREG.

DCMD_PROC_SETFPREG

Set the Floating Point Data registers with the values provided for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_SETFPREG   __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 13, procfs_fpreg)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_SETFPREG
dev_data_ptr	A pointer to a `procfs_fpreg` structure
n_bytes	`sizeof(procfs_fpreg)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_fpreg` structure (see `debug_fpreg_t` in **<sys/debug.h>**) that specifies the values of the Floating Point Data registers. For example:

```
procfs_fpreg my_fpreg;

/* Set the members of my_fpreg as required. */
devctl( fd, DCMD_PROC_SETFPREG, my_fpreg, sizeof(procfs_fpreg),
        NULL);
```

To get the Floating Point Data registers, use DCMD_PROC_GETFPREG.

DCMD_PROC_SETGREG

Set the CPU registers with the values provided for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_SETGREG   __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 11, procfs_greg)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_SETGREG
dev_data_ptr	A pointer to a `procfs_greg` structure
n_bytes	`sizeof(procfs_greg)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_greg` structure (see `debug_greg_t` in **<sys/debug.h>**) that specifies the values to assign to the CPU registers. For example:

```
procfs_greg my_greg;

/* Set the members of my_greg as required. */
devctl( fd, DCMD_PROC_SETGREG, my_greg, sizeof(procfs_greg),
        NULL);
```

To get the CPU registers, use DCMD_PROC_GETGREG.

DCMD_PROC_SETREGSET

Set the given register set.

```
#include <sys/procfs.h>

#define DCMD_PROC_SETREGSET   __DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 26, procfs_regset)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_SETREGSET
dev_data_ptr	A pointer to a `procfs_regset` structure
n_bytes	The number of bytes that you want to set
dev_info_ptr	A pointer to an `int` where the number of bytes set can be stored

The argument is a pointer to a `procfs_regset` structure that specifies the values to assign to the register set. For more information, see DCMD_PROC_GETREGSET. For example, to set the performance registers:

```
procfs_regset regset;
int           returned_length;
```

```
regset.id = REGSET_PERFREGS;

/* Set the buf member as appropriate. */
...
devctl( fd, DCMD_PROC_SETREGSET, &regset, sizeof(regset), &returned_length );
```

(QNX Neutrino 7.0.4 or later) To set the Auxiliary Control Register on AArch64:

```
procfs_regset regset;
int           returned_length;

regset.id = AARCH64_REGSET_ACTLR;
*(uint64_t *)&regset.buf[0] = regval;
devctl( fd, DCMD_PROC_SETREGSET, &regset, sizeof(uint32_t) + sizeof(uint64_t),
        &returned_length );
```

Because AARCH64_REGSET_ACTLR is a privileged register, your process needs the PROCMGR_AID_PRIVREG ability enabled; see *procmgr_ability()* in the *C Library Reference*. In order for you to use this register, your startup program needs to set the AARCH64_CPU_ACTLR flag in *cpuinfo.flags* in the system page. For more information, see the “System Page” chapter of *Building Embedded Systems*.

To get the given register set, use DCMD_PROC_GETREGSET.

DCMD_PROC_SET_FLAG

Set specific debug flags with the values provided for the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_SET_FLAG   __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 18, uint32_t)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_SET_FLAG
dev_data_ptr	A pointer to a `uint32_t`
n_bytes	`sizeof(uint32_t)`
dev_info_ptr	NULL

The flags that can be set are described in **<sys/debug.h>**. The argument is a pointer to an unsigned integer that specifies the debug flags to set. For example:

```
int flags;
```

```
flags = _DEBUG_FLAG_KLC;        /* Kill-on-Last-Close flag */
devctl( fd, DCMD_PROC_SET_FLAG, &flags, sizeof(flags), NULL);
```

To clear the debug flags, use DCMD_PROC_CLEAR_FLAG.

DCMD_PROC_SIGNAL

Drop a signal on the process that's associated with the file descriptor. This is a way for a debugger to artificially generate signals as if they came from the system.

```
#include <sys/procfs.h>

#define DCMD_PROC_SIGNAL   __DIOT(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 4, procfs_signal)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_SIGNAL
dev_data_ptr	A pointer to a `procfs_signal` structure
n_bytes	`sizeof(procfs_signal)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_signal` structure that specifies the signal to send. For example:

```
procfs_signal   signal;

signal.tid = 0;
signal.signo = SIGCONT;
signal.code = 0;
signal.value = 0;

devctl( fd, DCMD_PROC_SIGNAL, &signal, sizeof signal, NULL);
```

DCMD_PROC_STATUS

Get the current status of the current thread in the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_STATUS32  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status32))
#define DCMD_PROC_STATUS64  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status64))
#define DCMD_PROC_STATUS    (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_STATUS
dev_data_ptr	A pointer to a `procfs_status` structure
n_bytes	`sizeof(procfs_status)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_status` structure (see `debug_thread_t` in **<sys/debug.h>**) that's filled in with the required information on return. For example:

```
procfs_status my_status;

devctl( fd, DCMD_PROC_STATUS, &my_status, sizeof(my_status),
        NULL);
```

If the current thread no longer exists, the process manager returns information about the one with the next higher thread ID. If there are no threads with a higher ID, *devctl()* returns ESRCH.

For more information about the contents of this structure, see "*Thread information*," earlier in this chapter.

DCMD_PROC_STOP

Stop the process that's associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_STOP32   (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 5, procfs_status32))
#define DCMD_PROC_STOP64   (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 5, procfs_status64))
#define DCMD_PROC_STOP     (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 5, procfs_status))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process. You must have opened the file descriptor for writing.
dcmd	DCMD_PROC_STOP
dev_data_ptr	A pointer to a `procfs_status` structure

Argument	Value
n_bytes	`sizeof(procfs_status)`
dev_info_ptr	NULL

The argument to this command is the address of a `procfs_status` structure (see `debug_thread_t` in **<sys/debug.h>**). This structure is filled with status information on return. For example:

```
procfs_status my_status;

devctl( fd, DCMD_PROC_STOP, &my_status, sizeof(my_status), NULL);
```

For more information about the contents of this structure, see "*Thread information*," earlier in this chapter.

To resume the process, use DCMD_PROC_RUN.

DCMD_PROC_SYSINFO

Obtain information stored in the system page.

```
#include <sys/procfs.h>

#define DCMD_PROC_SYSINFO    __DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 0, procfs_sysinfo)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_SYSINFO
dev_data_ptr	NULL, or an array of `procfs_sysinfo` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer where the required size can be stored

The argument is a pointer to a `procfs_sysinfo` structure that's filled in with the required information upon return. To get the whole system page, you have to make two calls: the first gets the size required:

```
devctl( fd, DCMD_PROC_SYSINFO, NULL, 0, &totalsize );
```

You then allocate a buffer of the required size and pass that buffer to the second call:

```
buffer = malloc( totalsize );
devctl( fd, DCMD_PROC_SYSINFO, buffer, totalsize, NULL );
```

The `procfs_sysinfo` structure is the same as the system page; for more information, see the System Page chapter of *Building Embedded Systems*.

DCMD_PROC_THREADCTL

Perform a *ThreadCtl()* on another process/thread.

```
#include <sys/procfs.h>

#define DCMD_PROC_THREADCTL    __DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 27, procfs_threadctl)
```

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_THREADCTL
dev_data_ptr	A pointer to a `procfs_threadctl` structure
n_bytes	`sizeof(procfs_threadctl)`
dev_info_ptr	NULL

The argument is a pointer to a `procfs_threadctl` structure. For example:

```
procfs_threadctl    tctl;

tctl.tid = tid;
tctl.cmd = _NTO_TCTL_NAME;

tn = (struct _thread_name *)(&tctl.data);
tn->name_buf_len = sizeof(tctl.data) - sizeof(*tn);

//We can only communicate a maximum buffer size via devctl
if( newname_len > tn->name_buf_len || prevname_len >
    tn->name_buf_len) {
    return E2BIG;
}

tn->new_name_len = newname_len;
if(newname_len > 0) {
    memcpy(tn->name_buf, newname, newname_len);
}

devctl(fd, DCMD_PROC_THREADCTL, &tctl, sizeof(tctl), NULL);
```

DCMD_PROC_TIDSTATUS

Get the current status of a thread in the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_TIDSTATUS32   (__DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status32))
#define DCMD_PROC_TIDSTATUS64   (__DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status64))
#define DCMD_PROC_TIDSTATUS     (__DIOTF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_TIDSTATUS
dev_data_ptr	A pointer to a `procfs_status` structure
n_bytes	`sizeof(procfs_status)`
dev_info_ptr	NULL

This is a short form of using DCMD_PROC_CURTHREAD to set the current thread, then DCMD_PROC_STATUS to get information about that thread, and then restoring the current thread.

The argument is a pointer to a `procfs_status` structure (see `debug_thread_t` in **<sys/debug.h>**), with the required thread ID specified in the *tid* field. This structure is filled in with the required information on return. For example:

```
procfs_status my_status;

my_status.tid = 1;
devctl( fd, DCMD_PROC_TIDSTATUS, &my_status, sizeof(my_status),
        NULL);
```

If the thread that you specified no longer exists, the process manager returns information about the one with the next higher thread ID (in which case the *tid* member won't be the same as it was before you called the command). If there are no threads with a higher ID, *devctl()* returns ESRCH.

For more information about the contents of this structure, see "*Thread information*," earlier in this chapter.

DCMD_PROC_TIMERS

Get the timers owned by the process associated with the file descriptor.

```
#include <sys/procfs.h>

#define DCMD_PROC_TIMERS32  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 23, procfs_timer32))
#define DCMD_PROC_TIMERS64  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 23, procfs_timer64))
#define DCMD_PROC_TIMERS    (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 23, procfs_timer))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_TIMERS
dev_data_ptr	NULL, or an array of `procfs_timer` structures
n_bytes	0, or the size of the array
dev_info_ptr	A pointer to an integer where the number of timers can be stored

Call this the first time with an argument of NULL to get the number of timers:

```
devctl( fd, DCMD_PROC_TIMERS, NULL, 0, &n);
```

Next, allocate a buffer that's large enough to hold a `procfs_timer` structure for each timer, and pass it to another *devctl()* call:

```
my_buffer = (procfs_timer *) malloc( sizeof(procfs_timer) * n;
if ( my_buffer == NULL ) {
  /* Not enough memory. */
}

devctl( fd, DCMD_PROC_TIMERS, my_buffer,
        sizeof(procfs_timer) * n, &dummy);
```

The `procfs_timer` structure is the same as the `debug_timer_t` structure, which is defined for 64-bit architectures as follows in **<sys/debug.h>**:

```
typedef struct _debug_timer64 {
  timer_t              id;
  unsigned             spare;
  struct _timer_info32  __info;
  struct _timer_info64  info;
} debug_timer64_t;
```

For information about the `_timer_info` structure, see the entry for *TimerInfo()* in the QNX Neutrino *C Library Reference*, and the section on DCMD_PROC_INFO in the appendix about the **/procfs** filesystem in *The QNX Neutrino Cookbook*.

DCMD_PROC_WAITSTOP

Hold off the calling process until the process that's associated with the file descriptor reaches a point of interest.

```
#include <sys/procfs.h>

#define DCMD_PROC_WAITSTOP32  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 6, procfs_status32))
#define DCMD_PROC_WAITSTOP64  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 6, procfs_status64))
#define DCMD_PROC_WAITSTOP    (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 6, procfs_status))
```

The generic command maps onto the 64-bit version, unless you're compiling for a 32-bit architecture and you define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**.

The arguments to *devctl()* are:

Argument	Value
filedes	A file descriptor for the process.
dcmd	DCMD_PROC_WAITSTOP
dev_data_ptr	A pointer to a `procfs_status` structure
n_bytes	`sizeof(procfs_status)`
dev_info_ptr	NULL

You must have opened the file descriptor for writing. Use the DCMD_PROC_RUN command to set up the point of interest. If you don't want to block the calling process, use DCMD_PROC_EVENT instead of DCMD_PROC_WAITSTOP.

The argument is a pointer to a `procfs_status` structure (see `debug_thread_t` in **<sys/debug.h>**) that's filled with status information on return. For example:

```
procfs_status my_status;

devctl( fd, DCMD_PROC_WAITSTOP, &my_status, sizeof my_status, NULL);
```

For more information about the contents of this structure, see "*Thread information*," earlier in this chapter.

Chapter 4
Multicore Processing

Multiprocessing systems, whether discrete or multicore, can greatly improve your applications' performance. As described in the Multicore Processing chapter of the *System Architecture* guide, the QNX Neutrino RTOS can run on single-core or multicore systems.

To determine how many processors there are on your system, look at the *num_cpu* entry of the system page. For more information, see the System Page chapter of *Building Embedded Systems*.

QNX Neutrino supports these operating modes for multiprocessing:

Asymmetric multiprocessing (AMP)

A separate OS, or a separate instantiation of the same OS, runs on each CPU.

Symmetric multiprocessing (SMP)

A single instantiation of an OS manages all CPUs simultaneously, and applications can float to any of them.

Bound multiprocessing (BMP)

A single instantiation of an OS manages all CPUs simultaneously, but you can lock individual applications or threads to a specific CPU.

SMP lets you get the most performance out of your system, but you might need to use BMP for the few applications that may not work under SMP, or if you want to explicitly control the process-level distribution of CPU usage.

In QNX Neutrino 7.0 or later, we require that the hardware underlying *ClockCycles()* be synchronized across all processors on an SMP system. If it isn't, you might encounter some unexpected behavior, such as drifting times and timers. Using synchronized hardware means that you no longer have to use a runmask for threads to prevent them from migrating to other processors between calls to *ClockCycles()*.

The impact of multicore

The main thing to keep in mind when you run on a multicore system is this: in a single-processor environment, it may be a nice "design abstraction" to pretend that threads execute in parallel; under a multicore system, they *really do* execute in parallel! (With BMP, you can make your threads run on a specific CPU.)

In this section, we'll examine the impact of multicore on your system design.

Thread affinity

One issue that often arises in a multicore environment can be put like this: "Can I make it so that one processor handles the GUI, another handles the database, and the other two handle the realtime functions?"

The answer is: "Yes, absolutely."

This is done through *thread affinity*, the ability to associate certain programs (or even threads within programs) with a particular processor or processors.

Thread affinity works like this. When a thread starts up, its affinity mask (or runmask) is set to allow it to run on all processors. This implies that there's *no* inheritance of the thread affinity mask, so it's up to the thread to use *ThreadCtl()* with the _NTO_TCTL_RUNMASK control flag to set its runmask:

```
if (ThreadCtl( _NTO_TCTL_RUNMASK, (void *)my_runmask) == -1) {
     /* An error occurred. */
}
```

The runmask is simply a bitmap; each bit position indicates a particular processor. For example, the runmask `0x05` (binary `00000101`) allows the thread to run on processors `0` (the `0x01` bit) and `2` (the `0x04` bit).

If you use _NTO_TCTL_RUNMASK, the runmask is limited to the size of an `int` (currently 32 bits). Threads created by the calling thread don't inherit the specified runmask.

If you want to support more processors than will fit in an `int`, or you want to set the inherit mask, you'll need to use the _NTO_TCTL_RUNMASK_GET_AND_SET_INHERIT command described below.

The **<sys/neutrino.h>** file defines some macros that you can use to work with a runmask:

RMSK_SET(cpu, p)

Set the bit for *cpu* in the mask pointed to by *p*.

RMSK_CLR(cpu, p)

Clear the bit for *cpu* in the mask pointed to by *p*.

RMSK_ISSET(cpu, p)

Determine if the bit for *cpu* is set in the mask pointed to by *p*.

The CPUs are numbered from 0. These macros work with runmasks of any length.

Bound multiprocessing (BMP) is a variation on SMP that lets you specify which processors a process or thread *and its children* can run on. To specify this, you use an *inherit mask*.

To set a thread's inherit mask, you use *ThreadCtl()* with the _NTO_TCTL_RUNMASK_GET_AND_SET_INHERIT control flag. Conceptually, the structure that you pass with this command is as follows:

```
struct _thread_runmask {
    int size;
    unsigned runmask[size];
    unsigned inherit_mask[size];
};
```

If you set the *runmask* member to a nonzero value, *ThreadCtl()* sets the runmask of the calling thread to the specified value. If you set the *runmask* member to zero, the runmask of the calling thread isn't altered.

If you set the *inherit_mask* member to a nonzero value, *ThreadCtl()* sets the calling thread's inheritance mask to the specified value(s); if the calling thread creates any children by calling *pthread_create()*, *fork()*, *posix_spawn()*, *spawn()*, or *exec()*, the children inherit this mask. If you set the *inherit_mask* member to zero, the calling thread's inheritance mask isn't changed.

If you look at the definition of `_thread_runmask` in **<sys/neutrino.h>**, you'll see that it's actually declared like this:

```
struct _thread_runmask {
    int         size;
/*  unsigned    runmask[size];      */
/*  unsigned    inherit_mask[size]; */
};
```

This is because the number of elements in the *runmask* and *inherit_mask* arrays depends on the number of processors in your multicore system. You can use the *RMSK_SIZE()* macro to determine how many unsigned integers you need for the masks; pass the number of CPUs (found in the system page) to this macro.

Here's a code snippet that shows how to set up the runmask and inherit mask:

```
unsigned    num_elements = 0;
int         *rsizep, masksize_bytes, size;
unsigned    *rmaskp, *imaskp;
void        *my_data;

/* Determine the number of array elements required to hold
 * the runmasks, based on the number of CPUs in the system. */
num_elements = RMSK_SIZE(_syspage_ptr->num_cpu);

/* Determine the size of the runmask, in bytes. */
masksize_bytes = num_elements * sizeof(unsigned);

/* Allocate memory for the data structure that we'll pass
 * to ThreadCtl(). We need space for an integer (the number
 * of elements in each mask array) and the two masks
 * (runmask and inherit mask). */
```

```
size = sizeof(int) + 2 * masksize_bytes;
if ((my_data = malloc(size)) == NULL) {
    /* Not enough memory. */
    …
} else {
    memset(my_data, 0x00, size);

    /* Set up pointers to the "members" of the structure. */
    rsizep = (int *)my_data;
    rmaskp = rsizep + 1;
    imaskp = rmaskp + num_elements;

    /* Set the size. */
    *rsizep = num_elements;

    /* Set the runmask. Call this macro once for each processor
       the thread can run on. */
    RMSK_SET(cpu1, rmaskp);

    /* Set the inherit mask. Call this macro once for each
       processor the thread's children can run on. */
    RMSK_SET(cpu1, imaskp);

    if ( ThreadCtl( _NTO_TCTL_RUNMASK_GET_AND_SET_INHERIT,
                    my_data) == -1) {
        /* Something went wrong. */
        …
    }
}
```

If you're starting a new process, you can specify its runmask by:

- calling *posix_spawnattr_setrunmask()*, using *posix_spawnattr_setxflags()* to set the POSIX_SPAWN_EXPLICIT_CPU extended flag, and then calling *posix_spawn()*

  Or:

- setting the *runmask* member of the `inheritance` structure and specifying the SPAWN_EXPLICIT_CPU flag when you call *spawn()*

You can also use the `-C` and `-R` options to the `on` command to launch processes with a runmask (assuming they don't set their runmasks programmatically); for example, use `on -C 1 io-pkt-v4-hc` to start `io-pkt-v4-hc` and lock all threads to CPU 1. This command sets both the runmask and the inherit mask.

You can also use the same options to the `slay` command to modify the runmask of a running process or thread. For example, `slay -C 0 io-pkt-v4-hc` moves all of `io-pkt-v4-hc`'s threads to run on CPU 0. If you use the `-C` and `-R` options, `slay` sets the runmask; if you also use the `-i` option, `slay` also sets the process's or thread's inherit mask to be the same as the runmask.

Multicore and...

Synchronization primitives

Standard synchronization primitives (barriers, mutexes, condvars, semaphores, and all of their derivatives, e.g., sleepon locks) are safe to use on a multicore box. You don't have to do anything special here.

FIFO scheduling

A common single-processor "trick" for coordinated access to a shared memory region is to use FIFO scheduling between two threads running at the same priority. The idea is that one thread will access the region and then call *SchedYield()* to give up its use of the processor. Then, the second thread runs and accesses the region. When it's done, the second thread too calls *SchedYield()*, and the first thread runs again. Since there's only one processor, both threads would cooperatively share that processor.

This FIFO trick won't work on an SMP system, because *both* threads may run simultaneously on different processors. You'll have to use the more "proper" thread synchronization primitives (e.g., a mutex), or use BMP to tie the threads to specific CPUs.

Interrupts

The following method is closely related to the FIFO scheduling trick. On a single-processor system, a thread and an interrupt service routine are mutually exclusive, because the ISR runs at a higher priority than any thread. Therefore, the ISR can preempt the thread, but the thread can *never* preempt the ISR. So the only "protection" required is for the thread to indicate that during a particular section of code (the *critical section*) interrupts should be disabled.

Obviously, this scheme breaks down in a multicore system, because again the thread and the ISR could be running on different processors.

The solution in this case is to use the *InterruptLock()* and *InterruptUnlock()* calls to ensure that the ISR won't preempt the thread at an unexpected point. But what if the thread preempts the ISR? The solution is the same: use *InterruptLock()* and *InterruptUnlock()* in the ISR as well.

We recommend that you *always* use *InterruptLock()* and *InterruptUnlock()*, both in the thread and in the ISR.

Atomic operations

Note that if you wish to perform simple atomic operations, such as adding a value to a memory location, it isn't necessary to turn off interrupts to ensure that the operation won't be preempted. Instead, use the functions provided in the C include file **<atomic.h>**, which let you perform the following operations with memory locations in an atomic manner:

Function	Operation
atomic_add()	Add a number

Function	Operation
atomic_add_value()	Add a number and return the original value of **loc*
atomic_clr()	Clear bits
atomic_clr_value()	Clear bits and return the original value of **loc*
atomic_set()	Set bits
atomic_set_value()	Set bits and return the original value of **loc*
atomic_sub()	Subtract a number
atomic_sub_value()	Subtract a number and return the original value of **loc*
atomic_toggle()	Toggle (complement) bits
atomic_toggle_value()	Toggle (complement) bits and return the original value of **loc*

The *_value() functions may be slower on some systems, so don't use them unless you really want the return value.

Adaptive partitionining

You can use adaptive partitioning on a multicore system, but there are some interactions to watch out for. For more information, see "Using adaptive partitioning and multicore together" in the Adaptive Partitioning Scheduling Details chapter of the Adaptive Partitioning *User's Guide*.

Designing with multiprocessing in mind

This section contains some general tips on how to design programs so that they can scale to *N* processors.

Use the multicore primitives

Don't assume that your program will run only on one processor. This means staying away from the FIFO synchronization trick mentioned above. Also, you should use the multicore-aware *InterruptLock()* and *InterruptUnlock()* functions.

Assume that threads *really do* run concurrently

As mentioned above, it isn't merely a useful “programming abstraction” to pretend that threads run simultaneously; you should design as if they really do. That way, when you move to a multicore system, you won't have any nasty surprises (but you can use BMP if you have problems and don't want to modify the code).

Break the problem down

Most problems can be broken down into independent, parallel tasks. Some are easy to break down, some are hard, and some are impossible. Generally, you want to look at the data flow going through a particular problem. If the data flows are *independent* (i.e., one flow doesn't rely on the results of another), this can be a good candidate for parallelization within the process by starting multiple threads. Consider the following graphics program snippet:

```
do_graphics ()
{
    int     x;

    for (x = 0; x < XRESOLUTION; x++) {
        do_one_line (x);
    }
}
```

In the above example, we're doing ray-tracing. We've looked at the problem and decided that the function *do_one_line()* only generates output to the screen—it doesn't rely on the results from any other invocation of *do_one_line()*.

To make optimal use of a multicore system, you would start multiple threads, each running on one processor.

The question then becomes how many threads to start. Obviously, starting XRESOLUTION threads (where XRESOLUTION is far greater than the number of processors, perhaps 1024 to 4) isn't a particularly good idea—you're creating a lot of threads, all of which will consume stack resources and kernel resources as they compete for the limited pool of CPUs.

A simple solution would be to find out the number of CPUs that you have available to you (via the system page pointer) and divide the work up that way:

```
#include <sys/syspage.h>
```

```
int     num_x_per_cpu;

do_graphics ()
{
    int     num_cpus;
    int     i;
    pthread_t *tids;

    // figure out how many CPUs there are...
    num_cpus = _syspage_ptr -> num_cpu;

    // allocate storage for the thread IDs
    tids = malloc (num_cpus * sizeof (pthread_t));

    // figure out how many X lines each CPU can do
    num_x_per_cpu = XRESOLUTION / num_cpus;

    // start up one thread per CPU, passing it the ID
    for (i = 0; i < num_cpus; i++) {
        pthread_create (&tids[i], NULL, do_lines, (void *) i);
    }

    // now all the "do_lines" are off running on the processors

    // we need to wait for their termination
    for (i = 0; i < num_cpus; i++) {
        pthread_join (tids[i], NULL);
    }

    // now they are all done
}

void *
do_lines (void *arg)
{
    int    cpunum = (int) arg;  // convert void * to an integer
    int    x;

    for (x = cpunum * num_x_per_cpu; x < (cpunum + 1) *
          num_x_per_cpu; x++) { do_line (x);
    }
}
```

The above approach lets the maximum number of threads run simultaneously on the multicore system. There's no point creating more threads than there are CPUs, because they'll simply compete with each other for CPU time.

Note that in this example, we didn't specify which processor to run each thread on. We don't need to in this case, because the READY thread with the highest priority always runs on the next available processor. The threads will tend to run on different processors (depending on what else is running in the system). You typically use the same priority for all the worker threads if they're doing similar work.

An alternative approach is to use a semaphore. You could preload the semaphore with the count of available CPUs. Then, you create threads whenever the semaphore indicates that a CPU is available.

This is conceptually simpler, but involves the overhead of creating and destroying threads for each iteration.

Chapter 5
Working with Access Control Lists (ACLs)

Some filesystems, such as the Power-Safe (`fs-qnx6.so`) filesystem, extend file permissions with *Access Control Lists*, which are based on the withdrawn IEEE POSIX 1003.1e and 1003.2c draft standards.

As described in "Access Control Lists (ACLs)" in the QNX Neutrino *User's Guide*, ACLs extend the traditional permissions as set with `chmod`, giving you finer control over who has access to your files and directories.

- The POSIX draft also describes *default ACLs* that specify the initial ACL for new objects created within a directory. Default ACLs aren't currently implemented.
- The `cp` utility doesn't copy any ACL that the source file has, but if the destination file already exists and has an ACL, its ACL is preserved.

If you're using the command line, you can use the `getfacl` and `setfacl` utilities to get and set the ACL for a file or directory, but there are also ways to manipulate ACLs from a program.

Let's start with the ways that an ACL can be represented, and then we'll look at how to work with them.

ACL formats

There are several ways to represent an ACL, depending on how it's to be used.

External form

The exportable, contiguous, persistent representation of an ACL in user-managed space. A program such as `tar` could (but currently doesn't) use this representation so that it could later restore the ACLs, even on a different filesystem.

Internal form

The internal representation of an ACL in working storage, which you'll work with in your program. As described below, this form uses various data types to represent an ACL, its entries, and each entry's tag and permissions.

text form

The structured textual representation of an ACL, such as `getfacl` and `setfacl` use.

The internal form uses the following data types:

`acl_t`

A pointer to an opaque ACL data structure in working storage.

`acl_entry_t`

An opaque descriptor for an entry in an ACL.

`acl_permset_t`

An opaque set of permissions in an ACL entry.

`acl_perm_t`

An individual permission; one of:

- ACL_EXECUTE
- ACL_READ
- ACL_WRITE

`acl_tag_t`

The type of tag; one of the following:

- ACL_GROUP — a named group.
- ACL_GROUP_OBJ — the owning group.
- ACL_MASK — the maximum permissions allowed for named users, named groups, and the owning group.
- ACL_OTHER — users whose process attributes don't match any other ACL entry; the “world”.
- ACL_USER — named users.
- ACL_USER_OBJ — the owning user.

acl_type_t

The type of ACL; one of:

- ACL_TYPE_ACCESS — an access ACL. (If you expand the abbreviation, this term becomes "access access control list", but that's what the POSIX draft called it.)
- ACL_TYPE_DEFAULT — a default ACL that a directory can have. It specifies the initial ACL for files and directories created in that directory.

> Default ACLs aren't currently implemented.

You can use these functions to translate from one form of an ACL to another:

acl_copy_ext()

Copy an ACL from system space to user space (i.e., translate from the external form to the internal).

acl_copy_int()

Copy an ACL from user space to system space (i.e., translate from the internal form to the external).

acl_from_text()

Create an internal form of an ACL from a text form.

acl_size()

Determine the size of the external form of an ACL.

acl_to_text()

Convert an internal form of an ACL into a text form.

ACL storage management

There are several functions that manage the memory associated with ACLs.

acl_init()

Allocate and initialize an ACL working storage area. The argument to this function is the number of entries that you want in the list (although *acl_init()* might allocate more). It returns an `acl_t` pointer.

acl_dup()

Duplicate an access control list in working storage. You pass it an `acl_t` pointer, and it returns a pointer to the copy of the list.

acl_free()

Free the working storage area allocated for an access control list (ACL) data object. You should use this function to free the memory allocated by the other *acl_*()* functions.

Manipulating ACL entries in working storage

An ACL can have a number of entries in it. You can use these functions to work with these entries.

acl_copy_entry()

Copy the contents of one ACL entry into another.

acl_create_entry()

Create an entry in an ACL.

acl_delete_entry()

Delete an entry from an access control list.

acl_get_entry()

Get an entry in an access control list.

acl_valid()

Validate an ACL, which you should do before you assign it to a file or directory. This routine makes sure that the list contains the required entries, and that there's only one entry for each named user or group.

Manipulating permissions in an ACL entry

Each ACL entry has a *permissions set*. These functions work with these sets and the individual permissions.

The permissions are represented by the constants ACL_READ, ACL_EXECUTE, and ACL_WRITE. Because a permissions set is an opaque data type, you have to use these functions to work with them:

acl_add_perm()

Add a permission to an access control list (ACL) permissions set.

acl_calc_mask()

Calculate the group class mask for an access control list (ACL).

acl_clear_perms()

Clear all permissions from an ACL permissions set.

acl_delete_perm()

Delete a permission from an ACL permissions set.

acl_get_perm_np()

Test whether a given permission is present in an ACL permissions set.

acl_get_permset()

Get a permissions set from an ACL entry.

acl_set_permset()

Store a permissions set in an ACL entry.

Manipulating the tag type and qualifier in an ACL entry

Each ACL entry must have a tag type, and some also require a qualifier.

Entry type	Tag type	Qualifier
Owner	ACL_USER_OBJ	—
Named user	ACL_USER	`uid_t`
Owning group	ACL_GROUP_OBJ	—
Named group	ACL_GROUP	`gid_t`
Mask	ACL_MASK	—
Others	ACL_OTHER	—

The `uid_t` and `gid_t` data types are defined in **<sys/types.h>**.

The ACL entry is an opaque data type, so you need to use these functions to get or set the tag type and the qualifier:

acl_get_qualifier()

Get the qualifier from an ACL entry.

acl_get_tag_type()

Get the type of tag from an ACL entry.

acl_set_qualifier()

Set the qualifier for an ACL entry.

acl_set_tag_type()

Set the tag type of an ACL entry.

Manipulating ACLs on a file or directory

You can get or set the ACL for a file, via a file descriptor or a path.

acl_get_fd()

Get the access control list associated with a file descriptor.

acl_get_file()

Get the ACL for a given path.

acl_set_fd()

Set the access ACL for the object associated with a file descriptor.

acl_set_file()

Set the access control list for a path.

Example

This example demonstrates how you can get the ACL for a file, modify it, and then set it for the file.

```
#include <stdlib.h>
#include <stdio.h>
#include <sys/acl.h>
#include <sys/types.h>

int main(int argc, char *argv[]) {

 acl_t my_acl;
 char  *text_acl;
 ssize_t len;
 acl_entry_t my_entry;
 gid_t  group_id;
 acl_permset_t permset;
        int fd;

        fd = open( "my_file.txt", O_CREAT | O_RDONLY, 0666 );
        close(fd);

 /* Get the file's ACL. */
 my_acl = acl_get_file ("my_file.txt", ACL_TYPE_ACCESS);
 if (my_acl == NULL)
 {
  perror ("acl_get_file()");
  return EXIT_FAILURE;
 }

 /* Convert the ACL into text so we can see what it is. */
 text_acl = acl_to_text (my_acl, &len);
 if (text_acl == NULL)
 {
  perror ("acl_to_text()");
  return EXIT_FAILURE;
 }
 printf ("Initial ACL: %s\n", text_acl);

 /* We're done with the text version, so release it. */
 acl_free (text_acl);

 /* Add an entry for a named group to the ACL. */
 if (acl_create_entry (&my_acl, &my_entry) == -1)
 {
  perror ("acl_create_entry()");
  return EXIT_FAILURE;
 }

 if (acl_set_tag_type (my_entry, ACL_GROUP) == -1)
 {
  perror ("acl_set_tag_type");
  return EXIT_FAILURE;
```

```
}

group_id = 120;
if (acl_set_qualifier (my_entry, &group_id) == -1)
{
 perror ("acl_set_qualifier");
 return EXIT_FAILURE;
}

/* Modify the permissions. */
acl_get_permset (my_entry, &permset);
acl_clear_perms (permset);

if (acl_add_perm (permset, ACL_READ))
{
 perror ("acl_add_perm");
 return EXIT_FAILURE;
}

/* Recalculate the mask entry. */
if (acl_calc_mask (my_acl))
{
 perror ("acl_calc_mask");
 return EXIT_FAILURE;
}

/* Make sure the ACL is valid. */
if (acl_valid (my_acl) ==-1)
{
 perror ("acl_valid");
 return EXIT_FAILURE;
}

/* Update the ACL for the file. */
if (acl_set_file ("my_file.txt", ACL_TYPE_ACCESS, my_acl) == -1)
{
 perror ("acl_set_file");
 return EXIT_FAILURE;
}

/* Free the ACL in working storage. */
acl_free (my_acl);

/* Verify that it all worked, by getting and printing the file's ACL. */
my_acl = acl_get_file ("my_file.txt", ACL_TYPE_ACCESS);
if (my_acl == NULL)
{
 perror ("acl_get_file()");
 return EXIT_FAILURE;
}

text_acl = acl_to_text (my_acl, &len);
if (text_acl == NULL)
{
```

```
        perror ("acl_to_text()");
        return EXIT_FAILURE;
    }
    printf ("Updated ACL: %s\n", text_acl);

    /* We're done with the text version, so release it. */
    acl_free (text_acl);

    return EXIT_SUCCESS;
}
```

Chapter 6
Understanding the Microkernel's Concept of Time

Whether you're working with timers or simply getting the time of day, it's important that you understand how the OS works with time.

The first thing to consider is: what's a tick?

When you're dealing with timing, every moment within the microkernel is referred to as a *tick*. A tick is measured in milliseconds; its initial length is determined by the clock rate of your processor:

- If your CPU is 40 MHz or better, a tick is 1 ms.
- For slower processors, a tick represents 10 ms.

Programmatically you can change the clock period via the *ClockPeriod()* function.

Short delays

If you need a pause, use *delay()* or the POSIX *clock_nanosleep()*.

If you need a *very* short delay (e.g., for accessing hardware), you should look at the *nanospin*()* functions:

- *nanospin()*
- *nanospin_calibrate()*
- *nanospin_count()*
- *nanospin_ns()*
- *nanospin_ns_to_count()*

They basically do a `while` loop to a calibrated number of iterations to delay the proper amount of time. This wastes CPU, so you should use these functions only if necessary.

Oversleeping: errors in delays

The tick size becomes important just about every time you ask the kernel to do something related to pausing or delaying your process.

This includes calls to the following functions:

- *select()*
- *alarm()*
- *nanosleep()*
- *nanospin()*
- *delay()*
- the whole family of *timer_*()* functions

Normally, you use these functions assuming they'll do exactly what you say: “Sleep for 8 seconds!”, “Sleep for 1 minute!”, and so on. Unfortunately, you get into problems when you say “Sleep for 1 millisecond, ten thousand times!”

Delaying for a second: inaccurate code

Does this code work assuming a 1 ms tick?

```
void OneSecondPause() {

  /* Wait 1000 milliseconds. */
  for ( i=0; i < 1000; i++ ) delay(1);
}
```

Unfortunately, no, this won't return after one second on IBM PC hardware. It'll likely wait for three seconds. In fact, when you call any function based on the *nanosleep()* or *select()* functions, with an argument of *n* milliseconds, it actually takes anywhere from *n* to infinity milliseconds. But more than likely, this example will take three seconds.

So why exactly does this function take three seconds?

Timer quantization error

What you're seeing is called *timer quantization error*. One aspect of this error is actually something that's so well understood and accepted that it's even documented in a standard: the POSIX Realtime Extension (1003.1b-1993/1003.1i-1995). This document says that it's all right to delay too much, but it *isn't* all right to delay too little—the premature firing of a timer is undesirable.

Since the calling of *delay()* is asynchronous with the running of the clock interrupt, the kernel has to add one clock tick to a relative delay to ensure the correct amount of time (consider what would happen if it didn't, and a one-tick delay was requested just before the clock interrupt went off).

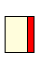


Figure 15: A single 1 ms sleep with error.

That normally adds half a millisecond each time, but in the example given, you end up synchronized with the clock interrupt, so the full millisecond gets tacked on each time.

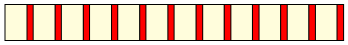


Figure 16: Twelve 1 ms sleeps with each one's error.

The small error on each sleep accumulates:

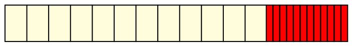


Figure 17: Twelve 1 ms sleeps with the accumulated error.

OK, that should make the loop last 2 seconds—where's the extra second coming from?

The tick and the hardware timer

The problem is that when you request a 1 ms tick rate, the kernel may not be able to actually give it to you because of the frequency of the input clock to the timer hardware. In such cases, it chooses the closest number that's faster than what you requested. In terms of IBM PC hardware, requesting a 1 ms tick rate actually gets you 999,847 nanoseconds between each tick. With the requested delay, that gives us the following:

- 1,000,000 ns + 999,847 ns = 1,999,847 ns of actual delay
- 1,999,847 ns / 999,847 ns = 2.000153 ticks before the timer expires

Since the kernel expires timers only at a clock interrupt, the timer expires after `ceil(2.000153)` ticks, so each `delay(1)` call actually waits:

999,847 ns * 3 = 2,999,541 ns

Multiply that by 1000 for the loop count, and you get a total loop time of 2.999541 seconds.

Delaying for a second: better code

So this code should work?

```
void OneSecondPause() {

     /* Wait 1000 milliseconds. */
    for ( i=0; i < 100; i++ ) delay(10);
}
```

It will certainly get you closer to the time you expect, with an accumulated error of only 1/10 of a second.

Another hiccup with hardware timers

The "*Oversleeping: errors in delays*" section explains the behavior of the sleep-related functions. Timers are similarly affected by the design of the PC hardware. For example, let's consider the following C code:

```
#include <assert.h>
#include <stdio.h>
#include <stdlib.h>
#include <stdint.h>
#include <sys/neutrino.h>
#include <sys/netmgr.h>
#include <sys/syspage.h>

int main( int argc, char *argv[] )
{
    int ret;
    int chid;
    int pulse_id;
    timer_t timer_id;
    struct sigevent event;
    struct itimerspec timer;
    struct _clockperiod clkper;
    struct _pulse pulse;
    uint64_t last_cycles=-1;
    uint64_t current_cycles;
    float cpu_freq;
    time_t start;
    struct sched_param scheduling_params;
    int prio;

    /* Get the CPU frequency in order to do precise time
       calculations. */
    cpu_freq =  SYSPAGE_ENTRY( qtime )->cycles_per_sec;

    /* Set our priority to the maximum, so we won't get disrupted
       by anything other than interrupts. */
    {
        struct sched_param param;
        int ret;

        param.sched_priority = sched_get_priority_max( SCHED_RR );
        ret = sched_setscheduler( 0, SCHED_RR, &param);
        assert ( ret != -1 );
    }

    /* Create a channel to receive timer events on. */
    chid = ChannelCreate( 0 );
    assert ( chid != -1 );

    /* Get our priority. */
    if (SchedGet( 0, 0, &scheduling_params) != -1)
```

```
{
   prio = scheduling_params.sched_priority;
}
else
{
   prio = 10;
}

/* Set up the timer and timer event. */
SIGEV_PULSE_PTR_INIT(&event,
                     ConnectAttach ( ND_LOCAL_NODE, 0, chid, 0, 0 ),
                     prio, 1023, pulse_id);

assert ( event.sigev_coid != -1 );

if ( timer_create(  CLOCK_REALTIME, &event, &timer_id ) == -1 )
{
    perror ( "can't create timer" );
    exit( EXIT_FAILURE );
}

/* Change the timer request to alter the behavior. */
#if 1
      timer.it_value.tv_sec        = 0;
      timer.it_value.tv_nsec       = 1000000;
      timer.it_interval.tv_sec     = 0;
      timer.it_interval.tv_nsec    = 1000000;
#else
      timer.it_value.tv_sec        = 0;
      timer.it_value.tv_nsec       = 999847;
      timer.it_interval.tv_sec     = 0;
      timer.it_interval.tv_nsec    = 999847;
#endif

/* Start the timer. */
if ( timer_settime( timer_id, 0, &timer, NULL ) == -1 )
{
    perror("Can't start timer.\n");
    exit( EXIT_FAILURE );
}

/* Set the tick to 1 ms. Otherwise if left to the default of
   10 ms, it would take 65 seconds to demonstrate. */
clkper.nsec       = 1000000;
clkper.fract      = 0;
ClockPeriod ( CLOCK_REALTIME, &clkper, NULL, 0  );   // 1ms

/* Keep track of time. */
start = time(NULL);
for( ;; )
{
    /* Wait for a pulse. */
    ret = MsgReceivePulse ( chid, &pulse, sizeof( pulse ),
                            NULL );
```

```
        /* Should put pulse validation here... */
        current_cycles = ClockCycles();

        /* Don't print the first iteration. */
        if ( last_cycles != -1 )
        {
            float elapse = (current_cycles - last_cycles) /
                           cpu_freq;

            /* Print a line if the request is 1.05 ms longer than
               requested. */
            if ( elapse > .00105 )
            {
                printf("A lapse of %f ms occurred at %ld seconds\n",
                        elapse, time( NULL ) - start );
            }
        }

        last_cycles = current_cycles;
    }
}
```

The program checks to see if the time between two timer events is greater than 1.05 ms. Most people expect that given QNX Neutrino's great realtime behavior, such a condition will never occur, but it will, not because the kernel is misbehaving, but because of the limitation in the PC hardware. It's impossible for the OS to generate a timer event at exactly 1.0 ms; it will be .99847 ms. This has unexpected side effects.

Where's the catch?

As described earlier in this chapter, there's a 153-nanosecond (ns) discrepancy between the request and what the hardware can do. The kernel timer manager is invoked every .999847 ms. Every time a timer fires, the kernel checks to see if the timer is periodic and, if so, adds the number of nanoseconds to the expected timer expiring point, no matter what the current time is. This phenomenon is illustrated in the following diagram:

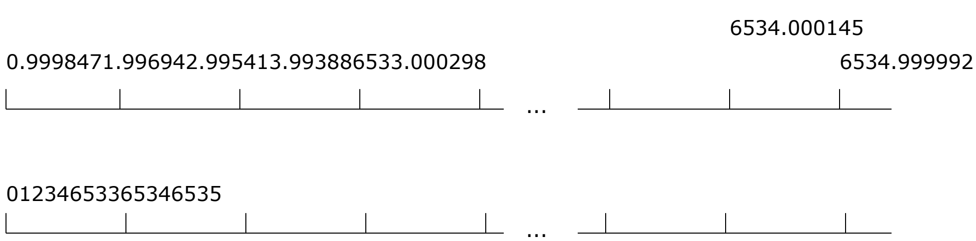


Figure 18: Actual and expected timer expirations.

The first line illustrates the actual time at which timer management occurs. The second line is the time at which the kernel expects the timer to be fired. Note what happens at 6534: the next value appears not to have incremented by 1 ms, thus the event 6535 *won't* be fired!

For signal frequencies, this phenomenon is called a *beat*. When two signals of various frequencies are "added," a third frequency is generated. You can see this effect if you use your camcorder to record a TV image. Because a TV is updated at 60 Hz, and camcorders usually operate on a different frequency, at playback, you can often see a white line that scrolls in the TV image. The speed of that line is related to the difference in frequency between the camcorder and the TV.

In this case we have two frequencies, one at 1000 Hz, and the other at 1005.495 Hz. Thus, the beat frequency is 1.5 micro Hz, or one blip every 6535 milliseconds.

This behavior has the benefit of giving you the expected number of fired timers, on average. In the example above, after 1 minute, the program would have received 60000 fired timer events (1000 events /sec * 60 sec). If your design requires very precise timing, you have no other choice but to request a timer event of .999847 ms and not 1 ms. This can make the difference between a robot moving very smoothly or scratching your car.

What time is it?

QNX Neutrino maintains two clocks in the system: one is a monotonic count of time since the system booted (CLOCK_MONOTONIC), and the other is a wall-clock time since January 1st, 1970 (CLOCK_REALTIME).

The OS actually just counts time since booting, and if asked for the current time, adds an adjustment value (`SYSPAGE_ENTRY(qtime)->nsec_tod_adjust`) to the monotonic time to get the current time. Any functions that change the current time simply modify the adjustment value.

There are several functions that you can use to determine the current time, for use in timestamps or for calculating execution times, including:

time()

Return the current time in seconds.

clock_gettime()

Return the current or monotonic time in seconds and nanoseconds since the last second.

ClockTime()

Set or get the current or monotonic time in 64-bit nanoseconds

QNX Neutrino uses unsigned 32-bit values for seconds since January 1st, 1970, allowing for time representations through approximately the year 2100 (rather than 2038). The internal time storage in 64-bit nanoseconds allows for time representations through the year 2500.

All the above methods have a precision that's based on the system timer tick. If you need more precision, you can use *ClockCycles()*. This function is implemented differently for each processor architecture, so there are tradeoffs. The implementation tries to be as quick as possible, so it tries to use a CPU register if possible.

In QNX Neutrino 7.0 or later, we require that the hardware underlying *ClockCycles()* be synchronized across all processors on an SMP system. If it isn't, you might encounter some unexpected behavior, such as drifting times and timers. Using synchronized hardware means that you no longer have to use a runmask for threads to prevent them from migrating to other processors between calls to *ClockCycles()*.

Some caveats for each processor:

x86

Reads from a 64-bit register.

ARM

Always faults, and the fault handler reads from an external clock chip to make a 64-bit value.

To convert the cycle number to real time, use `SYSPAGE_ENTRY(qtime)->cycles_per_sec`.

Clocks, timers, and power management

If your system needs to manage power consumption, you can set up your timers to help the system to sleep for longer intervals, saving power.

The kernel can reduce power consumption by running in *tickless mode*. This is a bit of a misnomer: the system still has clock ticks, and everything runs as normal unless the system is idle. Only when the system goes completely idle does the kernel “turn off” clock ticks, and in reality what it does is slow down the clock so that the next tick interrupt occurs just after the next active timer is to fire.

In order for the kernel to enter tickless mode, the following must all be true:

- You must have enabled tickless operation by specifying the `-Z` option for the `startup-*` code. If this option is set, the QTIME_FLAG_TICKLESS flag is set in the *qtime* member of the system page (see the System Page chapter of *Building Embedded Systems*).
- The clock must not be in the process of being adjusted because of a call to *ClockAdjust()*.
- All processors must be idle.

If the kernel decides to enter tickless mode, it determines the number of nanoseconds until the next timer is supposed to expire. If that expiry is more than a certain time away, the kernel reprograms the timer hardware to generate its next interrupt shortly after that, and then sets some variables to indicate that it's gone tickless. When something other than the idle thread is made ready, the kernel stops tickless operation, checks the list of active timers, and fires off any that were supposed to expire before it went to sleep.

Another way to reduce power consumption is to use “lazy” interrupts; for more information, see “*Interrupts and power management*” in the Writing an Interrupt Handler chapter in this guide.

Here are some tips for helping the kernel reduce power consumption:

- Avoid polling loops and periodic timers.

  Typical implementations of polling loops give the kernel no option to delay your application's execution when in low-power mode. On every iteration of your loop, you wake up the system and cause extra power usage as a result.

  Polling loops are commonly caused by using the following functions in an unbounded loop:

  - *sleep()*
  - *nanosleep()*
  - *pthread_cond_timedwait()*
  - *select()* or *poll()* with a timeout

  If you must use a polling loop, make its interval and tolerance as long as possible. This will minimize the power impact while allowing the kernel (through timer tolerance) to batch as many wakeups as possible.

- Use timer tolerance.

  When setting up a timer, you can specify how much tolerance the kernel is allowed when scheduling your thread after the timer fires. The kernel uses your timer's tolerance only when the system isn't awake. Essentially, tolerance allows the system to sleep longer and then do more work when it does wake up. For more information, see “*Tolerant and high-resolution timers*” in this chapter.

- Use *ionotify()* combined with a tolerant timer in place of *select()* with a timeout.

  The *select()* and *poll()* functions can't use a tolerant timer. You can duplicate the behavior of these functions by using *ionotify()*, while using a tolerant timer for the timeout. Using this method also has the advantage of providing a normal QNX Neutrino pulse when input is available, letting you use your application's existing *MsgReceive()* loop.

Tolerant and high-resolution timers

You can use *timer tolerance* to specify how strictly the kernel should enforce a timer's expiry time.

Tolerance	Effect
0	Use the process's default tolerance (see *procmgr_timer_tolerance()*). If the process's default tolerance is 0, use the default tolerance of 1 tick (see *ClockPeriod()*).
Greater than 0 and less than one tick	(QNX Neutrino 7.0 or later) The timer is considered to be a high-resolution timer; the kernel adjusts the hardware timer so that the clock tick interrupt occurs at the requested tolerance
Greater than or equal to one tick	The kernel uses the expiry time plus the tolerance to decide if and for how long it should enter tickless operation or a low-power mode; see "*Clocks, timers, and power management*" in this chapter
Amounts beyond any value the current time can have (e.g., ~0ULL)	Use infinite tolerance; a CLOCK_SOFTTIME timer is really a timer with infinite tolerance

After creating the timer by calling *timer_create()* or *TimerCreate()*, you can set the tolerance by specifying the TIMER_TOLERANCE flag when you call *timer_settime()* or *TimerSettime()*. Call one of these functions again (without TIMER_TOLERANCE) to set the expiry time and start the timer. The tolerance persists until you set it again or destroy the timer.

Timer tolerance also applies to the timeouts that you can use for kernel calls that block. You can set the tolerance by specifying the TIMER_TOLERANCE flag when you call *timer_timeout()* or *TimerTimeout()*. Call one of these functions again (without TIMER_TOLERANCE) to start the timeout. In this case, the tolerance is used only for the current timeout.

- The tolerance may lengthen, but never shortens, the time before the timer expires.
- Setting the tolerance doesn't affect the active/inactive status of the timer.
- Timer tolerance is a QNX Neutrino extension to the POSIX *timer_settime()* function. If you want to specify infinite timer tolerance, call *TimerSettime()* instead of *timer_settime()*.
- The startup code tries to determine the frequency of the hardware timer, but for greater accuracy you should specify the frequency by using the `-f` option; see `startup-*` options in the *Utilities Reference*.
- Using high-resolution timers causes extra timer interrupts; as you use more high-resolution timers, the impact on system performance increases. The total impact will vary with interrupt frequency and the hardware characteristics of the system.
- (QNX Neutrino 7.0.1 or later) In order to set the tolerance to a value between 0 and the clock period, you need to have the PROCMGR_AID_HIGH_RESOLUTION_TIMER ability enabled. For more information, see *procmgr_ability()*. The flags for a high-resolution timer (which you can get by calling *TimerInfo()*) include _NTO_TI_HIGH_RESOLUTION.

Here's an example of setting up a high-resolution timer:

```
struct sigevent event;
timer_t timerId;
int tolerance = 1; // Use a high-resolution timer.
struct itimerspec newTimerTolerance, newTimerSpec;
int rc;

event.sigev_notify = SIGEV_SIGNAL;
event.sigev_signo = SIGUSR1;

rc = timer_create(CLOCK_MONOTONIC, &event, &timerId);
if (rc == -1)
{
  // Handle the error
}

// Set the tolerance on the timer first because
// setting the time activates the timer.

memset(&newTimerTolerance, 0, sizeof(newTimerTolerance));
newTimerTolerance.it_value.tv_sec = 0;
newTimerTolerance.it_value.tv_nsec = tolerance;
newTimerTolerance.it_interval.tv_sec  = 0;
newTimerTolerance.it_interval.tv_nsec = 0;
rc = timer_settime(timerId, TIMER_TOLERANCE, &newTimerTolerance, NULL);
if (rc == -1)
{
  // Handle the error
}

memset(&newTimerSpec, 0, sizeof(newTimerSpec));
newTimerSpec.it_value.tv_sec =  sec;
newTimerSpec.it_value.tv_nsec = usec * 1000;
newTimerSpec.it_interval.tv_sec  = 0;
newTimerSpec.it_interval.tv_nsec = 0;
rc = timer_settime(timerId, 0, &newTimerSpec, NULL);
if (rc == -1)
{
  // Handle the error
}
```

You can use *procmgr_timer_tolerance()* to set a default timer tolerance for a process, to be used for timers that don't have a specific tolerance. The default timer tolerance is inherited across a *fork()*, but not an *exec*()* or a *spawn*()*. You can prevent the process's default tolerance from being used for a timer by specifying the TIMER_PRECISE flag when you call *timer_settime()* or *TimerSettime()* to set the timer's expiry time. For example:

TIMER_PRECISE	Process tolerance	Timer tolerance	Effective tolerance
Not set	Default (0)	Default (0)	1 tick
Not set	Default (0)	100 ms	100 ms
Not set	200 ms	Default (0)	200 ms
Not set	200 ms	100 ms	100 ms
Set	Default (0)	Default (0)	1 tick
Set	Default (0)	100 ms	100 ms
Set	200 ms	Default (0)	1 tick
Set	200 ms	100 ms	100 ms

To determine the tolerance for a timer, call *TimerInfo()*, specifying the _NTO_TI_REPORT_TOLERANCE flag; the function puts the tolerance in the *otime.interval_nsec* field. For example:

```
struct _timer_info tinfo;
int tolerance, p_tolerance;

memset(&tinfo, 0, sizeof(struct _timer_info));
rc = TimerInfo ( getpid(), timerId, _NTO_TI_REPORT_TOLERANCE, &tinfo);
if (rc == -1) {
   // Handle the error
}

// Get information about the timer.
if (tinfo.flags &_NTO_TI_PROCESS_TOLERANT) {
   rc = procmgr_timer_tolerance ( 0, NULL, &p_tolerance);
   if (rc == -1)
   {
       // Handle the error
   }
   printf ("PROCESS_TOLERANT: %ld ns.\n", p_tolerance);
}

if (tinfo.flags &_NTO_TI_TOLERANT) {
   printf ("TOLERANT");
   tolerance = tinfo.otime.interval_nsec;
```

```
    // If the tolerance is less than the output of ClockPeriod(),
    // the timer is a high-resolution one.
    if ((tolerance > 0) && (tolerance < period.nsec)) {
       printf (" (high-resolution): %d ns.\n", tolerance);
    } else {
       printf (": %d ns.\n", tolerance);
    }
}
```

For a more detailed example, see the entry for *TimerInfo()* in the *C Library Reference*.

Monitoring execution times

QNX Neutrino includes some special CPU-time clocks that you can use to monitor the execution times for processes and threads.

This mechanism is implemented following the POSIX “Execution Time Monitoring” option, which defines special clock IDs that represent the execution time of a thread or a process:

To obtain:	Call:	Specifying:	Classification
A process CPU-time clock ID	*clock_getcpuclockid()*	A process ID, or 0 to get the clock ID for the calling process	POSIX
A thread CPU-time clock ID	*pthread_getcpuclockid()*	A thread ID in the calling process	POSIX
Either of the above	*ClockId()*	A process ID and a thread ID	QNX Neutrino

A process has permission to get the CPU-time clock ID of any process.

To get the execution time for the process or thread, call *clock_gettime()* or *ClockTime()*, passing a process or thread CPU-time clock ID. POSIX also defines the following, which you can use instead of calling *clock_getcpuclockid()* or *pthread_getcpuclockid()*:

CLOCK_PROCESS_CPUTIME_ID

The CPU-time clock ID for the calling process.

CLOCK_THREAD_CPUTIME_ID

The CPU-time clock ID for the calling thread.

In QNX Neutrino 7.0.1 or later, the OS calculates the execution times on every clock tick and whenever an active thread is preempted.

Here's an example:

```
int process_clock_id, ret;
struct timespec process_time;

ret = clock_getcpuclockid(0, &process_clock_id);
if (ret != 0) {
    perror ("clock_getcpuid()");
    return (EXIT_FAILURE);
}

printf ("Process clock ID: %d\n", process_clock_id);

ret = clock_gettime (process_clock_id, &process_time);
if (ret != 0) {
```

```
        perror ("clock_gettime()");
        return (EXIT_FAILURE);
    }
    printf ("Process clock: %ld sec, %ld nsec\n", process_time.tv_sec,
            process_time.tv_nsec);
```

Given that we're getting the execution time for the calling process, we could use CLOCK_PROCESS_CPUTIME_ID instead of *clock_getcpuclockid()*:

```
int process_clock_id, ret;
struct timespec process_time;

ret = clock_gettime (CLOCK_PROCESS_CPUTIME_ID, &process_time);
if (ret != 0) {
    perror ("clock_gettime()");
    return (EXIT_FAILURE);
}
printf ("Process clock: %ld sec, %ld nsec\n", process_time.tv_sec,
        process_time.tv_nsec);
```

You can't use *clock_settime()* or *ClockTime()* to set a process or thread CPU-time clock.

Timers using a thread CPU-time clock

In QNX Neutrino 7.0.1 or later, you can arrange to be notified when a thread uses more than a given amount of CPU time. You can't currently do this for a process.

Setting up this type of notification involves creating a timer with a thread CPU-time clock ID:

1. Get a thread CPU-time clock ID, as described above.
2. Set up a `sigevent` that specifies how you want to be notified.
3. Call *timer_create()*, passing to it the thread CPU-time clock ID and the `sigevent`.

    - At any moment, only one timer can be using a thread's CPU-time clock ID. If there's already a timer for the a given thread CPU-time clock ID, *timer_create()* gives an error of EAGAIN.
    - If you try to create a timer for a process CPU-time clock, *timer_create()* gives an error of EINVAL.

4. Set up the appropriate data structure (e.g., an `itimerspec`), specifying the execution time as the timeout.
5. Call *timer_settime()*, passing to it the timer ID and the timeout.

Here's an example:

```
struct sigevent event;
timer_t timer_id;
struct itimerspec cpu_usage;

/* Set up the method of notification. */
SIGEV_SIGNAL_INIT(&event, SIGALRM);
signal( SIGALRM, sig_handler );

/* Create a timer. */
if (timer_create(CLOCK_THREAD_CPUTIME_ID, &event, &timer_id)) {
   perror( "timer_create" );
   return EXIT_FAILURE;
}

/* Set up the amount of CPU time and then set the timer. */
cpu_usage.it_value.tv_sec = 0;
cpu_usage.it_value.tv_nsec = nsec;
cpu_usage.it_interval.tv_sec = 0;
cpu_usage.it_interval.tv_nsec = period_nsec;

if (timer_settime(timer_id, 0, &cpu_usage, NULL)) {
   perror( "timer_settime" );
   exit(EXIT_FAILURE);
}

/* If the thread exceeds the specified CPU time, we'll get a SIGALRM,
   and our sig_handler() function will be called. */
```

The accuracy of this mechanism depends on the clock period; if the thread exceeds the given execution time, the actual amount of time used is at least the amount you specified but less than the same amount plus the clock period.

Chapter 7
Transparent Distributed Processing Using Qnet

Transparent Distributed Processing (TDP) allows you to leverage the processing power of your entire network by sharing resources and services transparently over the network. TDP uses the QNX Neutrino native network protocol, Qnet, to link the devices in your network.

Using Qnet, you can build a transparent distributed-processing platform that's fast and scalable. This is accomplished by extending the QNX Neutrino message-passing architecture over a network, creating a group of tightly integrated QNX Neutrino nodes (systems) or CPUs—a QNX Neutrino native network.

A program running on a QNX Neutrino node in this Qnet network can transparently access any resource, whether it's a file, device, or another process. These resources reside on any other node (a computer or a CPU in a system) in the Qnet network. The Qnet protocol builds an optimized network that provides a fast and seamless interface between QNX Neutrino nodes.

- For a high-level description, see Native Networking (Qnet) in the *System Architecture* guide; for information about what the *user* needs to know about networking, see Using Qnet for Transparent Distributed Processing in the QNX Neutrino *User's Guide*.
- You can have at most one instance of Qnet running on a node, even if you're running more than one instance of `io-pkt`.

Benefits of Qnet

The Qnet protocol extends interprocess communication (IPC) transparently over a network of microkernels.

This is done by taking advantage of the QNX Neutrino's message-passing paradigm. Message passing is the central theme of the QNX Neutrino RTOS that manages a group of cooperating processes by routing messages. This enhances the efficiency of all transactions among all processes throughout the system.

What works best

The Qnet protocol is deployed as a network of trusted machines. It lets these machines share all their resources efficiently with minimum overhead. This is accomplished by allowing a client process to send a message to a remote manager in the same way that it sends a message to a local one.

See the "*How does it work?*" section of this chapter. For example, using Qnet, you can use the QNX Neutrino utilities (`cp`, `mv` and so on) to manipulate files anywhere on the Qnet Network as if they were on your machine—by communicating with the filesystem manager on the remote nodes. In addition, the Qnet protocol doesn't do any authentication of remote requests. Files are protected by the normal permissions that apply to users and groups (see "File ownership and permissions" in Working with Files in the *User's Guide*).

Qnet, through its distributed processing platform, lets you do the following tasks efficiently:

- access your remote filesystem
- scale your application with unprecedented ease
- write applications using a collection of cooperating processes that communicate transparently with each other using QNX Neutrino message passing
- extend your application easily beyond a single processor or symmetric multiprocessor to several single-processor machines and distribute your processes among these processors
- divide your large application into several processes that coordinate their work using messages
- debug your application easily for processes that communicate at a very low level, and that use QNX Neutrino's memory protection feature
- use builtin remote procedure call functionality

Since Qnet extends QNX Neutrino message passing over the network, anything built on top of message passing also works over the network.

What type of application is well-suited for Qnet?

Any application that inherently needs more than one computer, due to its processing or physical layout requirements, could likely benefit from Qnet.

For example, you can apply Qnet networking successfully in many industrial-automation applications (e.g., a fabrication plant, with computers scattered around). From an application standpoint, Qnet provides an efficient form of distributed computing where all computers look like one big computer because Qnet extends the fundamental QNX Neutrino message passing across all the computers.

Another useful application is in the telecom space, where you need to implement large routers that have several processors. From an architectural standpoint, these routers generally have some interface cards and a central processor that runs a set of server processes. Each interface card, in turn, has a processor that runs another set of interface (e.g., client) processes. These client processes communicate via Qnet using QNX Neutrino message passing with the server processes on the central processor, as if they were all running on the same processor. The scalability of Qnet allows more and more interface cards to be plugged into the router, without any code changes required to the application.

Limitations

- Qnet's functionality is limited when applications create a shared-memory region. That works only when the applications run on the same machine.
- Server calls such as *MsgReply()*, *MsgError()*, *MsgWrite()*, *MsgRead()*, and *MsgDeliverEvent()* behave differently for local and network cases. In the local case, these calls are *nonblocking*, whereas in the network case, these calls *block*. In the nonblocking scenario, a lower priority thread won't run; in the network case, a lower priority thread can run.
- POSIX message queues using the `mq` (`-l mq`) implementation work only on the same machine.
- The *ConnectAttach()* function appears to succeed the first time, even if the remote node is nonoperational or is turned off. In this case, it *should* report a failure, but it doesn't. For efficiency, *ConnectAttach()* is paired up with *MsgSend()*, which in turn reports the error. For the first transmission, packets from both *ConnectAttach()* and *MsgSend()* are transmitted together.
- Qnet isn't appropriate for broadcast or multicast applications. Since you're sending messages on specific channels that target specific applications, you can't send messages to more than one node or manager at the same time.

How does it work?

As explained in the *System Architecture* guide, QNX Neutrino client and server applications communicate by QNX Neutrino message passing.

Function calls that need to communicate with a manager application, such as the POSIX functions *open()*, *write()*, *read()*, *ioctl()*, or other functions such as *devctl()* are all built on QNX Neutrino message passing.

Qnet allows these messages to be sent over a network. If these messages are being sent over a network, how is a message sent to a remote manager vs a local manager?

When you access local devices or manager processes (such as a serial device, `mqueue`, or TCP/IP socket), you access these devices by opening a pathname under **/dev**. This may be apparent in the application source code:

```
/*Open a serial device*/
fd = open("/dev/ser1",O_RDWR....);
```

or it may not. For example, when you open a socket:

```
/*Create a UDP socket*/
sock = socket(AF_INET, SOCK_DGRAM, 0);
```

The *socket()* function opens a pathname under **/dev** called **/dev/socket/2** (in the case of AF_INET, which is address family two). The *socket()* function call uses this pathname to establish a connection with the socket manager (`io-pkt*`), just as the *open()* call above established a connection to the serial device manager (`devc-ser8250`).

The magic of this is that you access all managers by the name that they added to the pathname space. For more information, see the *Writing a Resource Manager* guide.

When you enable the Qnet native network protocol, the pathname spaces of all the nodes in your Qnet network are added to yours. The pathname space of remote nodes appears (by default) under the prefix **/net**.

The **/net** directory is created by the Qnet protocol manager (**lsm-qnet.so**). If, for example, the other node is called **node1**, its pathname space appears as follows:

```
/net/node1/dev/socket
/net/node1/dev/ser1
/net/node1/home
/net/node1/bin
....
```

So with Qnet, you can now open pathnames (files or managers) on other remote Qnet nodes, in the same way that you open files locally. This means that you can access regular files or manager processes on other Qnet nodes as if they were executing on your local node.

First, let's see some basic examples of Qnet use:

- To display the contents of a file on another machine (`node1`), you can use `less`, specifying the path through **/net**:

  ```
  less /net/node1/etc/TIMEZONE
  ```

- To get system information about all of the remote nodes that are listed in **/net**, use `pidin` with the `net` argument:

  ```
  $ pidin net
  ```

- You can use `pidin` with the `-n` option to get information about the processes on another machine:

  ```
  pidin -n node1 | less
  ```

- You can even run a process on another machine, using the `-f` option to the `on` command:

  ```
  on -f node date
  ```

In all of these uses, the application source or the libraries (for example **libc**) they depend on, simply open the pathnames under **/net**. For example, if you wish to make use of a serial device on another node **node1**, perform an *open()* function with the pathname **/net/node1/dev/ser1**:

```
fd = open("/net/node1/dev/ser1",O_RDWR...);
```

As you can see, the code required for accessing remote resources and local resources is identical. The only change is the pathname used.

In the TCP/IP *socket()* case, it's the same, but implemented differently. In the socket case, you don't directly open a filename. This is done inside the socket library. In this case, an environment variable is provided to set the pathname for the socket call (the *SOCK* environment variable—see `io-pkt*`).

Some other applications are:

Remote filesystem access

In order to access **/tmp/file1** file on **node1** remotely from another node, use **/net/node1/tmp/file1** in *open()*.

Message queue

You can create or open a message queue by using *mq_open()*. The `mqueue` manager must be running. When a queue is created, it appears in the pathname space under **/dev/mqueue**. So, you can access **/dev/mqueue** on **node1** from another node by using **/net/node1/dev/mqueue**.

> The alternate implementation of message queues that uses the `mq` server and a queue within the kernel doesn't support access to a queue via Qnet.

Semaphores

Using Qnet, you can create or access named semaphores in another node. For example, use **/net/node1/semaphore_location** in the *sem_open()* function. This creates or accesses the named semaphore in **node1**.

This brings up an important issue for the client application or libraries that a client application uses. If you think that your application will be distributed over a network, you will want to include the capability to specify another pathname for connecting to your services. This way, your application will have the flexibility of being able to connect to local or remote services via a user-configuration adjustment. This could be as simple as the ability to pass a node name. In your code, you would add the prefix **/net/***node_name* to any pathname that may be opened on the remote node. In the local case, or default case if appropriate, you could omit this prefix when accessing local managers.

In this example, you're using standard resource managers, such as would be developed using the resource manager framework (see the *Writing a Resource Manager* guide).

There's another design issue to contend with at this point: the above design is a static one. If you have services at known locations, or the user will be placing services at known locations, then this may be sufficient. It would be convenient, though, if your client application could locate these services automatically, without the need to know what nodes exist in the Qnet network, or what pathname they've added to the pathname space. You can now use the Global Name Service (`gns`) manager to locate services with an arbitrary name representing that service. For example, you can locate a service with a name such as `printer` instead of opening a pathname of **/net/node/dev/par1** for a parallel port device. The `printer` name locates the parallel port manager process, whether it's running locally or remotely.

Locating services using GNS

You use gns, the Global Name Service or GNS manager to locate services. GNS is a standalone resource manager. With the help of this utility, an application can advertise, look up, and use (connect to) a service across Qnet network, without knowing the details of where the service is, or who the provider is.

Server and client modes

The gns utility runs in two different modes: server and client. A server-mode manager is a central database that stores advertised services, and handles lookup and connect requests. A client-mode manager relays advertisement, lookup, and connect requests between local application and the GNS server(s). For more information on starting and configuring GNS, see the gns utility in the *Utilities Reference*.

Here's a simple layout for a GNS client and a GNS server distributed over a network:

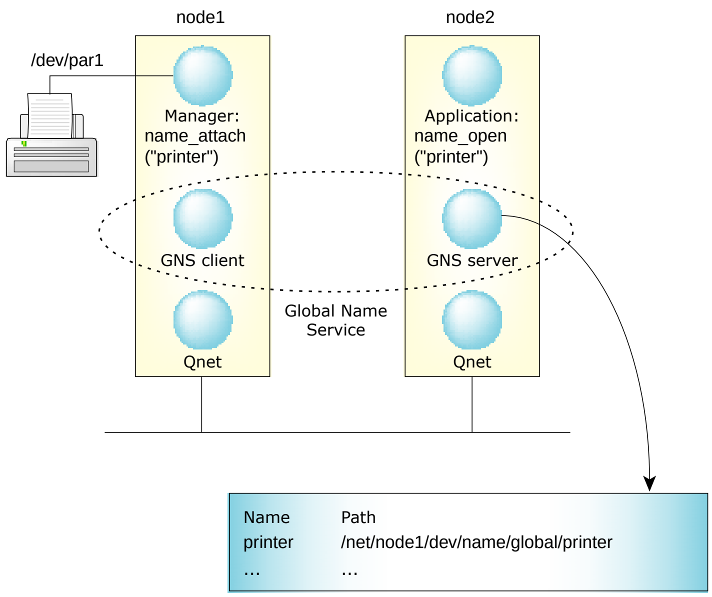


Figure 19: A simple GNS setup.

In this example, there's one gns client and one gns server. As far as an application is concerned, the GNS service is one entity. The client-server relationship is only between gns processes (we'll examine this later). The server GNS process keeps track of the globally registered services, while the client GNS process on the other node relays gns requests for that node to the gns server.

When a client and a server application interact with GNS, they use the following APIs:

Server:

name_attach()

Register your service with the GNS server.

name_detach()

Deregister your service with the GNS server.

Client:

name_open()

Open a service via the GNS server.

name_close()

Close the service opened with *name_open()*.

Registering a service

In order to use GNS, you need to first register the manager process with GNS, by calling *name_attach()*.

When you register a service, you need to decide whether to register this manager's service locally or globally. If you register your service locally, only the local node is able to see this service; another node is not able to see it. This allows you to have client applications that look for service *names* rather than pathnames on the node it is executing on. This section highlights registering services globally.

When you register GNS service globally, any node on the network running a client application can use this service, provided the node is running a `gns` client process and is connected to the `gns` server, along with client applications on the nodes running the `gns` server process. You can use a typical *name_attach()* call as follows:

```
if ((attach = name_attach(NULL, "printer", NAME_FLAG_ATTACH_GLOBAL)) == NULL) {
     return EXIT_FAILURE;
     }
```

The first thing you do is to pass the flag NAME_FLAG_ATTACH_GLOBAL. This causes your service to be registered globally instead locally.

The last thing to note is the *name*. This is the name that clients search for. This name can have a single level, as above, or it can be nested, such as **printer/ps**. The call looks like this:

```
if ((attach = name_attach(NULL, "printer/ps", NAME_FLAG_ATTACH_GLOBAL)) == NULL) {
     return EXIT_FAILURE;
     }
```

Nested names have no impact on how the service works. The only difference is how the services are organized in the filesystem generated by `gns`. For example:

```
$ ls -l /dev/name/global/
total 2
dr-xr-xr-x  0 root      techies           1 Feb 06 16:20 net
dr-xr-xr-x  0 root      techies           1 Feb 06 16:21 printer

$ ls -l /dev/name/global/printer
total 1
dr-xr-xr-x  0 root      techies           1 Feb 06 16:21 ps
```

The first argument to the *name_attach()* function is the dispatch handle. You pass a dispatch handle to *name_attach()* once you've already created a dispatch structure. If this argument is NULL, a dispatch structure is created automatically.

What happens if more than one instance of the server application (or two or more applications that register the same service name) are started and registered with GNS? This is treated as a redundant service. If one application terminates or detaches its service, the other service takes over. If the server is local to the client, that server is tried; if this isn't possible, there's no guaranteed ordering.

There's no credential restriction for applications that are attached as local services. An application can attach a service globally only if the application has **root** privilege.

When you no longer wish to provide serice via GNS, you should call *name_detach()*. This removes the service from GNS.

For more information, see *name_attach()* and *name_detach()* in the *C Library Reference*.

Locating a service

Your client should call *name_open()* to locate the service. If you wish to locate a global service, you need to pass the flag NAME_FLAG_ATTACH_GLOBAL:

```
if ((coid = name_open("printer", NAME_FLAG_ATTACH_GLOBAL)) == -1)
{
     return EXIT_FAILURE;
}
```

or:

```
if ((coid = name_open("printer/ps", NAME_FLAG_ATTACH_GLOBAL)) == -1)
{
     return EXIT_FAILURE;
}
```

If you don't specify this flag, GNS looks only for a local service. The function returns a side-channel connection (coid) that you can use to access the service manager by sending messages, just as if you had located a local service.

GNS pathname space

A service is represented by a pathname (without a leading "/") and is registered under **/dev/name/global** or **/dev/name/local**, depending on how it attaches itself. Every machine running a `gns` client or server on the same network has the same view of the **/dev/name/global** pathname space. Each machine has its own local pathname space **/dev/name/local** that reflects its own local services.

Here's an example after a service called `printer` has attached itself globally:

```
$ ls -l /dev/name/global/
total 2
dr-xr-xr-x  0 root      techies     1 Feb 06 16:20 net
dr-xr-xr-x  0 root      techies     1 Feb 06 16:21 printer
```

Deploying the `gns` processes

When you deploy the `gns` processes on your network, you start the `gns` process in two modes: server and client. You need at least one `gns` process running as a server on one node, and you can have one or more `gns` clients running on the remaining nodes. The role of the `gns` server process is to maintain the database that stores the advertised services. The role of a client `gns` process is to relay requests from its node to the `gns` server process on the other node. A `gns` process must be running on each node that wishes to access GNS.

It's possible to start multiple global name service managers (`gns` process) in server mode on different nodes. You can deploy server-mode `gns` processes in two ways: as redundant servers, or as servers that handle two or more different global domains.

In the first scenario, you have two or more servers with identical database information. The `gns` client processes are started with contact information for both servers. Operations are then sent to all `gns` server processes. The `gns` servers, however, don't communicate with each other. This means that if an application on one `gns` server node wants to register a global service, another `gns` server can't do it. This doesn't affect other applications on the network, because when they connect to that service, both GNS servers are contacted.

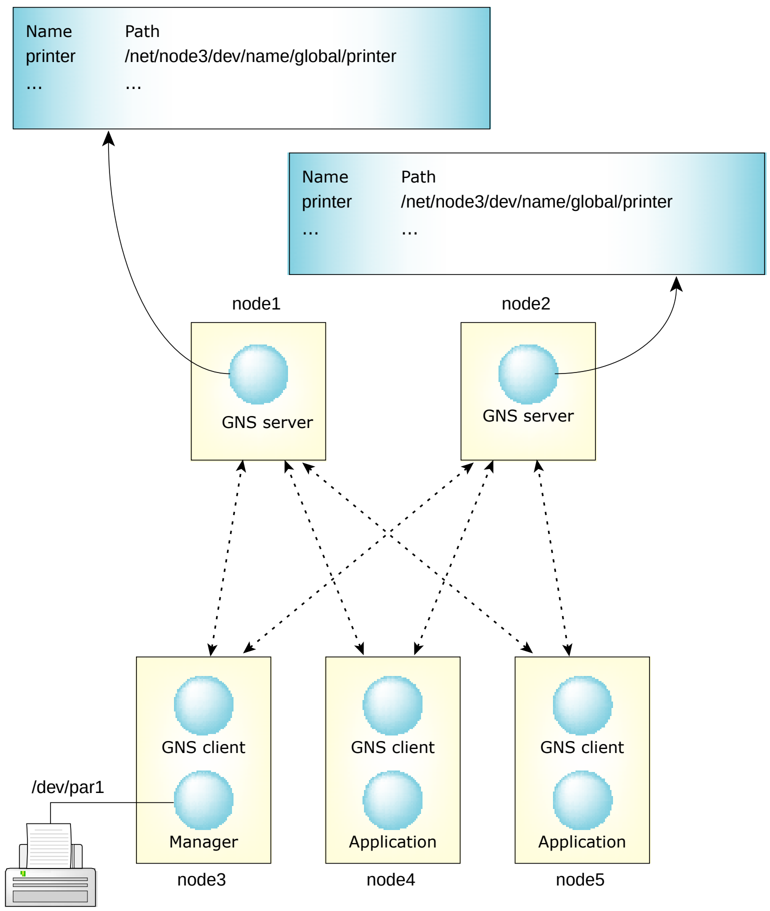


Figure 20: A redundant GNS setup.

You don't have to start all redundant `gns` servers at the same time. You can start one `gns` server process first, and then start a second `gns` server process at a later time. In this case, use the special option `-s` *backup_server* on the second `gns` server process to make it download the current service database from another node that's already running the `gns` server process. When you do this, the clients connected to the first node (that's already running the `gns` server process) are notified of the existence of the other server.

In the second scenario, you maintain more than one global domain. For example, assume you have two nodes, each running a `gns` server process. You also have a client node that's running a `gns` client process and is connecting to one of the servers. A different client node connects to the other server. Each server node has unique services registered by each client. A client connected to server **node1** can't see the service registered on the server **node2**.

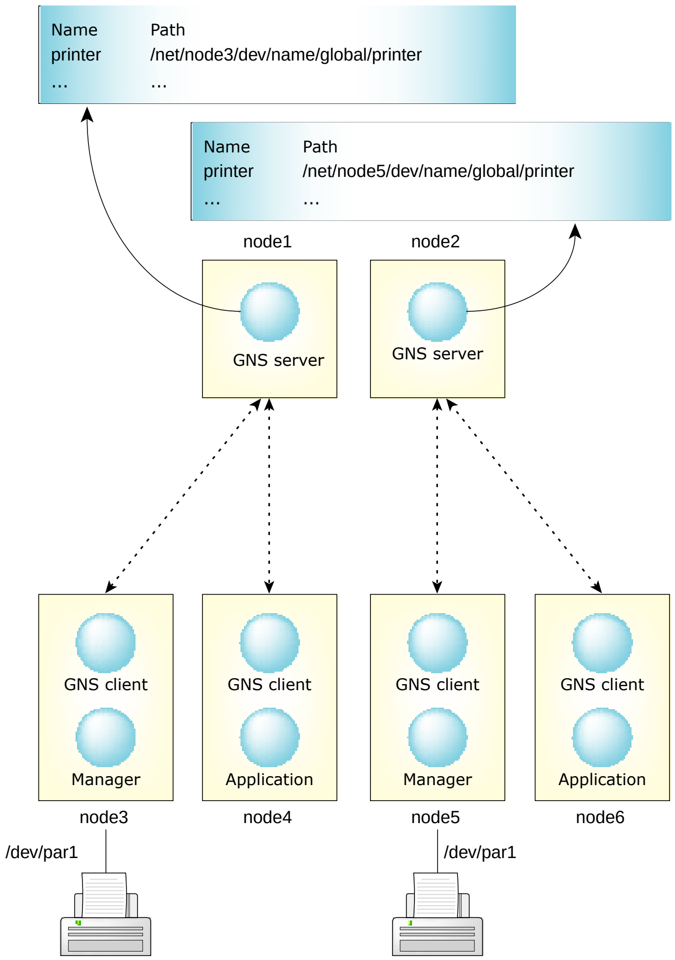


Figure 21: Separate global domains.

What is demonstrated in each scenario is that it's the client that determines whether a server is acting as a redundant server or not. If a client is configured to connect to two or more servers, then those servers are redundant servers for that client's services. The client can see the services that exist on those servers, and it registers its services with those servers.

There's no limit to the number of server mode `gns` processes that can be run on the network. Increasing the number of servers, however, in a redundant environment can increase network use and make `gns` function calls such as *name_attach()* more expensive as clients send requests to each server that exists in its configuration. It's recommended that you run only as many `gns` servers in a redundant configuration as your system design requires and no more than that.

A client on any node that's running a GNS server can't find a service provided by a server on any other node that's running a GNS server. In the examples above, if you start a service on **node1**, no client process on **node2** can find that service.

For more information, see `gns` documentation in the *Utilities Reference*.

Quality of Service (QoS) and multiple paths

Quality of Service (QoS) is an issue that often arises in high-availability networks as well as in realtime control systems. In the Qnet context, QoS really boils down to *transmission media selection*: in a system with two or more network interfaces, Qnet chooses which one to use, according to the policy you specify.

If you have only a single network interface, the QoS policies don't apply at all.

QoS policies

Qnet provides the following policies that let you specify how it should select a network interface for transmission:

- `loadbalance`: Qnet is free to use all available network links, and shares transmission equally among them.
- `preferred`: Qnet uses one specified link, ignoring all other networks (unless the preferred one fails).
- `exclusive`: Qnet uses one—and only one—link, ignoring all others, even if the exclusive link fails.

The default is `loadbalance`. Let's look at them in more detail:

`loadbalance`

Qnet decides which links to use for sending packets, depending on current load and link speeds as determined by `io-pkt*`. A packet is queued on the link that can deliver the packet the soonest to the remote end. This effectively provides greater bandwidth between nodes when the links are up (the bandwidth is the sum of the bandwidths of all available links) and allows a graceful degradation of service when links fail.

If a link does fail, Qnet switches to the next available link. By default, this switch takes a few seconds *the first time*, because the network driver on the bad link will have timed out, retried, and finally died. But once Qnet “knows” that a link is down, it *doesn't* send user data over that link.

The time required to switch to another link can be set to whatever is appropriate for your application using Qnet's command-line options; see the entry for **lsm-qnet.so** in the *Utilities Reference*.

Using these options, you can create a redundant behavior by minimizing the latency that occurs when switching to another interface in case one of the interfaces fails.

While load-balancing among the live links, Qnet sends periodic maintenance packets on the failed link in order to detect recovery. When the link recovers, Qnet places it back into the pool of available links.

preferred

With this policy, you specify a preferred link to use for transmissions. Qnet uses only that one link until it fails. If your preferred link fails, Qnet then turns to the other available links and resumes transmission, using the `loadbalance` policy.

When your preferred link is available again, Qnet again uses only that link, ignoring all others (unless the preferred link fails).

exclusive

You use this policy when you want to lock transmissions to only one link. Regardless of how many other links are available, Qnet latches onto the one interface you specify. And if that exclusive link fails, Qnet *doesn't* use any other link.

Why would you want to use the `exclusive` policy? Suppose you have two networks, one much faster than the other, and you have an application that moves large amounts of data. You might want to restrict transmissions to only the fast network, in order to avoid swamping the slow network if the fast one fails.

You specify the QoS policy as part of the pathname. For example, to access **/net/node1/dev/ser1** with a QoS of `exclusive`, you could use the following pathname:

```
/net/node1~exclusive:en0/dev/ser1
```

The QoS parameter always begins with a tilde (~) character. Here we're telling Qnet to lock onto the `en0` interface exclusively, even if it fails.

Symbolic links

You can set up symbolic links to the various "QoS-qualified" pathnames:

```
ln -sP /net/node1~preferred:en1 /remote/sql_server
```

This assigns an "abstracted" name of **/remote/sql_server** to the node **node1** with a preferred QoS (i.e., over the `en1` link).

You can't create symbolic links inside **/net** because Qnet takes over that pathname space.

Abstracting the pathnames by one level of indirection gives you multiple servers available in a network, all providing the same service. When one server fails, the abstract pathname can be "remapped" to point to the pathname of a different server. For example, if **node1** fails, then a monitoring program could detect this and effectively issue:

```
rm /remote/sql_server
ln -sP /net/node2 /remote/sql_server
```

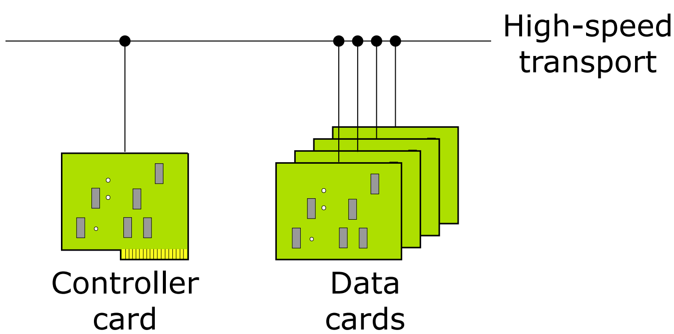
This removes **node1** and reassigns the service to **node2**. The real advantage here is that applications can be coded based on the abstract "service name" rather than be bound to a specific node name.

For a real-world example of choosing appropriate QoS policy in an application, see "*Designing a system using Qnet*."

Designing a system using Qnet

In order to explain the design of a system that takes advantage of the power of Qnet by performing distributed processing, consider a multiprocessor hardware configuration that's suitable for a typical telecom box.

This configuration has a generic controller card and several data cards to start with. These cards are interconnected by a high-speed transport (HST) bus. The controller card configures the box by communicating with the data cards, and establishes/enables data transport in and out of the box (i.e., data cards) by routing packets.



The typical challenges to consider for this type of box include:

- Configuring the data cards
- Configuring the controller card
- Replacing a data card
- Enhancing reliability via multiple transport buses
- Enhancing reliability via multiple controller cards

You need several pieces of software components (along with the hardware) to build your distributed system.

Before going into further details, you might like to review the following sections from Using Qnet for Transparent Distributed Processing chapter in the QNX Neutrino *User's Guide*:

- Software components for Qnet networking
- Starting Qnet
- Conventions for naming nodes

Configuring the data cards

Power up the data cards to start `procnto` and `qnet` in sequence. These data cards need a minimal amount of flash memory to store the QNX Neutrino image.

In the buildfile of the data cards, you should link the directories of the data cards to the controller cards as follows:

```
[type=link] /bin  = /net/cc0/bin
[type=link] /sbin = /net/cc0/sbin
[type=link] /usr  = /net/cc0/usr
```

where `cc0` is the name of the controller card.

Assuming that the data card has a console and shell prompt, try the following commands:

```
$ ls /net
```

You get a list of boards running QNX Neutrino and Qnet:

```
 cc0  dc0  dc1  dc2  dc3
```

Or, use the following command on a data card:

```
$ ls /net/cc0
```

You get the following output (i.e., the contents of the root of the filesystem for the controller card):

```
.                  .inodes          mnt0        tmp
..                 .longfilenames   mnt1        usr
.altboot           bin              net         var
.bad_blks          dev              proc        xfer
.bitmap            etc              sbin
.boot              home             scratch
```

Configuring the controller card

Configure the controller card in order to access different servers running on it—either by the data cards, or by the controller card itself. Make sure that the controller card has a larger amount of flash memory than the data cards do. This flash memory contains all the binaries, data and configuration files that the applications on the data cards access as if they were on a local storage device.

Call the following API to communicate with the `mqueue` server by any application:

```
mq_open("/net/cc0/dev/mqueue/app_q", ....)
```

A simple variation of the above command requires that you run the following command during initialization:

```
$ ln -s /net/cc0/dev/mqueue /mq
```

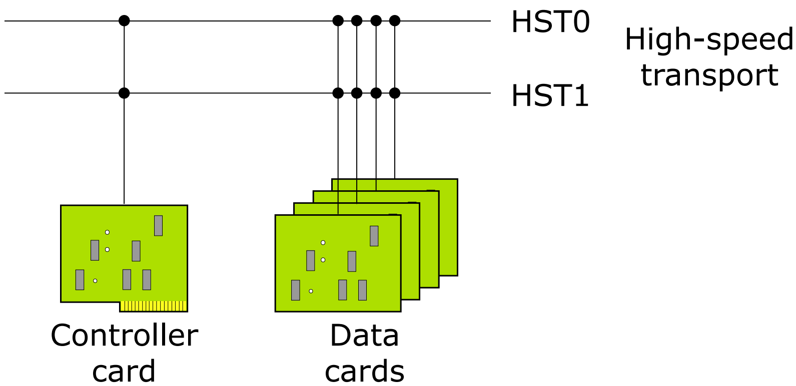
Then all applications, whether they're running on the data cards or on the controller card, can call:

```
mq_open("/mq/app_q", ....)
```

Similarly, applications can even utilize the TCP/IP stack running on the controller card.

Enhancing reliability via multiple transport buses

Qnet provides design choices to improve the reliability of a high-speed transport bus, most often a single-point of failure in such type of telecom box.



You can choose between different transport selections to achieve a different Quality of Service (or QoS), such as:

- loadbalance—no interface specified
- preferred—specify an interface, but allow failover
- exclusive—specify an interface, no failover

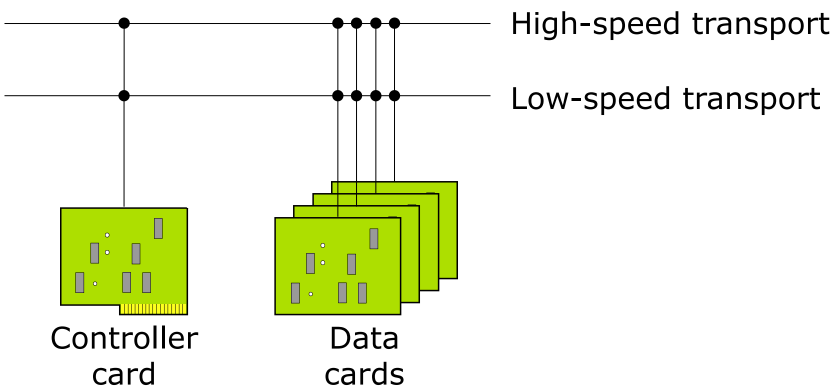
These selections allow you to control how data will flow via different transports.

In order to do that, first, find out what interfaces are available, by using the `ifconfig` command at the prompt of any card. For this example, we'll assume that the HST 0 and 1 (`hs0` and `hs1`) interfaces are available.

Select your choice of transport as follows:

Use this command:	To select this transport:
`ls /net/cc0`	Loadbalance, the default choice
`ls /net/cc0~preferred:hs0`	Preferred. Try HST 0 first; if that fails, then transmit on HST 1.
`ls /net/cc0~exclusive:hs0`	Exclusive. Try HST 0 first. If that fails, terminate transmission.

You can have another economical variation of the above hardware configuration:



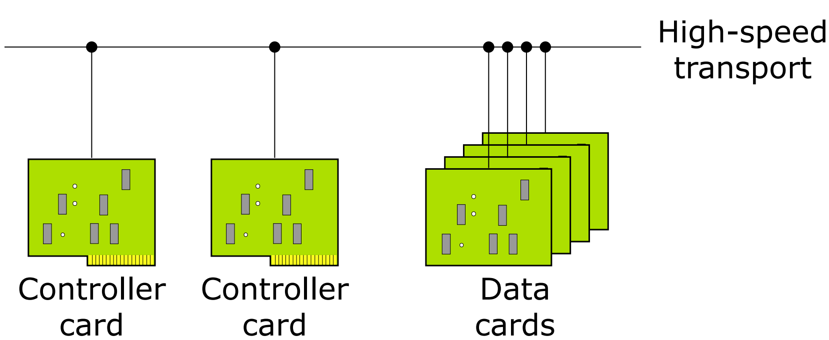
This configuration has asymmetric transport: a High-Speed Transport (HST) and a reliable and economical Low-Speed Transport (LST). You might use the HST for user data, and the LST exclusively for out-of-band control (which can be very helpful for diagnosis and during booting). For example, if you use generic Ethernet as the LST, you could use a `bootp` ROM on the data cards to economically boot—no flash would be required on the data cards.

With asymmetric transport, use of the QoS policy as described above likely becomes even more useful. You might want some applications to use the HST link first, but use the LST if the HST fails. You might want applications that transfer large amounts of data to exclusively use the HST, to avoid swamping the LST.

Redundancy and scalability using multiple controller cards

The reliability of such a telecom box also hinges on the controller card, which is a critical component and certainly a potential SPOF (single point of failure). You can increase the reliability of this telecom box by using additional controller cards.

For example, you could add another controller card for redundancy:



Once the (second) controller card is installed, the challenge is in the determination of the primary controller card. This is done by the software running on the controller cards. By default, applications on the data cards access the primary controller card. Assuming `cc0` is the primary controller card, Use the following command to access this card in the `/cc` directory:

```
ln -s /net/cc0 /cc
```

The above indirection makes communication between data card and controller card transparent. In fact, the data cards remain unaware of the number of controller cards, or which card is the primary controller card.

Applications on the data cards access the primary controller card. In the event of failure of the primary controller card, the secondary controller card takes over. The applications on the data cards redirect their communications via Qnet to the secondary controller card.

You can also scale your resources to run a particular server application using additional controller cards. For example, if your controller card (either a SMP or non-SMP board) doesn't have the necessary resources (e.g., CPU cycles, memory), you could increase the total processor and box resources by using additional controller cards. Qnet transparently distributes the (load of) application servers across two or more controller cards.

Autodiscovery vs static

When you're creating a network of QNX Neutrino hosts via Qnet, one thing you must consider is how they locate and address each other. This falls into two categories: autodiscovery and static mappings.

The decision to use one or the other can depend on security and ease of use.

The autodiscovery mechanism (i.e., `en_ionet`; see **lsm-qnet.so** for more information) allows Qnet nodes to discover each other automatically on a transport that supports broadcast. This is a very convenient and dynamic way to build your network, and doesn't require user intervention to access a new node.

One issue to consider is whether or not the physical link being used by your Qnet nodes is secure. Can another untrusted Qnet node be added to this physical network of Qnet nodes? If the answer is yes, you should consider another resolver (`file:filename`). If you use this resolver, only the nodes listed in the file can be accessed. This file consists of node names and a string representing the addressing scheme of your transport layer. In the Ethernet case, this is the unique MAC address of the Qnet node listed. If you're using the file resolver for this purpose, you also want to specify the option `auto_add`=0 in **lsm-qnet.so**. This keeps your node from responding to node discovery protocol requests and adding a host that isn't listed in your resolver `file`.

Another available resolver, `dns` lets you access another Qnet node if you know its name (`IP`). This is used in combination with the IP transport (**lsm-qnet.so** option `bind= ip`). Since it doesn't have an `auto_add` feature as the `en_ionet` resolver does, you don't need to specify a similar Qnet option. Your Qnet node resolves the remote Qnet node's name only via the file used by the Qnet `file` resolver.

When should you use Qnet, TCP/IP, or NFS?

In your network design, when should you use Qnet, TCP/IP, or NFS? The decision depends on what your intended application is and what machines you need to connect.

The advantage of using Qnet is that it lets you build a truly distributed processing system with incredible scalability. For many applications, it could be a benefit to be able to share resources among your application systems (nodes). Qnet implements a native network protocol to build this distributed processing system.

The basic purpose of Qnet is to extend QNX Neutrino message passing to work over a network link. It lets these machines share all their resources with little overhead. A Qnet network is a trusted environment where resources are tightly integrated, and remote manager processes can be accessed transparently. For example, with Qnet, you can use the QNX Neutrino utilities (`cp`, `mv` and so on) to manipulate files anywhere on the Qnet network as if they were on your machine. Because it's meant for a group of trusted machines (such as you'd find in an embedded system), Qnet doesn't do any authentication of remote requests. Also, the application really doesn't know whether it's accessing a resource on a remote system; and most importantly, the application doesn't need any special code to handle this capability.

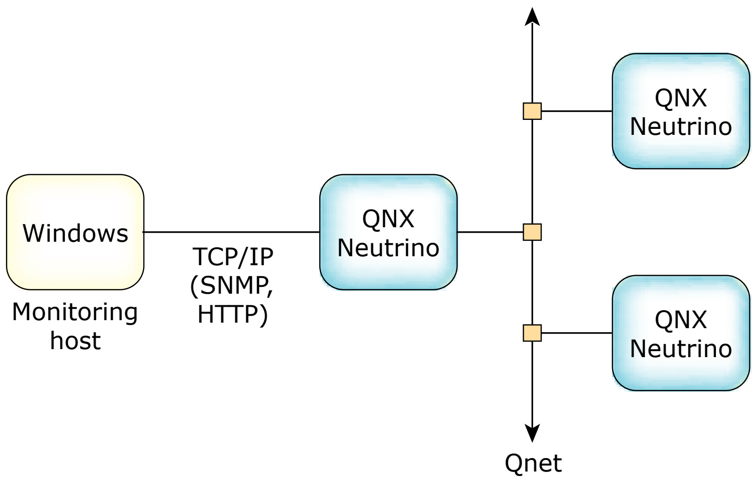
If you're developing a system that requires remote procedure calling (RPC), or remote file access, Qnet provides this capability transparently. In fact, you use a form of remote procedure call (a QNX Neutrino message pass) every time you access a manager on your QNX Neutrino system. Since Qnet creates an environment where there's no difference between accessing a manager locally or remotely, remote procedure calling (capability) is builtin. You don't need to write source code to distribute your services. Also, since you are sharing the filesystem between systems, there's no need for NFS to access files on other QNX Neutrino hosts (of the same endian), because you can access remote filesystem managers the same way you access your local one. Files are protected by the normal permissions that apply to users and groups (see “File ownership and permissions” in the Working with Files chapter in the *User's Guide*).

There are several ways to control access to a Qnet node, if required:

- Bind Qnet to a specific network interface; this ensures that the protocol functions only on that specific interface.
- Use `maproot` and `mapany` options to control—in a limited way—what other users can do on your system.
- Use a static list of your peer systems instead of dynamically discovering them.

You can also configure Qnet to be used on a local LAN, or routed over to a WAN if necessary (encapsulated in the IP protocol).

Depending on your system design, you may need to include TCP/IP protocols along with Qnet, or instead of Qnet. For example, you could use a TCP/IP-based protocol to connect your Qnet cluster to a host that's running another operating system, such as a monitoring station that controls your system, or another host providing remote access to your system. You'll probably want to deploy standard protocols (e.g SNMP, HTTP, or a `telnet` console) for this purpose. If all the hosts in your system are running different operating systems, then your likely choice to connect them would be TCP/IP. The TCP/IP protocols typically do authentication to control access; it's useful for connecting machines that you don't necessarily trust.



You can also build a QNX Neutrino-based TCP/IP network. A QNX Neutrino TCP/IP network can access resources located on any other system that supports TCP/IP protocol. For a discussion of QNX Neutrino TCP/IP specifics, see TCP/IP Networking in the *System Architecture* guide.

Another issue may be the required behavior. For example, NFS has been designed for filesystem operations between all hosts and all endians. It's widely supported and a connectionless protocol. In NFS, the server can be shut down and restarted, and the client resumes automatically. NFS also uses authentication and controls directory access. However, NFS retries forever to reach a remote host if it doesn't respond, whereas Qnet can return an error if connectivity is lost to a remote host. For more information, see “NFS filesystem” in Working with Filesystems in the *User's Guide*).

If you require broadcast or multicast services, you need to look at TCP/IP functionalities, because Qnet is based on QNX Neutrino message passing, and has no concept of broadcasting or multicasting.

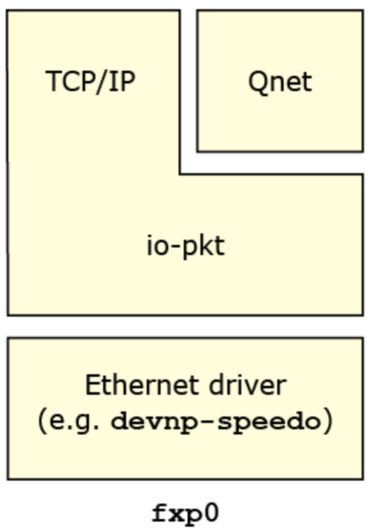
Drivers for Qnet

You don't need a specific driver for your hardware, for example, for implementing a local area network using Ethernet hardware or for implementing TCP/IP networking that requires IP encapsulation.

In these cases, the underlying `io-pkt*` and TCP/IP layer is sufficient to interface with the Qnet layer for transmitting and receiving packets. You use standard QNX Neutrino drivers to implement Qnet over a local area network or to encapsulate Qnet messages in IP (TCP/IP) to allow Qnet to be routed to remote networks.

The driver essentially performs three functions: transmitting a packet, receiving a packet, and resolving the remote node's interface (address).

First, let's define what exactly a driver is, from Qnet's perspective. When Qnet is run with its default binding of raw Ethernet (e.g., `bind=en0`), you'll find the following arrangement of layers that exists in the node:

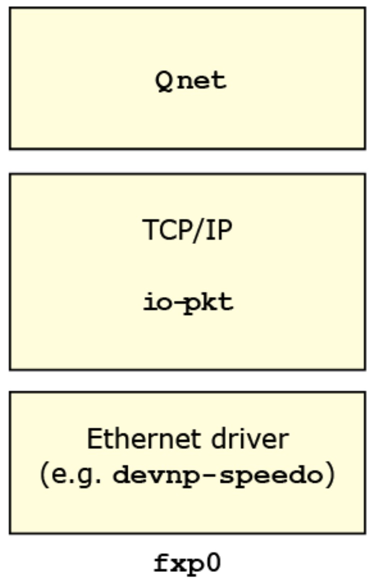


In the above case, `io-pkt*` is actually the driver that transmits and receives packets, and thus acts as a hardware-abstraction layer. Qnet doesn't care about details of the Ethernet hardware or driver.

So, if you simply want new Ethernet hardware supported, you don't need to write a Qnet-specific driver. What you need is just a normal Ethernet driver that knows how to interface to `io-pkt*`.

There is a bit of code at the very bottom of Qnet that's specific to `io-pkt*` and has knowledge of exactly how `io-pkt*` likes to transmit and receive packets. This is the L4 driver API abstraction layer.

Let's take a look at the arrangement of layers that exist in the node when Qnet is run with the optional binding of IP encapsulation (e.g., `bind=ip`):



As far as Qnet is concerned, the TCP/IP stack is now its driver. This stack is responsible for transmitting and receiving packets.

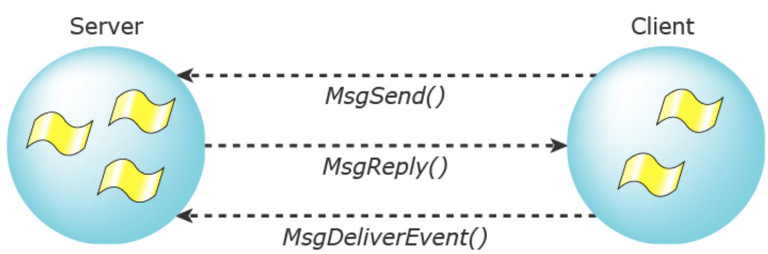
Low-level discussion of Qnet principles

The Qnet protocol extends interprocess communication (IPC) transparently over a network of microkernels. This is done by taking advantage of the QNX Neutrino RTOS's message-passing paradigm. Message passing is the central theme of QNX Neutrino that manages a group of cooperating processes by routing messages. This enhances the efficiency of all transactions among all processes throughout the system.

As we found out in the "*How does it work?*" section, many POSIX and other function calls are built on this message passing. For example, the *write()* function is built on the *MsgSendv()* function. In this section, you'll find several things, such as how Qnet works at the message-passing level, how node names are resolved to node numbers, and how such a number is used to create a connection to a remote node.

In order to understand how message passing works, consider two processes that wish to communicate with each other: a client process and a server process. First we consider a single-node case, where both client and server reside in the same machine. In this case, the client simply creates a connection (via *ConnectAttach()*) to the server, and then sends a message (perhaps via *MsgSend()*).

The Qnet protocol extends this message passing over to a network. For example, consider the case of a simple network with two machines: one contains the client process, the other contains the server process. The code required for client-server communication is identical (it uses the same API) to the code in the single-node case. The client creates a connection to the server and sends the server a message. The only difference in the network case is that the client specifies a different node descriptor for the *ConnectAttach()* function call in order to indicate the server's node. See the diagram below to understand how message passing works.



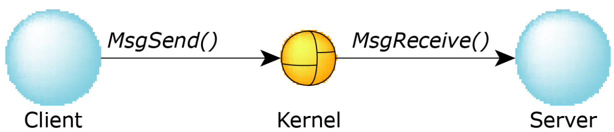
Details of Qnet data communication

As mentioned before, Qnet relies on the message passing paradigm of QNX Neutrino.

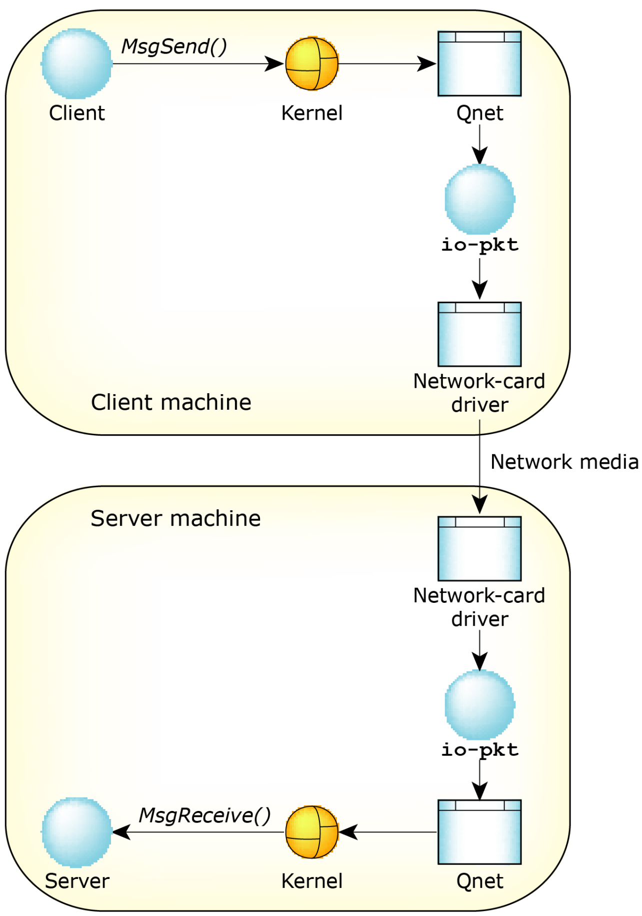
Before any message pass, however, the application (i.e., the client) must establish a connection to the server using the low-level *ConnectAttach()* function call:

```
ConnectAttach(nd, pid, chid, index, flags);
```

In the above call, *nd* is the node descriptor that specifies which node you're connecting to. The node descriptor tells the kernel whether you're communicating to a local or remote server process. If *nd* is zero, you're specifying a local server process, and you'll get local message passing from the client to the server, carried out by the local kernel as shown below:



When you specify a nonzero value for *nd*, the application transparently passes messages to a server on another machine, and connects to a server on another machine. This way, Qnet not only builds a network of trusted machines, it lets all these machines share their resources with little overhead.



Node descriptors

Node descriptors refer to nodes (machines) in a QNet network much the same way that file descriptors refer to a particular file.

They're dynamically created when needed, last as long as needed, and while in use refer to a particular file. But if two different nodes are referring to the same third node, they may end up with different node descriptors, just as when two different processes *open()* the same file, they may end up with different file descriptors. A node may even have two different node descriptors to the same remote node, if those references to the remote node have different *Quality of Service* information.

The **<sys/netmgr.h>** header defines the ND_LOCAL_NODE macro as zero. You can use it any time that you're dealing with node descriptors to make it obvious that you're talking about the local node.

If you want to see if two node descriptors from the same node refer to the same machine, you can't just arithmetically compare the descriptors for equality; use the *ND_NODE_CMP()* macro instead:

- If the return value from the macro is zero, the descriptors refer to the same node.
- If the value is less than 0, the first node is “less than” the second.
- If the value is greater than 0, the first node is “greater than” the second.

This is similar to the way that *strcmp()* and *memcmp()* work. It's done this way in case you want to do any sorting that's based on node descriptors.

The **<sys/netmgr.h>** header file also defines the following networking functions:

netmgr_strtond()

Convert a string into a node descriptor.

netmgr_ndtostr()

Convert a node descriptor into a string.

netmgr_remote_nd()

Get a node descriptor that's relative to a remote node.

For more information, see the *C Library Reference*.

Forcing retransmission

The _NETMGR_QOS_FLUSH message lets an application force a retransmission instead of waiting for Qnet to activate its own timeout.

This is useful for periodic detectable hardware failures where the application can take action, instead of enabling shorter timeout periods for Qnet, which would add more load to the system. For example:

```
#include <sys/netmgr.h>
#include <sys/netmsg.h>

extern int __netmgr_send( void *smsg1, int ssize1, const void *smsg2,
                          int ssize2, void *rmsg, int rsize);

int main (void)
{
            struct _io_msg msg;

            msg.type = _IO_MSG;
            msg.combine_len = sizeof(msg);
            msg.mgrid = _IOMGR_NETMGR;
            msg.subtype = _NETMGR_QOS_FLUSH;

            __netmgr_send(&msg, sizeof(msg), 0, 0, 0, 0);
}
```

Chapter 8
Writing an Interrupt Handler

The key to handling hardware events in a timely manner is for the hardware to generate an *interrupt*. An interrupt is simply a pause in, or interruption of, whatever the processor was doing, along with a request to do something else.

The hardware generates an interrupt whenever it has reached some state where software intervention is desired. Instead of having the software continually poll the hardware—which wastes CPU time—an interrupt is the preferred method of "finding out" that the hardware requires some kind of service. The software that handles the interrupt is therefore typically called an *Interrupt Service Routine* (ISR).

Although crucial in a realtime system, interrupt handling has unfortunately been a very difficult and awkward task in many traditional operating systems. Not so with the QNX Neutrino RTOS. As you'll see in this chapter, handling interrupts is almost trivial; given the fast context-switch times in QNX Neutrino, most if not all of the "work" (usually done by the ISR) is actually done by a thread.

Let's take a look at the QNX Neutrino interrupt functions and at some ways of dealing with interrupts. For a different look at interrupts, see the Interrupts chapter of *Getting Started with QNX Neutrino*.

Interrupts on multicore systems

On a multicore system, each interrupt is directed to one (and only one) CPU, although it doesn't matter which. How this happens is under control of the programmable interrupt controller chip(s) on the board. When you initialize the PICs in your system's startup, you can program them to deliver the interrupts to whichever CPU you want to; on some PICs you can even get the interrupt to rotate between the CPUs each time it goes off.

For the startups we write, we typically program things so that all interrupts (aside from the one(s) used for interprocessor interrupts) are sent to CPU 0. According to a study that Sun did a number of years ago, it's more efficient to direct all interrupts to one CPU, since you get better cache utilization.

For more information, see the Startup Programs chapter of *Building Embedded Systems*.

An ISR (Interrupt Service Routine) that's added by *InterruptAttach()* runs on the CPU that takes the interrupt.

An IST (Interrupt Service Thread) that receives the event set up by *InterruptAttachEvent()* runs on any CPU, limited only by the scheduler and the runmask.

A thread that calls *InterruptWait()* runs on any CPU, limited only by the scheduler and the runmask.

Attaching and detaching interrupts

In order to install an ISR, the software must tell the OS that it wishes to associate the ISR with a particular source of interrupts, which can be a hardware *Interrupt Request* line (IRQ) or one of several software interrupts.

The actual number of interrupts depends on the hardware configuration supplied by the board's manufacturer. For the interrupt assignments for specific boards, see the buildfile in that board's BSP.

In any case, a thread specifies which interrupt source it wants to associate with which ISR, using the *InterruptAttach()* or *InterruptAttachEvent()* function calls; when the software wishes to dissociate the ISR from the interrupt source, it can call *InterruptDetach()*. For example:

```
#define IRQ3 3

/*  A forward reference for the handler */
extern const sigevent *serint (void *, int);
…

/*
 *  Associate the interrupt handler, serint,
 *  with IRQ 3, the 2nd PC serial port
 */

id = InterruptAttach (IRQ3, serint, NULL, 0, 0);
…

/*  Perform some processing. */
…

/*  Done; detach the interrupt source. */
InterruptDetach (id);
```

The startup code is responsible for making sure that all interrupt sources are masked during system initialization. When the first call to *InterruptAttach()* or *InterruptAttachEvent()* is done for an interrupt vector, the kernel unmasks it. Similarly, when the last *InterruptDetach()* is done for an interrupt vector, the kernel remasks the level.

Because the interrupt handler can potentially gain control of the machine, we don't let just anybody associate an interrupt with ISR code. The process must have the PROCMGR_AID_INTERRUPT ability enabled. For more information, see *procmgr_ability()* in the *C Library Reference*.

Attaching an ISR superlocks the process's memory (see "Locking memory" in the "Process Manager" chapter of the *System Architecture* guide). This helps to reduce latency; we don't want to be handling page faults in an ISR.

Interrupt Service Routine (ISR)

In our example above, the function *serint()* is the ISR.

In general, an ISR is responsible for:

- determining which hardware device requires servicing, if any
- performing some kind of servicing of that hardware (usually this is done by simply reading and/or writing the hardware's registers)
- updating some data structures shared between the ISR and some of the threads running in the application
- notifying the application that some kind of event has occurred

Depending on the complexity of the hardware device, the ISR, and the application, some of the above steps may be omitted.

It isn't safe to use floating-point operations in Interrupt Service Routines.

Let's take a look at these steps in turn.

Determining the source of the interrupt

Depending on your hardware configuration, there may actually be *multiple* hardware sources associated with an interrupt. This issue is a function of your specific hardware and bus type. This characteristic (plus good programming style) mandates that your ISR ensure that the hardware associated with it actually *caused* the interrupt.

Most *PIC* (Programmable Interrupt Controller) chips can be programmed to respond to interrupts in either an *edge-sensitive* or *level-sensitive* manner. Depending on this programming, interrupts may be sharable.

For example:

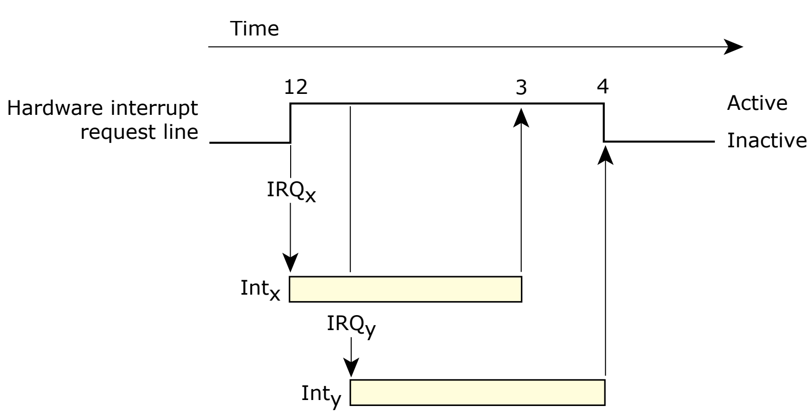


Figure 22: Interrupt request assertion with multiple interrupt sources.

In the above scenario, if the PIC is operating in a level-sensitive mode, the IRQ is considered active whenever it's high. In this configuration, while the second assertion (step 2) doesn't itself *cause* a new interrupt, the interrupt is still considered active even when the original cause of the interrupt is removed (step 3). Not until the last assertion is cleared (step 4) will the interrupt be considered inactive.

In edge-triggered mode, the interrupt is "noticed" only once, at step 1. Only when the interrupt line is cleared, and then reasserted, does the PIC consider another interrupt to have occurred.

QNX Neutrino allows ISR handlers to be *stacked*, meaning that multiple ISRs can be associated with one particular IRQ. The impact of this is that each handler in the chain must look at its associated hardware and determine if it caused the interrupt. This works reliably in a level-sensitive environment, but not an edge-triggered environment.

To illustrate this, consider the case where two hardware devices are sharing an interrupt. We'll call these devices "HW-A" and "HW-B." Two ISR routines are attached to one interrupt source (via the *InterruptAttach()* or *InterruptAttachEvent()* call), in sequence (i.e., ISR-A is attached first in the chain, ISR-B second).

Now, suppose HW-B asserts the interrupt line first. QNX Neutrino detects the interrupt and dispatches the two handlers in order. ISR-A runs first and decides (correctly) that its hardware *didn't* cause the interrupt. Then ISR-B runs and decides (correctly) that its hardware *did* cause the interrupt; it then starts servicing the interrupt. But before ISR-B clears the source of the interrupt, suppose HW-A asserts an interrupt; what happens depends on the type of IRQ:

Edge-triggered IRQ

If you have an edge-triggered bus, when ISR-B clears the source of the interrupt, the IRQ line is still held active (by HW-A). But because it's edge-triggered, the PIC is waiting for the next clear/assert transition before it decides that another interrupt has occurred. Since ISR-A already ran, it can't possibly run again to actually *clear* the source of the interrupt. The result is a "hung" system, because the interrupt will *never* transit between clear and asserted again, so no further interrupts on that IRQ line will ever be recognized.

Level-sensitive IRQ

On a level-sensitive bus, when ISR-B clears the source of the interrupt, the IRQ line is still held active (by HW-A). When ISR-B finishes running and QNX Neutrino sends an *EOI* (End Of Interrupt) command to the PIC, the PIC immediately reinterrupts the kernel, causing ISR-A (and then ISR-B) to run.

Since ISR-A clears the source of the interrupt (and ISR-B doesn't do anything, because its associated hardware doesn't require servicing), everything functions as expected.

Servicing the hardware

The above discussion may lead you to the conclusion that "level-sensitive is *good*; edge-triggered is *bad*." However, another issue comes into play.

In a level-sensitive environment, your ISR *must* clear the source of the interrupt (or at least mask it via *InterruptMask()*) before it completes. (If it didn't, then when the kernel issued the EOI to the PIC, the PIC would then immediately reissue a processor interrupt and the kernel would loop forever, continually calling your ISR code.)

In an edge-triggered environment, there's no such requirement, because the interrupt won't be noticed again until it transits from clear to asserted.

In general, to actually service the interrupt, your ISR has to do very little; the minimum it can get away with is to clear the source of the interrupt and then schedule a thread to actually do the work of handling the interrupt. This is the recommended approach, for a number of reasons:

- Context-switch times between the ISR completing and a thread executing are very small—typically on the order of a few microseconds.
- The type of functions that the ISR itself can execute is very limited (those that don't call any kernel functions, except the ones listed below).
- The ISR runs at a priority *higher* than any software priority in the system—having the ISR consume a significant amount of processor has a negative impact on the realtime aspects of the QNX Neutrino RTOS.

Since the range of hardware attached to an interrupt source can be very diverse, the specific how-to's of servicing the interrupt are beyond the scope of this document—this really depends on what your hardware requires you to do.

Safe functions

When the ISR is servicing the interrupt, it can't make any kernel calls (except for the few that we'll talk about shortly). This means that you need to be careful about the library functions that you call in an ISR, because their underlying implementation may use kernel calls.

For a list of the functions that you can call from an ISR, see the Full Safety Information appendix in the *C Library Reference*.

Here are the only kernel calls that the ISR can use:

- *InterruptMask()*
- *InterruptUnmask()*
- *TraceEvent()*

You'll also find these functions (which aren't kernel calls) useful in an ISR:

- *InterruptEnable()* (not recommended)
- *InterruptDisable()* (not recommended)
- *InterruptLock()*
- *InterruptUnlock()*

Let's look at these functions.

To prevent a thread and ISR from interfering with each other, you'll need to tell the kernel to disable interrupts. On a single-processor system, you can simply disable interrupts using the processor's “disable interrupts” opcode. But on an SMP system, disabling interrupts on one processor doesn't disable them on another processor.

The function *InterruptDisable()* (and the reverse, *InterruptEnable()*) performs this operation on a single-processor system. The function *InterruptLock()* (and the reverse, *InterruptUnlock()*) performs this operation on an SMP system, but combines it with a spin lock to synchronize across cores as well.

We recommend that you *always* use the SMP versions of these functions—this makes your code portable to SMP systems, with a negligible amount of overhead.

The *InterruptMask()* and *InterruptUnmask()* functions disable and enable the PIC's recognition of a particular hardware IRQ line. These calls are useful if your interrupt handler ISR is provided by the kernel via *InterruptAttachEvent()* or if you can't clear the cause of the interrupt in a level-sensitive environment quickly. (This would typically be the case if clearing the source of the interrupt is time-consuming—you don't want to spend a lot of time in the interrupt handler.) In this case, the ISR would call *InterruptMask()* and schedule a thread to do the actual work. The thread would call *InterruptUnmask()* when it had cleared the source of the interrupt.

Note that these two functions are *counting*; *InterruptUnmask()* must be called the same number of times as *InterruptMask()* in order to have the interrupt source considered enabled again.

The *TraceEvent()* function traces kernel events; you can call it, with some restrictions, in an interrupt handler. For more information, see the System Analysis Toolkit *User's Guide*.

Updating common data structures

Another issue that arises when using interrupts is how to safely update data structures in use between the ISR and the threads in the application.

Two important characteristics are worth repeating:

- The ISR runs at a higher priority than any software thread.
- The ISR can't issue kernel calls (except as noted).

This means that you *can't* use thread-level synchronization (such as mutexes, condvars, etc.) in an ISR.

Because the ISR runs at a higher priority than any software thread, it's up to the thread to protect itself against any preemption caused by the ISR. Therefore, the thread should issue *InterruptLock()* and *InterruptUnlock()* calls around any critical data-manipulation operations. Since these calls effectively turn off interrupts, the thread should keep the data-manipulation operations to a bare minimum.

With SMP, there's an additional consideration: one processor could be running the ISR, and another processor could be running a thread related to the ISR. On an SMP system, these functions take and release a spinlock to add synchronization across cores. Again, using these functions on a non-SMP system is safe; they'll work just like *InterruptDisable()* and *InterruptEnable()*, albeit with an insignificantly small performance penalty.

Another solution that can be used in some cases to at least guarantee atomic accesses to data elements is to use the *atomic_*()* function calls; see “*Atomic operations*.”

Variables accessed in both an ISR and normal thread processing must be marked as `volatile`.

Notifying the application code

Since the environment the ISR operates in is very limited, generally you'll want to perform most (if not all) of your actual "servicing" operations at the thread level.

At this point, you have two choices:

- You may decide that some time-critical functionality needs to be done in the ISR, with a thread being scheduled later to do the "real" work.
- You may decide that *nothing* needs to be done in the ISR; you just want to schedule a thread.

This is effectively the difference between *InterruptAttach()* (where an ISR is attached to the IRQ) and *InterruptAttachEvent()* (where a `struct sigevent` is bound to the IRQ).

Let's take a look at the prototype for an ISR function and the *InterruptAttach()* and *InterruptAttachEvent()* functions:

```
int
InterruptAttach (int intr,
                 const struct sigevent * (*handler) (void *, int),
                 const void *area,
                 int size,
                 unsigned flags);

int
InterruptAttachEvent (int intr,
                      const struct sigevent *event,
                      unsigned flags);

const struct sigevent *
handler (void *area, int id);
```

Using *InterruptAttach()*

The *InterruptAttach()* function associates the IRQ vector (*intr*) with your ISR handler (*handler*), passing it a communications area (*area*).

The *size* and *flags* arguments aren't germane to our discussion here (they're described in the *C Library Reference* for the *InterruptAttach()* function).

For the ISR, the *handler()* function takes a `void *` pointer and an `int` identification parameter; it returns a `const struct sigevent *` pointer. The `void *` *area* parameter is the value given to the *InterruptAttach()* function—any value you put in the *area* parameter to *InterruptAttach()* is passed to your *handler()* function. (This is simply a convenient way of coupling the interrupt handler ISR to some data structure. You're certainly free to pass in a `NULL` value if you wish.)

After it has read some registers from the hardware or done whatever processing is required for servicing, the ISR may or may not decide to schedule a thread to actually do the work. In order to schedule a thread, the ISR simply returns a pointer to a `const struct sigevent` structure—the kernel looks at the structure and delivers the event to the destination. (See the QNX Neutrino *C Library Reference* under `sigevent` for a discussion of event types that can be returned.) If the ISR decides not to schedule a thread, it simply returns a `NULL` value.

As mentioned in the documentation for `sigevent`, the event returned can be a signal or a pulse. You may find that a signal or a pulse is satisfactory, especially if you already have a signal or pulse handler for some other reason.

Note, however, that for ISRs we can also return a SIGEV_INTR event. This is a special event that really has meaning only for an ISR and its associated *controlling thread*.

A very simple, elegant, and fast way of servicing interrupts from the thread level is to have a thread dedicated to interrupt processing. The thread attaches the interrupt (via *InterruptAttach()*) and then the thread blocks, waiting for the ISR to tell it to do something. Blocking is achieved via the *InterruptWait()* call. This call blocks until the ISR returns a SIGEV_INTR event:

```
struct sigevent event;

main ()
{
    // perform initializations, etc.
    …
    // start up a thread that is dedicated to interrupt processing
    pthread_create (NULL, NULL, int_thread, NULL);
    …
    // perform other processing, as appropriate
    …
}

// this thread is dedicated to handling and managing interrupts
void *
int_thread (void *arg)
{
    /* Enable the INTERRUPT ability */
    procmgr_ability(0,
        PROCMGR_ADN_ROOT|PROCMGR_AOP_ALLOW|PROCMGR_AID_INTERRUPT,
        PROCMGR_AID_EOL);
    …
    // initialize the hardware, etc.
    …
    // initialize the event as type SIGEV_INTR
    SIGEV_INTR_INIT( &event );

    // attach the ISR to IRQ 3
    InterruptAttach (IRQ3, isr_handler, NULL, 0, 0);
    …
    // perhaps boost this thread's priority here
    …
    // now service the hardware when the ISR says to
    while (1)
    {
        InterruptWait (NULL, NULL);
        // at this point, when InterruptWait unblocks,
        // the ISR has returned a SIGEV_INTR, indicating
        // that some form of work needs to be done.

        …
        // do the work
```

```
        …
        // if the isr_handler did an InterruptMask, then
        // this thread should do an InterruptUnmask to
        // allow interrupts from the hardware
    }
}

// this is the ISR
const struct sigevent *
isr_handler (void *arg, int id)
{
    // look at the hardware to see if it caused the interrupt
    // if not, simply return (NULL);
    …
    // in a level-sensitive environment, clear the cause of
    // the interrupt, or at least issue InterruptMask to
    // disable the PIC from reinterrupting the kernel
    …
    // return a pointer to an event structure (preinitialized
    // by int_thread()) that contains SIGEV_INTR as its notification type.
    // This causes the InterruptWait() in int_thread() to unblock.
    return (&event);
}
```

In the above code sample, we see a typical way of handling interrupts. The main thread creates a special interrupt-handling thread (*int_thread()*). The sole job of that thread is to service the interrupts at the thread level. The interrupt-handling thread attaches an ISR to the interrupt (*isr_handler()*), and then waits for the ISR to tell it to do something. The ISR informs (unblocks) the thread by returning an event structure with the notification type set to SIGEV_INTR.

This approach has a number of advantages over using an event notification type of SIGEV_SIGNAL or SIGEV_PULSE:

- The application doesn't have to have a *MsgReceive()* call (which would be required to wait for a pulse).
- The application doesn't have to handle signals (which can be messy).
- If the interrupt servicing is critical, the application can create the *int_thread()* thread with a high priority; when the SIGEV_INTR is returned from the *isr_handler()* function, if the *int_thread()* function is of sufficient priority, it runs *immediately*. There's no delay as there might be, for example, between the time that the ISR sent a pulse and another thread eventually called a *MsgReceive()* to get it.

The only caveat to be noted when using *InterruptWait()* is that the thread that *attached* the interrupt is the one that must *wait* for the SIGEV_INTR.

Using *InterruptAttachEvent()*

Most of the discussion above for *InterruptAttach()* applies to the *InterruptAttachEvent()* function, with the obvious exception of the ISR. You don't provide an ISR in this case; the kernel notes that you called *InterruptAttachEvent()* and handles the interrupt itself. Since you also bound a `struct sigevent` to the IRQ, the kernel can now dispatch the event. The major advantage is that we avoid a context switch into the ISR and back.

In order to attach and interrupt event, you must have the PROCMGR_AID_INTERRUPTEVENT ability enabled. For more information, see *procmgr_ability()* in the *C Library Reference*.

An important point to note is that the kernel automatically performs an *InterruptMask()* in the interrupt handler. Therefore, it's up to you to perform an *InterruptUnmask()* when you actually clear the source of the interrupt in your interrupt-handling thread. This is why *InterruptMask()* and *InterruptUnmask()* are counting.

Running out of interrupt events

If you're working with interrupts, you might see an `Out of Interrupt Events` error.

This happens when the system is no longer able to run user code and is stuck in the kernel, most frequently because:

- The interrupt load is too high for the CPU (it's spending all of the time handling the interrupt).

  or:

- There's an interrupt handler—one connected with *InterruptAttach()*, not *InterruptAttachEvent()*—that doesn't properly clear the interrupt condition from the device (leading to the case above).

If you call *InterruptAttach()* in your code, look at the handler code first and make sure you're properly clearing the interrupt condition from the device before returning to the OS.

If you encounter this problem, and you're sure all your interrupt handlers are fine, it could be caused by broken interrupt callouts in the BSP.

Problems with shared interrupts

It's possible for different devices to share an interrupt (for example if you've run out of hardware interrupt lines), but we don't recommend you do this with hardware that will be generating a lot of interrupts. We also recommend you not share interrupts with drivers that you don't have complete source control over, because you need to be sure that the drivers process interrupts properly.

Sharing interrupts can decrease your performance, because when the interrupt fires, *all* of the devices sharing the interrupt need to run and check to see if it's for them. Many drivers read the registers in their interrupt handlers to see if the interrupt is really for them, and then ignore it if it isn't. But some drivers don't; they schedule their thread-level event handlers to check their hardware, which is inefficient and reduces performance.

If you have a frequent interrupt source sharing an interrupt with a driver that schedules a thread to check the hardware, the overhead of scheduling the thread becomes noticeable.

Sharing interrupts can increase interrupt latency, depending upon exactly what each of the drivers does. After an interrupt fires, the kernel doesn't reenable it until *all* driver handlers tell the kernel that they've finished handling it. If one driver takes a long time servicing a shared interrupt that's masked, and another device on the same interrupt causes an interrupt during that time period, the processing of that interrupt can be delayed for an unknown length of time.

Advanced topics

Now that we've seen the basics of handling interrupts, let's take a look at some more details and some advanced topics.

Interrupt environment

When your ISR is running, it runs in the context of the process that attached it, except with a different stack.

Since the kernel uses an internal interrupt-handling stack for hardware interrupts, your ISR is impacted in that the internal stack is small. Generally, you can assume that you have about 200 bytes available.

The PIC doesn't get the EOI command until *after* all ISRs—whether supplied by your code via *InterruptAttach()* or by the kernel if you use *InterruptAttachEvent()*—for that particular interrupt have been run. Then the kernel itself issues the EOI; your code should *not* issue the EOI command.

Ordering of shared interrupts

If you're using interrupt sharing, then by default when you attach an ISR using *InterruptAttach()* or *InterruptAttachEvent()*, the new ISR goes to the beginning of the list of ISRs for that interrupt. You can specifically request that your ISR be placed at the end of the list by specifying a *flags* argument of _NTO_INTR_FLAGS_END.

Note that there's no way to specify any other order (e.g., middle, fifth, second, etc.).

Interrupt latency

Another factor of concern for realtime systems is the amount of time taken between the generation of the hardware interrupt and the first line of code executed by the ISR.

There are two factors to consider here:

- If any thread in the system calls *InterruptDisable()* or *InterruptLock()*, then no interrupts are processed until the *InterruptEnable()* or *InterruptUnlock()* function call is issued.
- In any event, if interrupts are enabled, the kernel begins executing the first line of the *first* ISR (in case multiple ISRs are associated with an interrupt) in short order (e.g., under 21 CPU instructions on an x86).

Atomic operations

Some convenience functions are defined in the include file **<atomic.h>** that allow you to perform atomic operations (i.e., operations that are guaranteed to be indivisible or uninterruptible).

Using these functions alleviates the need to disable and enable interrupts around certain small, well-defined operations with variables, such as:

- adding a value
- subtracting a value

- clearing bits
- setting bits
- toggling bits

See the QNX Neutrino *C Library Reference* under *atomic_*()* for more information.

Interrupts and power management

In order to help the kernel save power, you can make an interrupt "lazy" by specifying an acceptable latency for it.

Before putting the CPU to sleep, the kernel checks all the interrupt latency values and sees if it can guarantee that another interrupt (e.g., for a timer tick) will occur before the latency period has expired. If it can prove that another interrupt will occur first, the kernel masks the lazy interrupt before going to sleep. When any interrupt is received by the CPU, all the lazily masked interrupts are unmasked.

To specify the interrupt latency, use the *InterruptCharacteristic()* kernel call:

```
int InterruptCharacteristic( int type,
                             int id,
                             unsigned *new,
                             unsigned *old );
```

setting the arguments as follows:

type

_NTO_IC_LATENCY

id

A value returned by *InterruptAttach()* or *InterruptAttachEvent()*

new

A pointer to an `unsigned` that contains the new latency value for the interrupt, in nanoseconds. The default latency value is zero.

old

If this is non-NULL, the function fills it with the old latency value for the interrupt.

In order to set a latency, the calling thread must be in the process that attached to the interrupt.

You can set the global latency value for the system by specifying an *id* of -1. If an interrupt attachment doesn't specify a latency value, the kernel uses the global latency number when calculating how deep a sleep state to use. In order to set the global latency value:

- The process must have the PROCMGR_AID_IO ability enabled (see *procmgr_ability()*)
- The calling thread must have obtained I/O privileges by calling *ThreadCtl()* with the _NTO_TCTL_IO command:

  ```
  ThreadCtl( _NTO_TCTL_IO, 0 );
  ```

For more information about power management, see "*Clocks, timers, and power management*" in the "Understanding the Microkernel's Concept of Time" chapter in this guide.

Chapter 9
32- and 64-Bit Architectures

QNX Neutrino 7.0 or later supports 32- and 64-bit versions of ARM (`armle-v7` and `aarch64le`) and x86 (`x86` and `x86_64`).

The 64-bit architecture provides a 64-bit virtual address space seen by programs. Current hardware supports only 48 bits; the top bits have to be a sign extension of bit 48, and the QNX Neutrino implementation allows user programs to use 39 bits.

The difference between 32- and 64-bit architectures is basically an artifact of compiling, but there are different versions of the kernel for 32- and 64-bit architectures (similar to ARM vs ARMv7 in earlier releases).

To determine whether a process is for a 64-bit architecture, use the DCMD_PROC_INFO *devctl()* command and look for the _NTO_PF_64BIT bit in the *flags* of the `procfs_info` or `debug_process_t` structure. For more information, see the Processes chapter in this guide, as well as the section on DCMD_PROC_INFO in the appendix on the **/procfs** filesystem in *The QNX Neutrino Cookbook*.

Sizes of data types

The 32- and 64-bit versions of QNX Neutrino use different C Language Data Type Models:

- 32-bit uses ILP32: integers, long integers, and pointers are 32 bits long.
- 64-bit uses LP64: long integers and pointers are 64 bits long.

The sizes of the basic data types are as follows:

Data type	32-bit	64-bit
`char`	8	8
`int`	32	32
`long`	32	64[a]
`long long`	64	64
`off_t`	signed 32	signed 64
`paddr_t`	unsigned 32	unsigned 64
`ptrdiff_t`	32	64
`short`	16	16
`size_t`, `ssize_t`	32	64
`time_t`	unsigned 32	signed 64
`uintptr_t`, `intptr_t`	32	64
`void *`	32	64

[a] 64-bit Windows uses 32 bits for a `long` because there's a lot of code that assumes that a `long` and an `int` are the same size. 64-bit Unix-type OSs use 64 bits for a `long`.

The sizes of many compound types depend on the architecture. These include the following:

- `struct sigevent`
- `union sigval`
- `siginfo_t`
- `struct iovec`
- `struct utimbuf`
- `struct sigaction`
- `struct _timer_info`
- `struct timeval`
- and anything else that includes a base type whose size varies

When we extended the structures, we defined additional versions for 32- and 64-bits. For example, in addition to `struct sigevent`, we've defined `struct __sigevent32` and `struct __sigevent64` that have the correctly sized fields. These additional types let you access—for example—the 32-bit structure in a program compiled for 64 bits. The fields might not be of the same type as in the original structure, but they'll be the correct size.

Because of all these differences, you need to be careful with data types. For example:

- NULL is now defined as `(void *) 0` instead of just 0, so it no longer fits in an `int` or `char`. Don't use NULL as the terminating character in a string.
- `int` and `unsigned` can't hold pointers or pointer differences in 64-bit architectures. Use `uintptr_t` to cast pointers to an integer type.
- Use `size_t` or `ptrdiff_t` to hold the result of subtracting one pointer from another.
- `pointer & ~unsigned` masks out more bits than you might expect. Use `pointer & ~uintptr_t` instead.

You can use the PRI* macros that are defined in **<inttypes.h>** to simplify calls to *printf()* that involve integers whose conversion specifier is different in 32- and 64-bit architectures.

You can use the `-Wconversion` compiler option to generate warnings about any implicit conversions that could alter a value. This option isn't enabled by `-Wall` or `-Wextra`, so you have to specify it explicitly. For more information, see the `gcc` documentation at *https://gcc.gnu.org/onlinedocs/gcc/*.

Kernel calls and macros for `sigval`s

The `sigval` data type is a union of an integer and a pointer, so its size depends on whether you compile for a 32- or 64-bit architecture, There are some other implications:

- In 32-bit architectures, you can send a pointer in a pulse by passing the pointer as the *value* argument to *MsgSendPulse()*, but this won't work with 64-bit pointers, so there's a *MsgSendPulsePtr()* kernel call:

  ```
  int MsgSendPulsePtr(int coid, int priority, int code, void *value);
  ```

  When you receive a pulse, you need to extract the value from the correct field: integers from *sival_int*, pointers from *sival_ptr*.

- There's also *SignalKillSigval()*, which lets you send a pointer as the value for a signal:

  ```
  int SignalKillSigval(uint32_t nd, pid_t pid, int tid, int signo, union sigval *sigval);
  ```

  It's the kernel call under the POSIX *sigqueue()* function, and you aren't likely to use it directly.

- We provide the following macros for initializing the `sigval` that's part of a `sigevent`:

  - *SIGEV_PULSE_INT_INIT()*
  - *SIGEV_PULSE_PTR_INIT()*
  - *SIGEV_SIGNAL_CODE_INT_INIT()*
  - *SIGEV_SIGNAL_CODE_PTR_INIT()*
  - *SIGEV_SIGNAL_VALUE_INT_INIT()*
  - *SIGEV_SIGNAL_VALUE_PTR_INIT()*

  The original initialization macros (e.g., *SIGEV_PULSE_INIT()*) store the value in *sigev_value.sival_ptr*, as do the *SIGEV_*_PTR_INIT()* macros. The *SIGEV_*_INT_INIT()* macros store the value in *sigev_value.sival_int* and set the hidden SIGEV_FLAG_SIVAL_INT bit in *sigev_notify*.

Large file support

When you compile a program for a 64-bit architecture, `off_t` is 64 bits long, so the *64() versions of functions (*open64()*, *stat64()*, etc.) aren't defined. If you're using a **64()* function, switch to the normal one (e.g., `s/open64/open/`); to maintain source compatibility when you're compiling for a 32-bit architecture, add `-D_FILE_OFFSET_BITS=64` to the command line, or define _LARGEFILE64_SOURCE to be 1.

sigevents

We've defined `struct __sigevent32` and `struct __sigevent64`, in addition to `struct sigevent`. The OS handles either form in both 32- and 64-bit architectures.

Since a `sigevent` might be passed between 32- and 64-bit programs, we've defined a SIGEV_64BIT flag that indicates which type of `sigevent` it is. We OR this flag into the *sigev_notify* types. For example, in addition to SIGEV_SIGNAL, we have SIGEV_SIGNAL32 and SIGEV_SIGNAL64:

- SIGEV_SIGNAL32 is the same value as SIGEV_SIGNAL was in earlier versions of the OS.
- SIGEV_SIGNAL64 is equal to SIGEV_SIGNAL32 with SIGEV_64BIT ORed in.
- In a 32-bit process, SIGEV_SIGNAL is equal to SIGEV_SIGNAL32; in a 64-bit process, it's equal to SIGEV_SIGNAL64.

Some programs use SIGEV_NONE to identify an empty `sigevent`. For compatibility, SIGEV_NONE is always the same as SIGEV_NONE32, no matter which architecture you compile for.

If your program stores `sigevent`s from 32- and 64-bit programs, you should replace `struct sigevent` with a union:

```
union {
   struct sigevent ev;
   struct __sigevent32 ev32;
   struct __sigevent64 ev64;
};
```

Your code can then check *ev.sigev_notify*, determine whether the `sigevent` is from a 32- or 64-bit program, and then use the *ev32* or *ev64* structure, as appropriate.

For more information, see the entry for `sigevent` in the *C Library Reference*. See also “*Kernel calls and macros for `sigval`s*” in this chapter.

TimerInfo()

The `struct _timer_info` data type includes a `sigevent`, so there are also `struct _timer_info32` and `struct _timer_info64` variants that include the 32- and 64-bit versions of `sigevent`, respectively. An additional problem is that a process for a 32-bit architecture might have to deal with a timer from a process in a 64-bit architecture.

In a 32-bit architecture, *TimerInfo()* gives an error of EOVERFLOW if you try to get information on a SIGEV_64BIT `sigevent`. You can make the call succeed by passing a pointer to a `struct _timer_info64` and adding the _NTO_TIMER_SUPPORT_64BIT bit to the *flags* argument.

In a 64-bit architecture, the `struct _timer_info` is big enough, so you don't have to do anything special.

struct stat

The `struct stat` is different in 64-bit architectures than in 32-bit ones because it includes 64-bit `time_t` members. POSIX 2008 added support for nanosecond-resolution timestamps (*st_mtim*, *st_atim*, and *st_ctim* fields are of type `struct timespec`). This means that there are several forms of the `stat` structure:

struct __stat_t32_2001

Includes 32-bit `time_t` fields, but not the nanosecond-resolution timestamps. This is what earlier versions of the OS supported and is the default for 32-bit architectures.

struct __stat_t32_2008

Includes 32-bit `time_t` fields, and the nanosecond-resolution timestamps.

struct __stat_t64_2008

Includes 64-bit `time_t` fields, and the nanosecond-resolution timestamps. This is the default for 64-bit architectures.

The `dirent_extra_stat` information (see *readdir()*) also handles the different `stat` formats. The `dirent_extra_type` enumerated type, which defines the possible values for the *d_type* member, is defined as follows:

```
enum dirent_extra_type {
 _DTYPE_NONE,
 _DTYPE_STAT_UNSET,
 _DTYPE_LSTAT_UNSET,
 _DTYPE_STAT_T32_2001,
 _DTYPE_LSTAT_T32_2001,
 _DTYPE_STAT_T32_2008,
 _DTYPE_LSTAT_T32_2008,
 _DTYPE_STAT_T64_2008,
 _DTYPE_LSTAT_T64_2008,
#if __PTR_BITS__ == 32
 _DTYPE_STAT = _DTYPE_STAT_T32_2001,
 _DTYPE_LSTAT = _DTYPE_LSTAT_T32_2001,
#else
 _DTYPE_STAT = _DTYPE_STAT_T64_2008,
 _DTYPE_LSTAT = _DTYPE_LSTAT_T64_2008,
#endif
};
```

As before, the _DTYPE_STAT* types indicate that the resource manager didn't resolve symbolic links, and the _DTYPE_LSTAT* types indicate that the resource manager did. _DTYPE_STAT_UNSET and _DTYPE_LSTAT_UNSET correspond to the former values of _DTYPE_STAT and _DTYPE_LSTAT; the others also indicate which form of the `stat` structure is included.

You can use *stat_convert_form()* to convert one form of a `struct stat` into another.

There are several different sets of constants for identifying the formats of the `stat` structure:

dircntl()

Use these flags (defined in **<dirent.h>**) to indicate which form of `stat` structure you want returned with *readdir()*:

```
#define D_FLAG_STAT     0x00000002      /* Attempt to return extra stat information */
#define D_FLAG_STAT_FORM_UNSET          0x00000000      /* == _STAT_FORM_UNSET */
#define D_FLAG_STAT_FORM_T32_2001       0x00000010      /* want _STAT_FORM_T32_2001 */
#define D_FLAG_STAT_FORM_T32_2008       0x00000020      /* want _STAT_FORM_T32_2008 */
#define D_FLAG_STAT_FORM_T64_2008       0x00000030      /* want _STAT_FORM_T32_2008 */
```

There's a mask too:

```
#define D_FLAG_STAT_FORM_MASK 0x000000f0
```

If you set a D_FLAG_STAT_FORM_* flag, it's ORed into the current flags for the directory; otherwise, the flags you pass to *dircntl()* **replace** the directory's flags. The D_FLAG_STAT_FORM_* values are the corresponding _STAT_FORM_* values shifted up four bits.

_readdir_r()

If D_FLAG_STAT is set, set _IO_XFLAG_DIR_EXTRA_HINT in the _IO_READ message's *xtype*.

If D_FLAG_STAT_FORM_* is set, set the appropriate one of the following (from **<sys/iomsg.h>**) in the _IO_READ message:

```
_IO_XFLAG_DIR_STAT_FORM_UNSET    = 0x00000000,
_IO_XFLAG_DIR_STAT_FORM_T32_2001 = 0x00010000,
_IO_XFLAG_DIR_STAT_FORM_T32_2008 = 0x00020000,
_IO_XFLAG_DIR_STAT_FORM_T64_2008 = 0x00030000,
```

There's a mask too:

```
_IO_XFLAG_DIR_STAT_FORM_MASK     = 0x000f0000,
```

_IO_READ handler

Append the appropriate form of the `stat` structure to the message, setting *d_type* (in `dirent_extra_stat`) to one of the following (from **<dirent.h>**):

```
enum dirent_extra_type {
        _DTYPE_NONE,
        _DTYPE_STAT_UNSET,
        _DTYPE_LSTAT_UNSET,
        _DTYPE_STAT_T32_2001,
        _DTYPE_LSTAT_T32_2001,
        _DTYPE_STAT_T32_2008,
        _DTYPE_LSTAT_T32_2008,
```

```
        _DTYPE_STAT_T64_2008,
        _DTYPE_LSTAT_T64_2008,
#if __PTR_BITS__ == 32
        _DTYPE_STAT = _DTYPE_STAT_T32_2001,
        _DTYPE_LSTAT = _DTYPE_LSTAT_T32_2001,
#else
        _DTYPE_STAT = _DTYPE_STAT_T64_2008,
        _DTYPE_LSTAT = _DTYPE_LSTAT_T64_2008,
#endif
};
```

_IO_STAT messages

Choose the appropriate type (from **<sys/stat.h>**):

```
#define _STAT_FORM_UNSET        0
#define _STAT_FORM_T32_2001     1
#define _STAT_FORM_T32_2008     2
#define _STAT_FORM_T64_2008     3
#if __PTR_BITS__ == 32
#define _STAT_FORM_SYS_2008             (_STAT_FORM_T32_2008)
#define _STAT_FORM_PREFERRED    (_STAT_FORM_T32_2001)
#else
#define _STAT_FORM_SYS_2008             (_STAT_FORM_T64_2008)
#define _STAT_FORM_PREFERRED    (_STAT_FORM_T64_2008)
#endif
```

There's a mask too:

```
#define _STAT_FORM_MASK         0x03u
```

The handler returns, via the *status* argument to *MsgReply()*, the format that was generated.

Communicating with processes of different architectures

If you're using Transparent Distributed Processing (TDP) across Qnet, your programs might need to communicate with processes that use a different architecture. We support connections across Qnet between QNX Neutrino 7.0 (32- or 64-bit) and the following:

- QNX Neutrino 7.0 (32- or 64-bit)
- QNX Neutrino 6.6 (32-bit)
- QNX Neutrino 6.5 SP1 (32-bit, little endian only)

If you get a message, you can check the message information that *MsgReceive()* provides. The `_msg_info` structure's *flag* member can include the following bits:

_NTO_MI_BITS_64

The sender is using a 64-bit architecture.

_NTO_MI_BITS_DIFF

The sender and receiver are using different word-size architectures (e.g, the sender is using a 32-bit architecture, and the receiver is using a 64-bit architecture).

If your program can't handle the format of the message, it can use *MsgError()* to return an error (for example, ENOTSUP) to the sender. For more information, see “Replying with no data, or an *errno*” in the Message Passing chapter of *Getting Started with QNX Neutrino*.

I/O messages

There are some 64-bit I/O messages that are used with resource managers:

- _IO_READ64 and _IO_WRITE64 have repurposed a zero field to allow the specification of the high 32 bits of length. There are *_IO_READ_GET_NBYTES()* and *_IO_WRITE_GET_NBYTES()* macros that calculate the number of bytes specified by _IO_READ, _IO_READ64, _IO_WRITE, and _IO_WRITE64 messages. For more information, see the Handling Read and Write Messages chapter in *Writing a Resource Manager*.
- _IO_UTIME64 defines a structure to handle 64-bit `time_t`s and to support *futimens()* and *utimensat()*. For more information, see *iofunc_utime()*.
- _IO_NOTIFY64 extends the structure to handle 64-bit `sigevent` structures; see *iofunc_notify()*.
- _IO_STAT repurposed a zero field to identify which format of `stat` structure is requested:

```
#define _STAT_FORM_UNSET 0
#define _STAT_FORM_T32_2001 1
#define _STAT_FORM_T32_2008 2
#define _STAT_FORM_T64_2008 3
#if __PTR_BITS__ == 32
#define _STAT_FORM_SYS_2008  (_STAT_FORM_T32_2008)
#define _STAT_FORM_PREFERRED (_STAT_FORM_T32_2001)
#else
#define _STAT_FORM_SYS_2008  (_STAT_FORM_T64_2008)
#define _STAT_FORM_PREFERRED (_STAT_FORM_T64_2008)
#endif
```

  and uses the *MsgReply() status* parameter to indicate which format was generated. See *iofunc_stat_default()*.

The client side sends the 64-bit message types only when the data won't fit into the old message types.

`iofunc` support for ns-resolution timestamps

The `iofunc_attr_t` structure includes `unsigned` *mtime_ns*, *atime_ns*, and *ctime_ns* fields to accompany the *mtime*, *atime*, and *ctime* fields:

- These fields are included by default for 64-bit architectures, but you can include them for 32-bit compiles as well by defining IOFUNC_NS_TIMESTAMP_SUPPORT before including **<sys/iofunc.h>**.
- If these fields are included, IOFUNC_ATTR_NS_TIMESTAMPS is set in the attribute's *flags*.
- The *iofunc_time_update()* function updates the nanosecond-resolution fields as well as the second-resolution fields, if IOFUNC_ATTR_NS_TIMESTAMPS is set in the attribute's flags.

DCMD_PROC_* and the /proc filesystem

As described in the QNX Neutrino *Programmer's Guide*, you can use the DCMD_PROC_* *devctl()* commands defined in **<sys/procfs.h>** to control processes. There are 32- and 64-bit versions of some of these commands. For example:

```
#define DCMD_PROC_STATUS32  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status32))
#define DCMD_PROC_STATUS64  (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status64))
#define DCMD_PROC_STATUS    (__DIOF(_DCMD_PROC, __PROC_SUBCMD_PROCFS + 7, procfs_status))
```

The first two forms are for specific sizes; the generic form (DCMD_PROC_STATUS) maps onto the 64-bit version, whether you compile for a 32- or 64-bit architecture. If you're compiling for a 32-bit architecture, and you want the generic version to map onto the 32-bit command, define WANT_OLD_DEVCTLS before you include **<sys/procfs.h>**. If you're compiling for a 64-bit architecture, you always get the 64-bit version of the command.

For more information, see "*Controlling processes via the /proc filesystem*" in the Processes chapter of this guide.

Trace events

If you use the instrumented kernel to trace events in your system, note the following:

- Some kernel events have _NTO_TRACE_KERCALL64 ORed into the event type to indicate that the event includes 64-bit data types.
- There are 64-bit versions of some System class events:
    - _NTO_TRACE_SYS_IPI_64 — emitted when a interprocessor interrupt is received
    - _NTO_TRACE_SYS_MAPNAME_64 — emitted when *dlopen()* is called

For more information, see the System Analysis Toolkit *User's Guide*.

Other tips for programming

Parsing executables

Executables/shared objects are ELF64; use **libelf** or **libgl** to parse them when possible.

32- and 64-bit message compatibility

Don't pass messages where a field changes size between 32- and 64-bit architectures.

Change fields to a consistent type

- `s/unsigned long/unsigned`
- Use when additional length isn't required and the field type isn't specified by an external standard.

Create a “messenger” type

- Use when field types are specified by an external standard, but we don't really need the extra space.
- Client side does field-by-field assignments to copy user type to/from the messenger type.
- For example, `struct __msg_mq_attr`

Create a new message type

- Do this when there isn't enough space in the existing message structure.
- Hide extra information in previously reserved fields (e.g., _IO_READ64), or extend the structure (e.g., _IO_NOTIFY64)
- Maintain field offsets for as many fields as possible to ease handling; add new fields to the end, and rename existing fields rather than deleting them.

Chapter 10
Heap Analysis

If you develop a program that dynamically allocates memory, you're also responsible for tracking any memory that you allocate whenever a task is performed, and for releasing that memory when you no longer need it. If you fail to track the memory correctly, you may introduce “memory leaks” or unintentionally write to an area outside of the memory space.

Conventional debugging techniques usually prove to be ineffective for locating the source of corruption or leaks because memory-related errors typically manifest themselves in an unrelated part of the program. Tracking down an error in a multithreaded environment becomes even more complicated because the threads all share the same memory address space.

In this chapter, we'll describe how QNX Neutrino manages the heap and introduce you to some techniques that can help you to diagnose your memory management problems.

Memory management in QNX Neutrino

Before we look at the heap, let's consider memory management in general.

By design, the QNX Neutrino architecture helps ensure that faults, including memory errors, are confined to the program that caused them. Programs are less likely to cause a cascade of faults because processes are isolated from each other and from the microkernel. Even device drivers behave like regular debuggable processes:

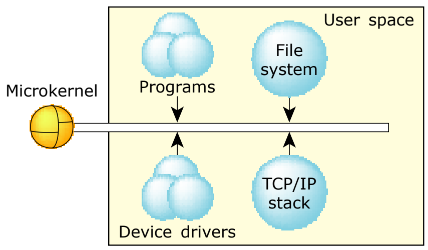


Figure 23: The microkernel architecture.

This robust architecture ensures that crashing one program has little or no effect on other programs throughout the system. If a program faults, you can be sure that the error is restricted to that process's operation.

The full memory protection means that almost all the memory addresses your program encounters are *virtual addresses*. The process manager maps your program's virtual memory addresses to the actual physical memory; memory that is contiguous in your program may be transparently split up in your system's physical memory:

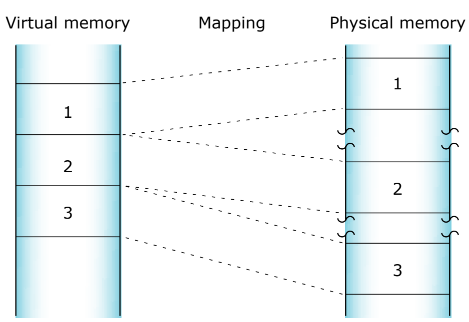


Figure 24: How the process manager allocates memory into pages.

The process manager allocates memory in small pages (typically 4 KB each). To determine the size for your system, use the *sysconf()* function.

Your program's virtual address space includes the following categories:

- program
- stack
- shared library
- object
- heap

In general terms, the memory is laid out as follows:

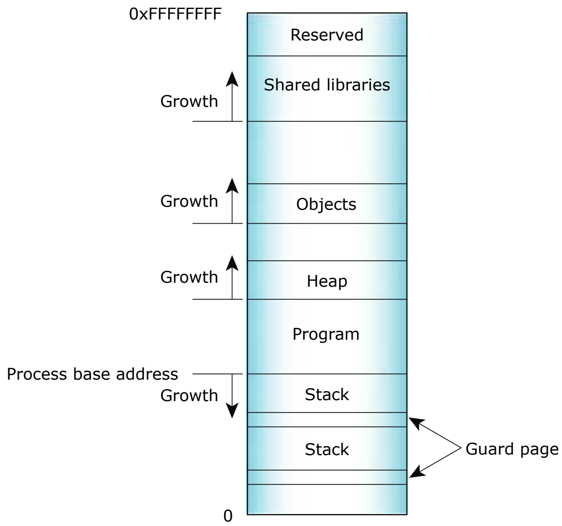


Figure 25: Process memory layout on an x86.

In reality, it's a little more complex. The various types of allocations, stacks, heap, shared objects, etc. have separate places where the memory manager starts looking for free virtual address space. The relative positions of the starting point for the search are as indicated in the diagram. Given those starting points, the memory manager starts looking up (if MAP_BELOW isn't set) or down (if MAP_BELOW is set) in the virtual address space of the process, looking for a free region that's big enough. This tends to make allocations group as the diagram shows, but a shared memory allocation, for example, can be located anywhere in the process address space.

QNX Neutrino 6.5 or later supports *address space layout randomization* (ASLR), which randomizes the stack start address and code locations in executables and libraries, and heap cookies. With ASLR, the memory manager starts at the appropriate virtual address for the allocation type and searches up or down as appropriate. Once it's found an open spot, it randomly adjusts the address up or down from what it would have used without ASLR.

Use the `-mr` option for `procnto` to use ASLR, or `-m~r` to not use it (the default). A child process normally inherits its parent's ASLR setting, but in QNX Neutrino 6.6 or later, you can change it by using the POSIX_SPAWN_ASLR_INVERT extended flag for *posix_spawn()* or the SPAWN_ASLR_INVERT flag for *spawn()* to toggle the setting of ASLR when you create a process from a program.

To determine whether or not your process is using ASLR, use the DCMD_PROC_INFO *devctl()* command and test for the _NTO_PF_ASLR bit in the *flags* member of the `procfs_info` structure.

Program memory

Program memory holds the executable contents of your program. The code section contains the read-only execution instructions (i.e., your actual compiled code); the data section contains all the values of the global and static variables used during your program's lifetime:

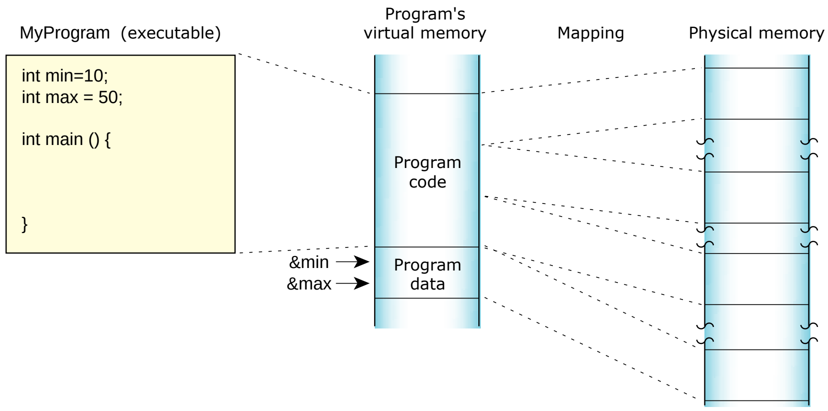


Figure 26: The program memory.

Stack memory

Stack memory holds the local variables and parameters your program's functions use. Each process in QNX Neutrino contains at least the main thread; each of the process's threads has an associated stack. When the program creates a new thread, the program can either allocate the stack and pass it into the thread-creation call, or let the system allocate a default stack size and address.

> If you allocate the stack yourself, it's up to you to manage the memory; the rest of this discussion assumes the system allocates the stack.

If the system allocates the stack, the memory is laid out like this:

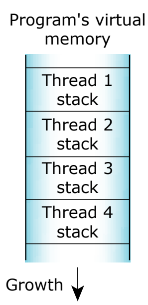


Figure 27: The stack memory.

When the process manager creates a thread, it reserves the full stack in virtual memory, but not in physical memory. Instead, the process manager requests additional blocks of physical memory only when your program actually needs more stack memory. As one function calls another, the state of the calling function is pushed onto the stack. When the function returns, the local variables and parameters are popped off the stack.

The used portion of the stack holds your thread's state information and takes up physical memory. The unused portion of the stack is initially allocated in virtual address space, but not physical memory:

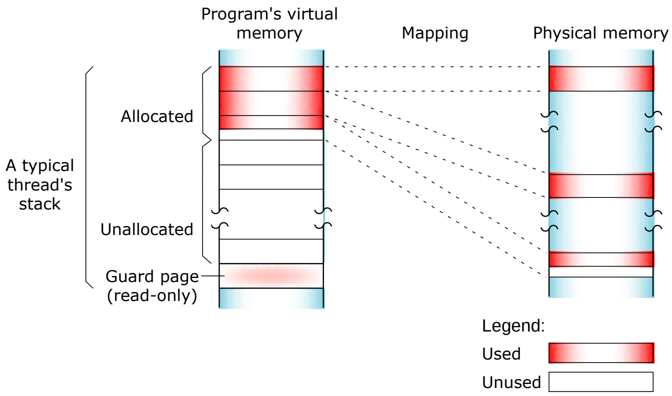


Figure 28: Stack memory: virtual and physical.

At the end of each virtual stack is a *guard page* that the microkernel uses to detect stack overflows. If your program writes to an address within the guard page, the microkernel detects the error and sends the process a SIGSEGV signal. There's no physical memory associated with the guard page.

As with other types of memory, the stack memory appears to be contiguous in virtual process memory, but isn't necessarily so in physical memory.

Shared-library memory

Shared-library memory stores the libraries you require for your process. Like program memory, library memory consists of both code and data sections. In the case of shared libraries, all the processes map to the same physical location for the code section and to unique locations for the data section:

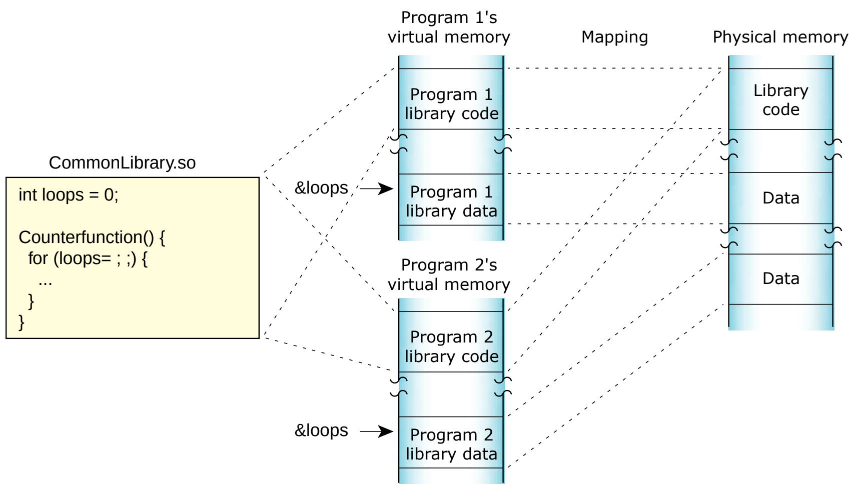


Figure 29: The shared library memory.

Object memory

Object memory represents the areas that map into a program's virtual memory space, but this memory may be associated with a physical device. For example, the graphics driver may map the video card's memory to an area of the program's address space:

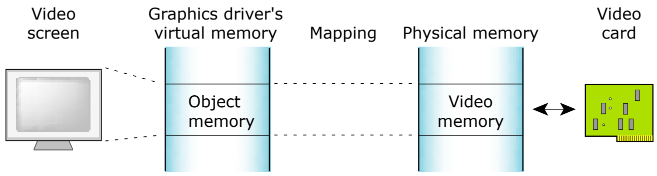


Figure 30: The object memory.

Heap memory

Heap memory represents the dynamic memory used by programs at runtime. Typically, processes allocate this memory using the *malloc()*, *realloc()*, and *free()* functions. These calls ultimately rely on the *mmap()* function to reserve memory that the library distributes.

The process manager usually allocates memory in 4 KB blocks, but allocations are typically much smaller. Since it would be wasteful to use 4 KB of physical memory when your program wants only 17 bytes, the library manages the heap. The library dispenses the paged memory in smaller chunks and keeps track of the allocated and unused portions of the page:

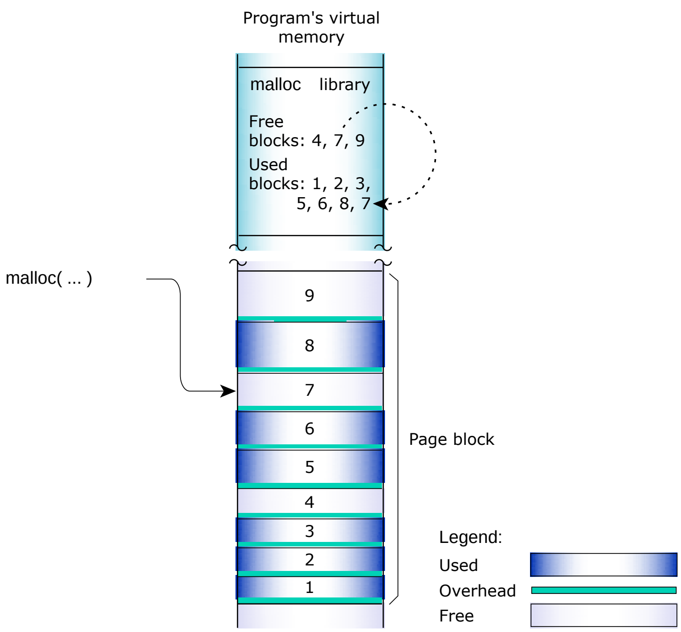


Figure 31: The allocator manages the blocks of memory.

Each allocation uses a small amount of fixed overhead to store internal data structures. Since there's a fixed overhead with respect to block size, the ratio of allocator overhead to data payload is larger for smaller allocation requests.

When your program uses *malloc()* to request a block of memory, the library returns the address of an appropriately sized block. For efficiency, the library includes two allocators:

- a small-block allocator that maintains pools of blocks in various sizes
- a large-block allocator that handles requests for blocks that are larger than the small-block allocator can provide

For example, the library may return a 20-byte block to fulfill a request for 17 bytes, a 1088-byte block for a 1088-byte request, and so on.

When the library receives an allocation request that it can't meet with its existing heap, it requests additional physical memory from the process manager. These allocations are done in chunks called *arenas*. By default, the arena allocations are performed in 32 KB chunks. The arena size must be a multiple of 4 KB and must currently be less than 256 KB. If your program requests a block that's larger than an arena, the allocator gets a block whose size is a multiple of the arena size from the process manager, gives your program a block of the requested size, and puts any remaining memory on a free list.

When memory is freed, the library merges adjacent free blocks within arenas and may, when appropriate, release an arena back to the system.

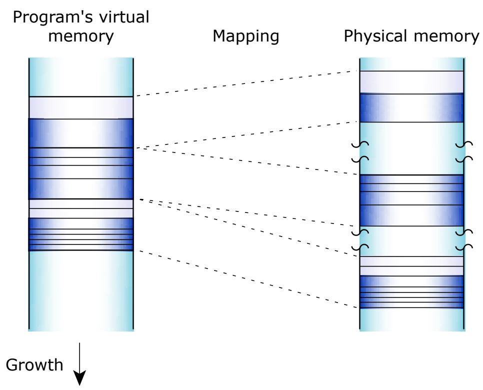


Figure 32: A process's heap memory.

Dynamic memory management

Let's examine how the heap is used for dynamically allocated memory.

You request memory buffers or blocks of a particular size from the runtime environment by using *malloc()*, *realloc()*, or *calloc()*, and you release them back to the runtime environment when you no longer need them by using *free()*. The C++ `new` and `delete` operators are built on top of *malloc()* and *free()*, so this discussion applies to them as well.

The *memory allocator* ensures that your requests are satisfied by managing a region of the program's memory area known as the *heap*. In this heap, the allocator tracks all of the information—such as the size of the original block—about the blocks and heap buffers that it's allocated to your program, in order that it can make the memory available to you during subsequent allocation requests. When a block is released, the allocator places it on a list of available blocks called a *free list*. It usually keeps the information about a block in the header that precedes the block itself in memory.

The runtime environment grows the size of the heap when it no longer has enough memory available to satisfy allocation requests, and it may return memory from the heap to the OS when the program releases memory.

The basic heap allocation mechanism is broken up into two separate pieces, a chunk-based small block allocator and a list-based large block allocator. By configuring specific parameters, you can select the sizes for the chunks in the small block allocator and also the boundary between the small and large allocators.

Arena allocations

Both the small and large block allocators allocate and deallocate memory from the OS in the form of chunks known as *arenas*, by calling *mmap()* and *munmap()*. By default, the arena size is 32 KB. It must be a multiple of 4 KB and must currently be less than 256 KB. If your program requests a block that's larger than an arena, the allocator gets a block whose size is a multiple of the arena size from the process manager, gives your program a block of the requested size, and puts any remaining memory on a free list.

You can configure this parameter by doing one of the following:

- setting the *_amblksiz* global variable (e.g., `_amblksiz = 16384;`)
- calling *mallopt()* with MALLOC_ARENA_SIZE as the command (e.g., `mallopt(MALLOC_ARENA_SIZE, 16384);`)
- setting the *MALLOC_ARENA_SIZE* environment variable (e.g., `export MALLOC_ARENA_SIZE=16384`)

The *MALLOC_** environment variables are checked only at program startup, but changing them is the easiest way to configure the allocator so that these parameters are used for allocations that occur before *main()*.

The allocator also attempts to cache recently freed blocks. In QNX Neutrino 6.6 or later, this cache is used only for blocks that are the current arena size or smaller. You can configure the arena cache by setting the following environment variables:

MALLOC_ARENA_CACHE_MAXBLK

The number of cached blocks.

MALLOC_ARENA_CACHE_MAXSZ

The total size of the cached blocks, in bytes.

Alternatively, you can call:

```
mallopt(MALLOC_ARENA_CACHE_MAXSZ, size);
mallopt(MALLOC_ARENA_CACHE_MAXBLK, number);
```

There's a difference between setting these environment variables and using the corresponding *mallopt()* commands:

- If you don't want the allocator to cache any memory at all, call *mallopt()* with a command of MALLOC_ARENA_CACHE_MAXBLK and a value of 0.
- If you set the *MALLOC_ARENA_CACHE_MAXSZ* or *MALLOC_ARENA_CACHE_MAXBLK* environment variable to 0, the allocator ignores the setting.

To tell the allocator to never release memory back to the OS, you can set the *MALLOC_MEMORY_HOLD* environment variable to 1:

```
export MALLOC_MEMORY_HOLD=1
```

or call:

```
mallopt(MALLOC_MEMORY_HOLD, 1);
```

Once you've used *mallopt()* to change the values of MALLOC_ARENA_CACHE_MAXSZ and MALLOC_ARENA_CACHE_MAXBLK, you can call *mallopt()* again with a command of MALLOC_ARENA_CACHE_FREE_NOW to immediately adjust the arena cache. The behavior depends on the *value* argument:

1

The arena cache is adjusted immediately, and all cached memory that can be freed to the OS is released. Exactly what can be freed depends on how the allocations up to that point have been laid out in memory.

0

The arena cache is adjusted immediately to correspond to the current settings. Enough cache blocks are freed to match the adjusted MALLOC_ARENA_CACHE_MAXBLK value.

If you don't use the MALLOC_ARENA_CACHE_FREE_NOW command, the changes made to the cache parameters take effect whenever memory is subsequently released to the cache.

You can preallocate and populate the arena cache by setting the *MALLOC_MEMORY_PREALLOCATE* environment variable to a value that specifies the size of the total arena cache. The cache is populated by multiple arena allocation calls in chunks whose size is specified by the value of *MALLOC_ARENA_SIZE*.

The preallocation option doesn't alter the *MALLOC_ARENA_CACHE_MAXBLK* and *MALLOC_ARENA_CACHE_MAXSZ* options. So if you preallocate 10 MB of memory in cache blocks, and you want to ensure that this memory stays in the application throughout the lifetime of the application, you should also set the values of *MALLOC_ARENA_CACHE_MAXBLK* and *MALLOC_ARENA_CACHE_MAXSZ* to something appropriate.

Large block allocator

The large block allocator uses a free list to keep track of any available blocks. To minimize fragmentation, the allocator uses a first-fit algorithm to determine which block to use to service a request. If the allocator doesn't have a block that's large enough, it uses *mmap()* to get memory from the OS in multiples of the arena size, and then carves out the appropriate user pieces from this, putting the remaining memory onto the free list.

If all the memory that makes up an arena is eventually freed, the arena is returned to the OS. In QNX Neutrino 6.6 or later, when you free a block of memory that's larger than the arena size, the allocator uses *munmap()* to immediately return the block to the OS (unless you've set MALLOC_MEMORY_HOLD to 1 to prevent the allocator from releasing freed memory back to the OS). Freed blocks that are the arena size or smaller are cached according to the cache settings.

Small block allocator

The small block allocator manages a pool of memory blocks of different sizes. These blocks are arranged into linked lists called *bands*; each band contains blocks that are the same size. When your program allocates a small amount of memory, the small block allocator returns a block from the band that best fits your request. Allocations larger than the largest band size are serviced by the large allocator. If there are no more blocks available in the band, the allocator uses *mmap()* to get an arena from the OS and then divides it into blocks of the required size.

The allocator initially adjusts all band sizes to be multiples of _MALLOC_ALIGN (which is 8). The allocator normalizes the size of each pool so that each band has as many blocks as can be carved from a 4 KB piece of memory, taking into account alignment restrictions and overhead needed by the allocator to manage the blocks. The default band sizes and pool sizes are as follows:

Band size	Number of blocks
_MALLOC_ALIGN × 2 = 16	167
_MALLOC_ALIGN × 3 = 24	125
_MALLOC_ALIGN × 4 = 32	100
_MALLOC_ALIGN × 6 = 48	71
_MALLOC_ALIGN × 8 = 64	55
_MALLOC_ALIGN × 10 = 80	45
_MALLOC_ALIGN × 12 = 96	38
_MALLOC_ALIGN × 16 = 128	28

> You might also see references to *bins*, which are allocation ranges that you want to collect statistics for. For example, you can check how many allocations are done for 40, 80, and 120 byte bins. The default bins are 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, and ULONG_MAX (the last bin catches all allocations larger than 4096 bytes). The bins are completely independent of the bands.

When used in conjunction with the *MALLOC_MEMORY_PREALLOCATE* option for the arena cache, the preallocation of blocks in bands is performed by initially populating the arena cache, and then allocating bands from this arena cache.

You can configure the bands by setting the *MALLOC_BAND_CONFIG_STR* environment variable to a string in this format:

```
N:s1,n1,p1:s2,n2,p2:s3,n3,p3: ... :sN,nN,pN
```

where the components are:

N

The number of bands.

s

The band size.

n

The number of blocks in the band.

p

The number of blocks to preallocate, which can be zero.

The parsing is simple and strict:

- The sizes must all be distinct and be provided in ascending order (i.e., *s1* < *s2* < *s3*, and so on).
- You must specify *s*, *n*, and *p* for each band.
- The string can't include any spaces; the only valid characters are digits, colons (`:`), and commas (`,`).

If the allocator doesn't like the string, it ignores it completely.

For example, setting *MALLOC_BAND_CONFIG_STR* to:

```
8:2,32,60:15,32,60:29,32,60:55,24,60:100,24,60:130,24,60:260,8,60:600,4,60
```

specifies these bands, with 60 blocks preallocated for each band:

Band size	Number of blocks
2	32
15	32
29	32

Band size	Number of blocks
55	24
100	24
130	24
260	8
600	4

The allocator normalizes this configuration to:

Band size	Number of blocks
8	251
16	167
32	100
56	62
104	35
136	27
264	13
600	5

For the above configuration, allocations larger than 600 bytes are serviced by the large block allocator.

Heap corruption

Heap corruption occurs when a program damages the allocator's view of the heap.

The outcome can be relatively benign and cause a memory leak (where some memory isn't returned to the heap and is inaccessible to the program afterward), or it may be fatal and cause a memory fault, usually within the allocator itself. A memory fault typically occurs within the allocator when it manipulates one or more of its free lists after the heap has been corrupted.

It's especially difficult to identify the source of corruption when the source of the fault is located in another part of the code base. This is likely to happen if the fault occurs when:

- a program attempts to free memory
- a program attempts to allocate memory after it's been freed
- the heap is corrupted long before the release of a block of memory
- the fault occurs on a subsequent block of memory
- adjacent memory blocks are used
- your program is multithreaded
- the memory allocation strategy changes

Adjacent memory blocks

When adjacent blocks are used, a program that writes outside of the bounds can corrupt the allocator's information about the block of memory it's using, as well as the allocator's view of the heap. The view may include a block of memory that's before or after the block being used, and it may or may not be allocated. In this case, a fault in the allocator will likely occur during an unrelated attempt to allocate or release memory.

Multithreaded programs

Multithreaded execution may cause a fault to occur in a different thread from the thread that actually corrupted the heap, because threads interleave requests to allocate or release memory.

When the source of corruption is located in another part of the code base, conventional debugging techniques usually prove to be ineffective. Conventional debugging typically applies breakpoints—such as stopping the program from executing—to narrow down the offending section of code. While this may be effective for single-threaded programs, it's often unyielding for multithreaded execution because the fault may occur at an unpredictable time, and the act of debugging the program may influence the appearance of the fault by altering the way that thread execution occurs.

Even when the source of the error has been narrowed down, there may be a substantial amount of manipulation performed on the block before it's released, particularly for long-lived heap buffers.

Allocation strategy

A program that works in a particular memory allocation strategy may abort when the allocation strategy is changed in a minor way. A good example of this is a memory overrun condition (see "Common sources," below) where the allocator is permitted to return blocks that are larger than requested in order to satisfy allocation requests. Under this circumstance, the program may behave normally in the presence of overrun conditions. But a simple change, such as changing the size of the block requested, may result in the allocation of a block of the exact size requested, resulting in a fatal error for the offending program.

Fatal errors may also occur if the allocator is configured slightly differently, or if the allocator policy is changed in a subsequent release of the runtime library. This makes it all the more important to detect errors early in the life cycle of an application, even if it doesn't exhibit fatal errors in the testing phase.

Common sources

Some of the most common sources of heap corruption include:

- a memory assignment that corrupts the header of an allocated block
- an incorrect argument that's passed to a memory allocation function
- an allocator that made certain assumptions in order to avoid keeping additional memory to validate information, or to avoid costly runtime checking
- invalid information that's passed in a request, such as to *free()*
- overrun and underrun errors
- releasing memory
- using uninitialized or stale pointers

Even the most robust allocator can occasionally fall prey to the above problems. Let's take a look at the last three items in more detail.

Overrun and underrun errors

Overrun and underrun errors occur when your program writes outside of the bounds of the allocated block. They're one of the most difficult type of heap corruption to track down, and usually the most fatal to program execution.

Overrun errors occur when the program writes *past* the end of the allocated block. Frequently this causes corruption in an adjacent block in the heap, whether or not it's allocated. When this occurs, the behavior that's observed varies depending on whether that block is allocated or free, and whether it's associated with a part of the program related to the source of the error. When a neighboring block that's allocated becomes corrupted, the corruption is usually apparent when that block is released elsewhere in the program. When an unallocated block becomes corrupted, a fatal error will usually result during a subsequent allocation request. Although this may well be the next allocation request, it actually depends on a complex set of conditions that could result in a fault at a much later point in time, in a completely unrelated section of the program, especially when small blocks of memory are involved.

Underrun errors occur when the program writes *before* the start of the allocated block. Often they corrupt the header of the block itself, and sometimes, the preceding block in memory. Underrun errors usually result in a fault that occurs when the program attempts to release a corrupted block.

Releasing memory

In order to release memory, your program must track the pointer for the allocated block and pass it to the *free()* function. If the pointer is stale, or if it doesn't point to the exact start of the allocated block, it may result in heap corruption.

A pointer is *stale* when it refers to a block of memory that's already been released. A duplicate request to *free()* involves passing *free()* a stale pointer—there's no way to know whether this pointer refers to unallocated memory, or to memory that's been used to satisfy an allocation request in another part of the program.

Passing a stale pointer to *free()* may result in a fault in the allocator, or worse, it may release a block that's been used to satisfy another allocation request. If this happens, the code making the allocation request may compete with another section of code that subsequently allocated the same region of heap, resulting in corrupted data for one or both.

The most effective way to avoid this error is to NULL out pointers when the block is released, but this is uncommon, and difficult to do when pointers are aliased in any way.

A second common source of errors is to attempt to release an interior pointer (i.e., one that's somewhere inside the allocated block rather than at the beginning). This isn't a legal operation, but it may occur when the pointer has been used in conjunction with pointer arithmetic. The result of providing an interior pointer is highly dependent on the allocator and is largely unpredictable, but it frequently results in a fault in the *free()* call.

A rarer source of errors is to pass an uninitialized pointer to *free()*. If the uninitialized pointer is an automatic (stack) variable, it may point to a heap buffer, causing the types of coherency problems described for duplicate *free()* requests above. If the pointer contains some other non-NULL value, it may cause a fault in the allocator.

Using uninitialized or stale pointers

If you use uninitialized or stale pointers, you might corrupt the data in a heap buffer that's allocated to another part of the program, or see memory overrun or underrun errors.

Detecting and reporting errors

The primary goal for detecting heap corruption problems is to correctly identify the source of the error, to avoid getting a fault in the allocator at some later point in time.

A first step to achieving this goal is to create an allocator that's able to determine whether the heap was corrupted on every entry into the allocator, whether it's for an allocation request or for a release request. For example, on a release request, the allocator should be capable of determining whether:

- the pointer given to it is valid
- the associated block's header is corrupt
- either of the neighboring blocks is corrupt

To achieve this goal, we use a replacement library for the allocator that can keep additional block information in the header of every heap buffer. You can use the **librcheck.so** library while testing the application to help isolate any heap corruption problems.

When this allocator detects a source of heap corruption, it can print an error message indicating:

- the point at which the error was detected
- the program location that made the request
- information about the heap buffer that contained the problem

The library technique can be refined to also detect some of the sources of errors that may still elude detection, such as memory overrun or underrun errors, that occur before the corruption is detected by the allocator. This may be done when the standard libraries are the vehicle for the heap corruption, such as an errant call to *memcpy()*, for example. In this case, the standard memory manipulation functions and string functions can be replaced with versions that use the information in the **librcheck** library to determine if their arguments reside in the heap, and whether they would cause the bounds of the heap buffer to be exceeded. Under these conditions, the function can then call the error-reporting functions to provide information about the source of the error.

Using the `librcheck` library

The **librcheck** library provides the capabilities for detecting and reporting errors. It's available when you link your program with the `-lrcheck` option.

Another way to use the **librcheck** library is to use the *LD_PRELOAD* capability to the dynamic loader. The *LD_PRELOAD* environment variable lets you specify libraries to load before any other library in the system. In this case, set the *LD_PRELOAD* variable as follows:

```
LD_PRELOAD=librcheck.so
```

For example:

```
LD_PRELOAD=librcheck.so ./my_program
```

By default, the **librcheck** library provides a minimal level of checking. When an allocation or release request is performed, the library checks only the immediate block under consideration and its neighbors, looking for sources of heap corruption.

Additional checking and more informative error reporting can be done by using additional options provided by the **librcheck** library. The *mallopt()* function provides control over the types of checking performed by the library. In addition to reporting the file and line information about the caller when an error is detected, the error-reporting mechanism prints out the file and line information that was associated with the allocation of the offending heap buffer.

To control the use of the **librcheck** library, you need to include a different header file, **<rcheck/malloc.h>**. If you want to use any of the additional *mallopt()* commands that this header file declares, make sure that you link your application with **librcheck**; the **libc** version of *mallopt()* gives an error of EINVAL for these additional commands.

In addition, you may want to add an exit handler that provides a dump of leaked memory, and initialization code that turns on a reasonable level of checking for the debug variant of the program.

The **librcheck** library keeps additional information in the header of each heap buffer, including doubly-linked lists of all allocated blocks, file, line, and other debug information, flags, and a CRC of the header. The allocation policies and configuration are identical to the normal memory allocation routines except for the additional internal overhead imposed by the **librcheck** library. This allows the **librcheck** library to perform checks without altering the size of blocks requested by the program. Such manipulation could result in an alteration of the behavior of the program with respect to the allocator, yielding different results when linked against the **librcheck** library.

All allocated blocks are integrated into a number of allocation chains associated with allocated regions of memory kept by the allocator in arenas or blocks. The **librcheck** library has intimate knowledge about the internal structures of the allocator, allowing it to use short cuts to find the correct heap buffer associated with any pointer, resorting to a lookup on the appropriate allocation chain only when necessary. This minimizes the performance penalty associated with validating pointers, but it's still significant.

The time and space overheads imposed by the **librcheck** library are too great to make it suitable for use as a production library, but are manageable enough to allow them to be used during the test phase of development and during program maintenance.

What's checked?

The **librcheck** library provides a minimal level of checking by default. This includes a check of the integrity of the allocation chain at the point of the local heap buffer on every allocation request. In addition, the flags and CRC of the header are checked for integrity. When the library can locate the neighboring heap buffers, it also checks their integrity. There are also checks specific to each type of allocation request that are done. Call-specific checks are described according to the type of call below.

You can enable additional checks by using the *mallopt()* call. For more information on the types of checking, and the sources of heap corruption that can be detected, see "*Controlling the level of checking*."

Allocating memory

When a heap buffer is allocated using any of the heap-allocation routines, the heap buffer is added to the allocation chain for the arena or block within the heap that the heap buffer was allocated from. At this time, any problems detected in the allocation chain for the arena or block are reported. After successfully inserting the allocated buffer in the allocation chain, the previous and next buffers in the chain are also checked for consistency.

Reallocating memory

When an attempt is made to resize a buffer through a call to the *realloc()* function, the pointer is checked for validity if it's a non-NULL value. If it's valid, the header of the heap buffer is checked for consistency. If the buffer is large enough to satisfy the request, the buffer header is modified, and the call returns. If a new buffer is required to satisfy the request, memory allocation is performed to obtain a new buffer large enough to satisfy the request with the same consistency checks being applied as in the case of memory allocation described above. The original buffer is then released.

If fill-area boundary checking is enabled (described in the "*Controlling the level of checking*" section), the guard code checks are also performed on the allocated buffer before it's actually resized. If a new buffer is used, the guard code checks are done just before releasing the old buffer.

Releasing memory

This includes, but isn't limited to, checking to ensure that the pointer provided to a *free()* request is correct and points to an allocated heap buffer. Guard code checks may also be performed on release operations to allow fill-area boundary checking.

Controlling the level of checking

You can use environment variables or the *mallopt()* function to enable extra checks within the **librcheck** library.

If you decide to use *mallopt()*, you have to modify your application to enable the additional checks. Using environment variables lets you specify options that go into effect from the time the program runs. If your program does a lot of allocations before *main()*, setting options using *mallopt()* may be too late. In such cases, it's better to use environment variables.

The prototype of *mallopt()* is:

```
int mallopt ( int cmd,
              intptr_t value );
```

The arguments are:

cmd

The command you want to use. The options used to enable additional checks in the library are:

- MALLOC_CKACCESS
- MALLOC_CKBOUNDS
- MALLOC_CKCHAIN

We'll look at some of the other commands later in this chapter.

value

A value corresponding to the command used. For these particular commands, the *value* argument can be:

- 0 to disable the checking (the default for these commands)
- 1 to enable it

For information about all the commands, see the entry for *mallopt()* in the QNX Neutrino *C Library Reference*. Let's look at the commands that control the additional checks:

MALLOC_CKACCESS

Turn on (or off) boundary checking for memory and string operations.

Environment variable: *MALLOC_CKACCESS*

This helps to detect buffer overruns and underruns that are a result of memory or string operations. When on, each pointer operand to a memory or string operation is checked to see if it's a heap buffer. If it is, the size of the heap buffer is checked, and the information is used to ensure that no assignments are made beyond the bounds of the heap buffer. If an attempt is made that would assign past the buffer boundary, a diagnostic warning message is printed.

Here's how you can use this option to find an overrun error:

```
...
char *p;
int opt;
opt = 1;
mallopt(MALLOC_CKACCESS, opt);
p = malloc(strlen("hello"));
strcpy(p, "hello, there!");  /* a warning is generated here */
...
```

The following illustrates how access checking can trap a reference through a stale pointer:

```
...

char *p;
int opt;
opt = 1;
mallopt(MALLOC_CKACCESS, opt);
p = malloc(30);
free(p);
strcpy(p, "hello, there!");
```

MALLOC_CKBOUNDS

Turn on (or off) fill-area boundary checking that validates that the program hasn't overrun the user-requested size of a heap buffer.

Environment variable: *MALLOC_CKBOUNDS*

It does this by applying a guard code check when the buffer is released or when it's resized. The guard code check works by filling any excess space available at the end of the heap buffer with a pattern of bytes. When the buffer is released or resized, the trailing portion is checked to see if the pattern is still present. If not, a diagnostic warning message is printed.

The effect of turning on fill-area boundary checking is a little different than enabling other checks: the checking is performed only on memory buffers allocated after the check was enabled, and not on memory buffers allocated earlier.

Here's how you can catch an overrun with the fill-area boundary checking option:

```
...
...
int *foo, *p, i, opt;
opt = 1;
mallopt(MALLOC_CKBOUNDS, opt);
foo = (int *)malloc(10*4);
for (p = foo, i = 12; i > 0; p++, i--)
    *p = 89;
free(foo);  /* a warning is generated here */
```

MALLOC_CKCHAIN

Enable (or disable) full chain checking. This option is expensive and should be considered as a last resort when some code is badly corrupting the heap and otherwise escapes the detection of boundary checking or fill-area boundary checking.

Environment variable: *MALLOC_CKCHAIN*

This kind of corruption can occur under a number of circumstances, particularly when they're related to direct pointer assignments. In this case, the fault may occur before a check such as fill-area boundary checking can be applied. There are also circumstances in which both fill-area boundary checking and the normal attempts to check the headers of neighboring buffer fail to detect the source of the problem. This may happen if the buffer that's overrun is the first or last buffer associated with a block or arena. It may also happen when the allocator chooses to satisfy some requests, particularly those for large buffers, with a buffer that exactly fits the program's requested size.

Full-chain checking traverses the entire set of allocation chains for all arenas and blocks in the heap every time a memory operation (including allocation requests) is performed. This lets the developer narrow down the search for a source of corruption to the nearest memory operation.

Forcing verification

You can force a full allocation chain check at certain points while your program is executing, without turning on chain checking.

Specify the following option for the *cmd* argument to the **librcheck** version of *mallopt()*:

MALLOC_VERIFY

Perform a chain check immediately. If an error is found, perform error handling. The *value* argument is ignored.

Specifying an error handler

Typically, when the library detects an error, it displays a diagnostic message, and the program continues executing. In cases where the allocation chains or another crucial part of the allocator's view is hopelessly corrupted, an error message is printed and the program is aborted (via *abort()*).

You can override this default behavior by using the **librcheck** version of *mallopt()* to specify what to do when a warning or a fatal condition is detected:

cmd

The error handler to set; one of:

MALLOC_FATAL

Specify how to handle fatal errors.

MALLOC_WARN

Specify how to handle warnings.

Environment variable: *MALLOC_ACTION*, which sets the handling for fatal errors and warnings to the same value.

value

An integer value that indicates how you want to handle the error:

Symbolic name	Value	Action
M_HANDLE_IGNORE	0	Ignore the error and continue
M_HANDLE_ABORT	1	Terminate execution with a call to *abort()*
M_HANDLE_EXIT	2	Exit immediately
M_HANDLE_CORE	3	Cause the program to dump a core file
M_HANDLE_STOP	4	Send a stop signal (SIGSTOP) to the current thread. This lets you attach to this process using a debugger. The program is stopped inside the error-handler function, and a backtrace from there should show you the exact location of the error.

If you call *mallopt()*, you can OR any of these handlers with M_HANDLE_DUMP, to cause a complete dump of the heap before the handler takes action.

If you use the environment variable, you must set it to one of the numeric values, not the corresponding M_HANDLE_* symbolic name.

Here's how you can cause a memory overrun error to abort your program:

```
...
int *foo, *p, i;
int opt;
```

```
opt = 1;
mallopt(MALLOC_CKBOUNDS,  opt);
foo = (int *)malloc(10*4);
for (p = foo, i = 12; i > 0; p++, i--)
    *p = 89;

opt = M_HANDLE_ABORT;
mallopt(MALLOC_WARN, opt);
free(foo); /* a fatal error is generated here */
```

Caveats

- The **librcheck** library, when enabled with various checking, uses more stack space (i.e., calls more functions, uses more local variables etc.) than the regular **libc** allocator.

  This implies that programs that explicitly set the stack size to something smaller than the default may encounter problems such as running out of stack space. This may cause the program to crash. You can prevent this by increasing the stack space allocated to the threads in question.
- *MALLOC_CKCHAIN* performs extensive heap checking on every allocation. When you enable this environment variable, allocations can be much slower. Also since full heap checking is performed on every allocation, an error anywhere in the heap could be reported upon entry into the allocator for any operation. For example, a call to **free(x)** will check block *x* as well as the complete heap for errors before completing the operation (to free block *x*). So any error in the heap will be reported in the context of freeing block *x*, even if the error itself isn't specifically related to this operation.
- When the **librcheck** library reports errors, it doesn't always exit immediately; instead it continues to perform the operation that causes the error, and corrupts the heap (since the operation that raises the warning is actually an illegal operation). You can control this behavior by using the MALLOC_WARN and MALLOC_FATAL handlers described earlier. If you don't provide specific handlers, the heap will be corrupted, and other errors could result and be reported later because of the first error. The best solution is to focus on the first error and fix it before moving onto other errors. See the description of *MALLOC_CKCHAIN* for more information on how these errors may end up getting reported.
- Although the **librcheck** library allocates blocks to the process using the same algorithms as the standard allocator, the library itself requires additional storage to maintain block information, as well as to perform sanity checks. This means that the layout of blocks in memory using the debug allocator is slightly different than with the standard allocator.
- If you use certain optimization options such as `-O1`, `-O2`, or `-O3`, the **librcheck** library won't work correctly because these options make `gcc` use builtin versions of some functions, such as *strcpy()* and *strcmp()*. Use the `-fno-builtin` option to prevent this.

Manual checking (bounds checking)

There are times when it may be desirable to obtain information about a particular heap buffer or print a diagnostic or warning message related to that heap buffer.

This is particularly true when the program has its own routines providing memory manipulation and you wish to provide bounds checking. This can also be useful for adding additional bounds checking to a program to isolate a problem such as a buffer overrun or underrun that isn't associated with a call to a memory or string function.

In the latter case, rather than keeping a pointer and performing direct manipulations on the pointer, you can define a pointer type that contains all relevant information about the pointer, including the current value, the base pointer, and the extent of the buffer. You could then control access to the pointer through macros or access functions. The access functions can perform the necessary bounds checks and print a warning message in response to attempts to exceed the bounds.

Memory leaks

The ability of the **librcheck** library to keep full allocation chains of all the heap memory allocated by the program—as opposed to just accounting for some heap buffers—allows heap memory leaks to be detected by the library in response to requests by the program. Leaks can be detected in the program by performing *tracing* on the entire heap.

Tracing is an operation that attempts to determine whether a heap object is reachable by the program. In order to be reachable, a heap buffer must be available either directly or indirectly from a pointer in a global variable or on the stack of one of the threads. If this isn't the case, then the heap buffer is no longer visible to the program and can't be accessed without constructing a pointer that refers to the heap buffer—presumably by obtaining it from a persistent store such as a file or a shared memory object.

The set of global variables and stack for all threads is called the *root set*. Because the root set must be stable for tracing to yield valid results, tracing requires that all threads other than the one performing the trace be suspended while the trace is performed.

Tracing operates by constructing a reachability graph of the entire heap. It begins with a *root set scan* that determines the root set comprising the initial state of the reachability graph. The roots that can be found by tracing are:

- data of the program
- uninitialized data of the program
- initialized and uninitialized data of any shared objects dynamically linked into the program
- used portion of the stacks of all active threads in the program

Once the root set scan is complete, tracing initiates a *mark* operation for each element of the root set. The mark operation looks at a node of the reachability graph, scanning the memory space represented by the node, looking for pointers into the heap. Since the program may not actually have a pointer directly to the start of the buffer—but to some interior location—and it isn't possible to know which part of the root set or a heap object actually contains a pointer, tracing uses specialized techniques for coping with *ambiguous roots.* The approach taken is described as a conservative pointer estimation since it assumes that any word-sized object on a word-aligned memory cell that *could* point to a heap buffer or the interior of that heap buffer actually points to the heap buffer itself.

Using conservative pointer estimation for dealing with ambiguous roots, the mark operation finds all children of a node of the reachability graph. For each child in the heap that's found, it checks to see whether the heap buffer has been marked as *referenced*. If the buffer has been marked, the operation moves on to the next child. Otherwise, the trace marks the buffer, and then recursively initiates a mark operation on that heap buffer.

The tracing operation is complete when the reachability graph has been fully traversed. At this time every heap buffer that's reachable will have been marked, as could some buffers that aren't actually reachable, due to the conservative pointer estimation. Any heap buffer that hasn't been marked is definitely unreachable, constituting a memory leak. At the end of the tracing operation, all unmarked nodes can be reported as leaks.

Starting a trace and giving results

A program can cause a trace to be performed and memory leaks to be reported by calling the **librcheck** version of *mallopt()* with a command of MALLOC_DUMP_LEAKS:

```
mallopt( MALLOC_DUMP_LEAKS, 1);
```

The second argument is ignored.

Analyzing dumps

The dump of unreferenced buffers prints out one line of information for each unreferenced buffer. The information provided for a buffer includes:

- the address of the buffer
- the function that was used to allocate it (*malloc()*, *calloc()*, *realloc()*)
- the file that contained the allocation request, if available
- the line number or return address of the call to the allocation function
- the size of the allocated buffer

File and line information is available if the call to allocate the buffer was made using one of the library's debug interfaces. Otherwise, the return address of the call is reported in place of the line number. In some circumstances, no return address information is available. This usually indicates that the call was made from a function with no frame information, such as the system libraries. In such cases, the entry can usually be ignored and probably isn't a leak.

From the way tracing is performed, we can see that some leaks may escape detection and may not be reported in the output. This happens if the root set or a reachable buffer in the heap has something that looks like a pointer to the buffer.

Likewise, you should check each reported leak against the suspected code identified by the line or call return address information. If the code in question keeps interior pointers—pointers to a location inside the buffer, rather than the start of the buffer—the trace operation will likely fail to find a reference to the buffer. In this case, the buffer may well not be a leak. In other cases, there is almost certainly a memory leak.

C++ issues

There are some additional techiniques that you can use in C++ programs.

`CheckedPtr` template

The **<rcheck/malloc.h>** header file defines a `CheckedPtr` template that you can use in place of a raw pointer in C++ programs. In order to use this template, you must link your program with **librcheck**.

This template acts as a smart pointer; its initializers obtain complete information about the heap buffer on an assignment operation and initialize the current pointer position. Any attempt to dereference the pointer causes bounds-checking to be performed and prints a diagnostic error in response an attempt to dereference a value beyond the bounds of the buffer.

You can modify this template to suit the needs of the program. The bounds-checking performed by the checked pointer is restricted to checking the actual bounds of the heap buffer, rather than the program's requested size.

Clean C

For C programs it's possible to compile individual modules that obey certain rules with the C++ compiler to get the behavior of the `CheckedPtr` template. C modules obeying these rules are written to a dialect of ANSI C referred to as *Clean C*.

The Clean C dialect is the subset of ANSI C that's compatible with the C++ language. Writing Clean C requires imposing coding conventions to the C code that restrict use to features that are acceptable to a C++ compiler. This section provides a summary of some of the more pertinent points to be considered. It is a mostly complete but by no means exhaustive list of the rules that must be applied.

To use the C++ checked pointers, the module, including all header files it includes, must be compatible with the Clean C subset. All the system header files for QNX Neutrino satisfy this requirement.

The most obvious aspect to Clean C is that it must be strict ANSI C with respect to function prototypes and declarations. The use of K&R prototypes or definitions isn't allowed in Clean C. Similarly, you can't use default types for variable and function declarations.

Another important consideration for declarations is that you must provide forward declarations when referencing an incomplete structure or union. This frequently occurs for linked data structures such as trees or lists. In this case, the forward declaration must occur before any declaration of a pointer to the object in the same or another structure or union. For example, you could declare a list node as follows:

```
struct ListNode;
struct ListNode {
   struct ListNode *next;
   void *data;
};
```

Operations on void pointers are more restrictive in C++. In particular, implicit coercions from void pointers to other types aren't allowed, including both integer types and other pointer types. You must explicitly cast void pointers to other types.

The use of `const` should be consistent with C++ usage. In particular, pointers that are declared as `const` must always be used in a compatible fashion. You can't pass `const` pointers as non-`const` arguments to functions unless you typecast the `const` away.

C++ example

Here's how you could use checked pointers in the overrun example given earlier to determine the exact source of the error:

```
typedef CheckedPtr<int> intp_t;
...
intp_t foo, p;
int i;
int opt;
opt = 1;
mallopt(MALLOC_CKBOUNDS, opt);
foo = (int *)malloc(10*4);
opt = M_HANDLE_ABORT;
mallopt(MALLOC_WARN, opt);
for (p = foo, i = 12; i > 0; p++, i--)
    *p = 89; /* a fatal error is generated here */
opt = M_HANDLE_IGNORE;
mallopt(MALLOC_WARN, opt);
free(foo);
```

Because you're using the `CheckedPtr` template, you must link this program with **librcheck**.

Appendix A
Freedom from Hardware and Platform Dependencies

Common problems

With the advent of multiplatform support, which involves non-x86 platforms as well as peripheral chipsets across these multiple platforms, we don't want to have to write different versions of device drivers for each and every platform.

While some platform dependencies are unavoidable, let's talk about some of the things that you as a developer can do to minimize the impact. At QNX Software Systems, we've had to deal with these same issues—for example, we support the 8250 serial chip on several different types of processors. Ethernet controllers and others are no exception.

Let's look at these problems:

- I/O space vs memory-mapped
- Big-endian vs little-endian
- alignment and structure packing
- atomic operations

I/O space vs memory-mapped

The x86 architecture has two distinct address spaces:

- 16-address-line I/O space
- 32-address-line instruction and data space

The processor asserts a hardware line to the external bus to indicate which address space is being referenced. The x86 has special instructions to deal with I/O space (e.g., `IN AL, DX` vs `MOV AL,` *address*). Common hardware design on an x86 indicates that the control ports for peripherals live in the I/O address space. On non-x86 platforms, this requirement doesn't exist—all peripheral devices are mapped into various locations within the same address space as the instruction and code memory.

Big-endian vs little-endian

Big-endian vs little-endian is another compatibility issue with various processor architectures. The issue stems from the byte ordering of multibyte constants. The x86 architecture is little-endian.

For example, the hexadecimal number 0x12345678 is stored in memory as:

```
address contents
      0 0x78
      1 0x56
      2 0x34
      3 0x12
```

A big-endian processor would store the data in the following order:

```
address contents
      0 0x12
      1 0x34
      2 0x56
      3 0x78
```

This issue is worrisome on a number of fronts:

- typecast mangling
- hardware access
- network transparency

The first and second points are closely related.

Typecast mangling

Consider the following code:

```
func ()
{
    long a = 0x12345678;
    char *p;

    p = (char *) &a;
    printf ("%02X\n", *p);
}
```

On a little-endian machine, this prints the value "`0x78`"; on a big-endian machine, it prints "`0x12`". This is one of the big (pardon the pun) reasons why structured programmers generally frown on typecasts.

Hardware access

Sometimes the hardware can present you with a conflicting choice of the "correct" size for a chunk of data. Consider a piece of hardware that has a 4 KB memory window. If the hardware brings various data structures into view with that window, it's impossible to determine *a priori* what the data size should be for a particular element of the window. Is it a 32-bit long integer? An 8-bit character? Blindly performing operations as in the above code sample will land you in trouble, because the CPU will determine what it believes to be the correct endianness, regardless of what the hardware manifests.

Network transparency

These issues are naturally compounded when heterogeneous CPUs are used in a network with messages being passed among them. If the implementor of the message-passing scheme doesn't decide up front what byte order will be used, then some form of identification needs to be done so that a machine with a different byte ordering can receive and correctly decode a message from another machine. This problem has been solved with protocols like TCP/IP, where a defined *network byte order* is always adhered to, even between homogeneous machines whose byte order differs from the network byte order.

Alignment and structure packing

On the x86 CPU, you can access any sized data object at any address (albeit some accesses are more efficient than others). On non-x86 CPUs, you can't—as a general rule, you can access only *N*-byte objects on an *N*-byte boundary.

For example, to access a 4-byte `long` integer, it must be aligned on a 4-byte address (e.g., 0x7FBBE008). An address like 0x7FBBE009 will cause the CPU to generate a fault. (An x86 processor happily generates multiple bus cycles and gets the data anyway.)

Generally, this will not be a problem with structures defined in the header files for QNX Neutrino, as we've taken care to ensure that the members are aligned properly. The major place that this occurs is with hardware devices that can map a window into the address space (for configuration registers, etc.), and protocols where the protocol itself presents data in an unaligned manner (e.g., CIFS/SMB protocol).

Atomic operations

One final problem that can occur with different families of processors, and SMP configurations in general, is that of atomic access to variables.

Since this is so prevalent with interrupt service routines and their handler threads, we've already talked about this in the chapter on *Writing an Interrupt Handler*.

Solutions

Now that we've seen the problems, let's take a look at some of the solutions you can use.

The following header files are shipped standard with QNX Neutrino:

<gulliver.h>

Isolates big-endian vs little-endian issues.

<hw/inout.h>

Provides input and output functions for I/O or memory address spaces.

Determining endianness

The file **<gulliver.h>** contains macros to help resolve endian issues.

The first thing you may need to know is the target system's endianness, which you can find out via the following macros:

__LITTLEENDIAN__

defined if little-endian

__BIGENDIAN__

defined if big-endian

A common coding style in the header files (e.g., **<gulliver.h>**) is to check which macro is defined and to report an error if none is defined:

```
#if defined(__LITTLEENDIAN__)
// do whatever for little-endian
#elif defined(__BIGENDIAN__)
// do whatever for big-endian
#else
#error ENDIAN Not defined for system
#endif
```

The `#error` statement will cause the compiler to generate an error and abort the compilation.

Swapping data if required

Suppose you need to ensure that data obtained in the host order (i.e., whatever is "native" on this machine) is returned in a particular order, either big- or little-endian. Or vice versa: you want to convert data from host order to big- or little-endian.

You can use the following macros (described here as if they were functions for syntactic convenience):

`uint16_t ENDIAN_LE16 (uint16_t` ***var*** **`)`**

If the host is little-endian, this macro does nothing (expands simply to *var*); else, it performs a byte swap.

uint32_t ENDIAN_LE32(uint32_t *var*)

If the host is little-endian, this macro does nothing (expands simply to *var*); else, it performs a quadruple byte swap.

uint64_t ENDIAN_LE64(uint64_t *var*)

If the host is little-endian, this macro does nothing (expands simply to *var*); else, it swaps octets of bytes.

uint16_t ENDIAN_BE16(uint16_t *var*)

If the host is big-endian, this macro does nothing (expands simply to *var*); else, it performs a byte swap.

uint32_t ENDIAN_BE32(uint32_t *var*)

If the host is big-endian, this macro does nothing (expands simply to *var*); else, it performs a quadruple byte swap.

uint64_t ENDIAN_BE64(uint64_t *var*)

If the host is big-endian, this macro does nothing (expands simply to *var*); else, it swaps octets of bytes.

Accessing unaligned data

To access data on nonaligned boundaries, you have to access the data one byte at a time (the correct endian order is preserved during byte access).

The following macros (documented as functions for convenience) accomplish this:

uint16_t UNALIGNED_RET16(uint16_t ****addr16* **)

Returns a 16-bit quantity from the address specified by *addr16*.

uint32_t UNALIGNED_RET32(uint32_t ****addr32* **)

Returns a 32-bit quantity from the address specified by *addr32*.

uint64_t UNALIGNED_RET64(uint64_t ****addr64* **)

Returns a 64-bit quantity from the address specified by *addr64*.

void UNALIGNED_PUT16(uint16_t ****addr16*, uint16_t** *val16* **)**

Stores the 16-bit value *val16* at the address specified by *addr16*.

void UNALIGNED_PUT32(uint32_t ****addr32*, uint32_t** *val32* **)**

Stores the 32-bit value *val32* at the address specified by *addr32*.

void UNALIGNED_PUT64(uint64_t ****addr64*, uint64_t** *val64* **)**

Stores the 64-bit value *val64* the address specified by *addr64*.

Examples

Here are some examples showing how to access different pieces of data using the macros introduced so far.

Mixed-endian accesses

This code is written to be portable. It accesses *little_data* (i.e., data that's known to be stored in little-endian format, perhaps as a result of some on-media storage scheme), and then manipulates it, writing the data back. This illustrates that the *ENDIAN_*()* macros are bidirectional:

```
uint16_t    native_data;
uint16_t    little_data;

native_data = ENDIAN_LE16 (little_data);// used as "from little-endian"
native_data++;                          // do something with native form
little_data = ENDIAN_LE16 (native_data);// used as "to little-endian"
```

Accessing hardware with dual-ported memory

Hardware devices with dual-ported memory may "pack" their respective fields on nonaligned boundaries.

For example, if we had a piece of hardware with the following layout, we'd have a problem:

Address	Size	Name
0x18000000	1	*PKTTYPE*
0x18000001	4	*PKTCRC*
0x18000005	2	*PKTLEN*

Let's see why.

The first field, *PKTTYPE*, is fine—it's a 1-byte field, which according to the rules could be located anywhere. But the second and third fields aren't fine. The second field, *PKTCRC*, is a 4-byte object, but it's *not* located on a 4-byte boundary (the address is not evenly divisible by 4). The third field, *PKTLEN*, suffers from a similar problem—it's a 2-byte field that's not on a 2-byte boundary.

The *ideal* solution would be for the hardware manufacturer to obey the same alignment rules that are present on the target processor, but this isn't always possible. For example, if the hardware presented a raw data buffer at certain memory locations, the hardware would have no idea how you wish to interpret the bytes present—it would simply manifest them in memory.

To access these fields, you'd make a set of manifest constants for their offsets:

```
#define PKTTYPE_OFF     0x0000
#define PKTCRC_OFF      0x0001
#define PKTLEN_OFF      0x0005
```


Then, you'd map the memory region via *mmap_device_memory()*. Let's say it gave you a `char *` pointer called *ptr*. Using this pointer, you'd be tempted to:

```
cr1 = *(ptr + PKTTYPE_OFF);
// wrong!
sr1 = * (uint32_t *) (ptr + PKTCRC_OFF);
er1 = * (uint16_t *) (ptr + PKTLEN_OFF);
```

However, this would give you an alignment fault on non-x86 processors for the *sr1* and *er1* lines.

One solution would be to manually assemble the data from the hardware, byte by byte. And that's exactly what the *UNALIGNED_*()* macros do. Here's the rewritten example:

```
cr1 = *(ptr + PKTTYPE_OFF);
// correct!
sr1 = UNALIGNED_RET32 (ptr + PKTCRC_OFF);
er1 = UNALIGNED_RET16 (ptr + PKTLEN_OFF);
```

The access for *cr1* didn't change, because it was already an 8-bit variable—these are *always* “aligned.” However, the access for the 16- and 32-bit variables now uses the macros.

An implementation trick used here is to make the pointer that serves as the base for the mapped area by a `char *`—this lets us do pointer math on it.

To write to the hardware, you'd again use macros, but this time the *UNALIGNED_PUT*()* versions:

```
*(ptr + PKTTYPE_OFF) = cr1;
UNALIGNED_PUT32 (ptr + PKTCRC_OFF, sr1);
UNALIGNED_PUT16 (ptr + PKTLEN_OFF, er1);
```

Of course, if you're writing code that should be portable to different-endian processors, you'll want to combine the above tricks with the previous endian macros. Let's define the hardware as big-endian. In this example, we've decided that we're going to store everything that the program uses in host order and do translations whenever we touch the hardware:

```
cr1 = *(ptr + PKTTYPE_OFF);  // endian neutral
sr1 = ENDIAN_BE32 (UNALIGNED_RET32 (ptr + PKTCRC_OFF));
er1 = ENDIAN_BE16 (UNALIGNED_RET16 (ptr + PKTLEN_OFF));
```

And:

```
*(ptr + PKTTYPE_OFF) = cr1;  // endian neutral
UNALIGNED_PUT32 (ptr + PKTCRC_OFF, ENDIAN_BE32 (sr1));
UNALIGNED_PUT16 (ptr + PKTLEN_OFF, ENDIAN_BE16 (er1));
```

Here's a simple way to remember which *ENDIAN_*()* macro to use. Recall that the *ENDIAN_*()* macros won't change the data on their respective platforms (i.e. the `LE` macro will return the data unchanged on a little-endian platform, and the `BE` macro will return the data unchanged on a big-endian platform). Therefore, to access the data (which we know has a *defined* endianness), we effectively want to select the *same macro as the type of data*. This way, if the platform is the same as the type of data present, no changes will occur (which is what we expect).

Accessing I/O ports

When you're porting code that accesses hardware, the x86 architecture has a set of instructions that manipulate a separate address space called the *I/O address space*. This address space is completely separate from the memory address space. On non-x86 platforms, such an address space doesn't exist—all devices are mapped into memory.

In order to keep code portable, we've defined a number of functions that isolate this behavior. By including the file **<hw/inout.h>**, you get the following functions:

in8()

Reads an 8-bit value.

in16(), ***inbe16()***, ***inle16()***

Reads a 16-bit value.

in32(), ***inbe32()***, ***inle32()***

Reads a 32-bit value.

in8s()

Reads a number of 8-bit values.

in16s()

Reads a number of 16-bit values.

in32s()

Reads a number of 32-bit values.

out8()

Writes a 8-bit value.

out16(), ***outbe16()***, ***outle16()***

Writes a 16-bit value.

out32(), ***outbe32()***, ***outle32()***

Writes a 32-bit value.

out8s()

Writes a number of 8-bit values.

out16s()

Writes a number of 16-bit values.

out32s()

Writes a number of 32-bit values.

On the x86 architecture, these functions perform the machine instructions `in`, `out`, `rep ins*`, and `rep outs*`. On non-x86 architectures, they dereference the supplied address (the *addr* parameter) and perform memory accesses.

Note that the calling process must use *mmap_device_io()* to access the device's I/O registers.

Appendix B
Conventions for Recursive Makefiles and Directories

In this chapter, we'll take a look at the supplementary files used in the QNX Neutrino development environment. Although we use the standard `make` command to create libraries and executables, you'll notice we use some of our own conventions in the **Makefile** syntax.

We'll start with a general description of a full, multiplatform source tree. Then we'll look at how you can build a tree for your products. Next. we'll discuss some *advanced topics*, including collapsing unnecessary levels and performing partial builds. Finally, we'll wrap up with some *examples of creating Makefiles*.

Although you're certainly not obliged to use our format for the directory structure and related tools, you may choose to use it because it's convenient for developing multiplatform code. If you do use this structure, you should use the `addvariant` command to create it; for more information, see the *Utilities Reference* as well as the *examples* at the end of this chapter.

Structure of a multiplatform source tree

Here's a sample directory tree for a product that can be built for two different operating systems (QNX 4 and Neutrino), on two CPU platforms (x86 and ARM):

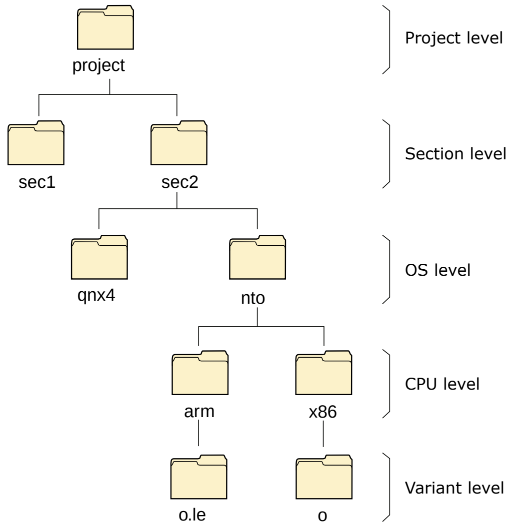


Figure 33: Source tree for a multiplatform project.

We'll talk about the names of the directory levels shortly. At each directory level is a **Makefile** file that the `make` utility uses to determine what to do in order to make the final executable.

However, if you examine the makefiles, you can see that most of them simply contain:

```
include recurse.mk
```

Why do we have makefiles at every level? Because `make` can recurse into the bottommost directory level (the variant level in the diagram). That's where the actual work of building the product occurs. This means that you could type `make` at the topmost directory, and it would go into all the subdirectories and compile everything. Or you could type `make` from a particular point in the tree, and it would compile only what's needed from that point down.

We'll discuss how to cause `make` to compile only certain parts of the source tree, even if invoked from the top of the tree, in the "*Advanced topics*" section.

When deciding where to place source files, as a rule of thumb you should place them as high up in the directory tree as possible. This not only reduces the number of directory levels to traverse when looking for source, but also encourages you to develop source that's as generic as possible (i.e. that isn't specific to the OS, CPU, or board). Lower directory levels are reserved for more and more specific pieces of source code.

If you look at the source tree that we ship, you'll notice that we follow the directory structure defined above, but with a few shortcuts. We'll cover those shortcuts in the "*Advanced Topics*" section.

Makefile structure

As mentioned earlier, the makefile structure is almost identical, regardless of the level that the makefile is found in. All makefiles (except the bottommost level) include the **recurse.mk** file and may set one or more macros.

Here's an example of one of our standard (nonbottommost) **Makefile**s:

```
LATE_DIRS=boards
include recurse.mk
```

The `recurse.mk` file

The **recurse.mk** file resides under **$QNX_TARGET/usr/include/mk**. This directory contains other files that are included within makefiles. Note that while the `make` utility automatically searches **$QNX_TARGET/usr/include**, we've created symbolic links from there to **$QNX_TARGET/usr/include/mk**.

The **recurse.mk** include file is typically used by higher-level makefiles to recurse into lower-level makefiles. All subdirectories present are scanned for files called **makefile** or **Makefile**. Any subdirectories that contain such files are recursed into, then `make` is invoked from within those directories, and so on, down the directory tree.

You can create a special file named **Makefile.dnm** ("dnm" stands for "Do Not Make") next to a real **Makefile** to cause **recurse.mk** *not* to descend into that directory. The contents of **Makefile.dnm** aren't examined in any way—you can use `touch` to create an empty file for it.

Macros

The example given above uses the *LATE_DIRS* macro. Here are the macros that you can place within a makefile:

- *EARLY_DIRS*
- *LATE_DIRS*
- *LIST*
- *MAKEFILE*
- *CHECKFORCE*

The *EARLY_DIRS* and *LATE_DIRS* macros

To give you some control over the ordering of the directories, the macros *EARLY_DIRS* and *LATE_DIRS* specify directories to recurse into *before* or *after* all others.

You'd use this facility with directory trees that contain one directory that depends on another directory at the same level; you want the independent directory to be done first, followed by the dependent directory.

In our example above, we've specified a *LATE_DIRS* value of **boards**, because the **boards** directory depends on the library directory (**lib**).

Note that the *EARLY_DIRS* and *LATE_DIRS* macros accept a list of directories. The list is treated as a group, with no defined ordering *within* that group.

The *LIST* macro

The *LIST* macro serves as a tag for the particular directory level that the makefile is found in.

The *LIST* macro can contain a list of names that are separated by spaces. This is used when we squash directory levels together; see "*Advanced Topics*," later in this chapter.

Here are the common values corresponding to the directory levels:

- `VARIANT`
- `CPU`
- `OS`

Note that you're free to define whatever values you wish—these are simply conventions that we've adopted for the three directory levels specified. See the section on "*More uses for LIST*," below.

Once the directory has been identified via a tag in the makefile, you can specifically exclude or include the directory and its descendants in a `make` invocation. See "*Performing partial builds*," below.

The *MAKEFILE* macro

The *MAKEFILE* macro specifies the name of the makefile that **recurse.mk** should search for in the child directories.

Normally this is `[Mm]akefile`, but you can set it to anything you wish by changing the *MAKEFILE* macro. For example, in a GNU `configure`-style makefile, `addvariant` sets it to `GNUmakefile` (see "*GNU `configure`*," later in this chapter.

The *CHECKFORCE* macro

The *CHECKFORCE* macro is a trigger. Its actual value is unimportant, but if you set it, the **recurse.mk** file looks for **Makefile.force** files in the subdirectories. If it finds one, `make` recurses into that directory, even if the *LIST* macro settings would normally prevent this from happening.

Directory levels

Let's look at the directory levels themselves in some detail. Note that you can add as many levels as you want *above* the levels described here; these levels reflect the structure of your product. For example, in a factory automation system, the product would consist of the *entire* system, and you'd then have several subdirectories under that directory level to describe various projects within that product (e.g. **gui**, **pidloop**, **robot_plc**, etc.).

Project level

You use the project-level directory mainly to store the bulk of the source code and other directories, structuring these directories logically around the project being developed.

For our factory-automation example, a particular project level might be the **gui** directory, which would contain the source code for the graphical user interface as well as further subdirectories.

Section level (optional)

You use the section-level directory to contain the source base relevant to a part of the project.

You can omit it if you don't need it; see "*Collapsing unnecessary directory levels*," later in this chapter.

OS level

If you were building products to run on multiple operating systems, you'd include an OS-level directory structure. This would serve as a branchpoint for OS-specific subdirectories.

In our factory-floor example, the **gui** section might be built for both QNX 4 and QNX Neutrino, whereas the other sections might be built just for QNX Neutrino.

If no OS level is detected, QNX Neutrino is assumed.

CPU level

Since we're building executables and libraries for multiple platforms, we need a place to serve as a branchpoint for the different CPUs. Generally, the CPU level contains nothing but subdirectories for the various CPUs, but it may also contain CPU-specific source files.

Variant level

Finally, the variant level contains object, library, or executable files specific to a particular variant of the processor.

For example, some processors can operate in big-endian or little-endian mode. In that case, we'd have to generate two different sets of output modules. On the other hand, an x86 processor is a little-endian machine only, so we need to build only one set of output modules.

Specifying options

At the project level, there's a file called **common.mk**. This file contains any special flags and settings that need to be in effect in order to compile and link.

At the bottommost level (the variant level), the format of the makefile is different—it *doesn't* include **recurse.mk**, but instead includes **common.mk** (from the project level).

The `common.mk` file

The **common.mk** include file is where you put the traditional makefile options, such as compiler options.

In order for the **common.mk** file to be able to determine which system to build the particular objects, libraries, or executables for, we analyze the pathname components in the bottommost level *in reverse order* as follows:

- the last component is assigned to the *VARIANT1* macro
- the next previous component is assigned to the *CPU* macro
- the next previous component is assigned to the *OS* macro
- the next previous component is assigned to the *SECTION* macro
- the next previous component is assigned to the *PROJECT* macro

For example, if we have a pathname of **/source/factory/robot_plc/driver/nto/arm/o.le**, then the macros are set as follows:

Macro	Value
VARIANT1	`o.be`
CPU	`arm`
OS	`nto`
SECTION	`driver`
PROJECT	`robot_plc`

The variant-level makefile

The variant-level makefile (i.e., the bottommost makefile in the tree) contains the single line:

```
include ../../common.mk
```

The number of **../** components must be correct to get at the **common.mk** include file, which resides in the project level of the tree. The reason that the number of **../** components isn't necessarily the same in all cases has to do with whether directory levels are being collapsed.

Recognized variant names

You can combine variant names into a *compound variant*, using a period (`.`), dash (`-`), or slash (`/`) between the variants.

The common makefiles are triggered by a number of distinguished variant names:

a

The image being built is an object library.

so

The image being built is a shared object.

dll

The image being built is a DLL; it's linked with the `-Bsymbolic` option (see `ld` in the *Utilities Reference*).

If the compound variant doesn't include **a**, **so**, or **dll**, an executable is being built.

shared

Compile the object files for **.so** use, but don't create an actual shared object. You typically use this name in an **a.shared** variant to create a static link archive that can be linked into a shared object.

g

Compile and link the source with the debugging flag set.

be, le

Compile and link the source to generate big- (if **be**) or little- (if **le**) endian code.

gcc

Use the GCC (**gcc**) compiler to compile the source. If you don't specify a compiler, the makefiles provide a default.

o

This is the NULL variant name. It's used when building an image that doesn't really have any variant components to it (e.g., an executable for an x86 CPU, which doesn't support bi-endian operation).

Variant names can be placed in any order in the compound variant, but to avoid confusing a source configuration management tool (e.g., CVS), make sure that the last variant in the list never looks like a generated file suffix. In other words, don't use variant names ending in **.a**, **.so**, or **.o**.

The following table lists some examples:

Variant	Purpose
g.le	A debugging version of a little-endian executable.
so.be	A big-endian version of a shared object.

Variant	Purpose
403.be	A user-defined “403” variant for a big-endian system.

The only valid characters for variant names are letters, digits, and underscores (_).

In order for the source code to tell what variant(s) it's being compiled for, the common makefiles arrange for each variant name to be suffixed to the string `VARIANT_` and have that defined as a C or assembler macro on the command line. For example, if the compound variant is **so.403.be**, the makefiles define the following C macros:

- VARIANT_so
- VARIANT_403
- VARIANT_be

Note that neither VARIANT_be nor VARIANT_le is defined on a CPU that doesn't support bi-endian operation, so any endian-specific code should always test for the C macros __LITTLEENDIAN__ or __BIGENDIAN__ (instead of VARIANT_le or VARIANT_be) to determine what endian-ness it's running under.

Using the standard macros and include files

We've described the pieces you'll provide when building your system, including the **common.mk** include file. Now let's look at some other include files:

- *qconfig.mk*
- *qrules.mk*
- *qtargets.mk*

We'll also look at some of the macros that these files set or use.

The `qconfig.mk` include file

Since the common makefiles have a lot of defaults based on the names of various directories, you can simplify your life enormously in the **common.mk** include file if you choose your directory names to match what the common makefiles want.

For example, if the name of the project directory is the same as the name of the image, you don't have to set the *NAME* macro in **common.mk**.

The prototypical **common.mk** file looks like this:

```
ifndef QCONFIG
QCONFIG=qconfig.mk
endif
include $(QCONFIG)

# Preset make macros go here

include $(MKFILES_ROOT)/qtargets.mk

# Post-set make macros go here
```

The **qconfig.mk** include file provides the root paths to various install, and usage trees on the system, along with macros that define the compilers and some utility commands that the makefiles use. The purpose of the **qconfig.mk** include file is to let you tailor the root directories, compilers, and commands used at your site, if they differ from the standard ones that we use and ship. Therefore, nothing in a project's makefiles should refer to a compiler name, absolute path, or command name directly. Always use the **qconfig.mk** macros.

The **qconfig.mk** file resides in **$QNX_TARGET/usr/include/mk** as **qconf-*os*.mk** (where *os* is the host OS, e.g., `nto`, `linux`, `win32`), which is a symbolic link from the place where `make` wants to find it (namely **$QNX_TARGET/usr/include/qconfig.mk**). You can override the location of the include file by specifying a value for the *QCONFIG* macro.

If you wish to override the values of some of the macros defined in **qconfig.mk** without modifying the contents of the file, set the *QCONF_OVERRIDE* environment variable (or `make` macro) to be the name of a file to include at the end of the main **qconfig.mk** file.

Some examples of override files set *VERSION_REL*, which specifies the version of the OS that you're building for. This variable is primarily for internal use at QNX Software Systems; it indicates that `make` is running on a build machine instead of on a developer's desktop. If you set this variable, `make` becomes a lot more particular about other settings (e.g., it will insist that you set *PINFO*).

Preset macros

Before including **qtargets.mk**, you might need to set some macros to specify things like what additional libraries need to be searched in the link, the name of the image (if it doesn't match the project directory name), and so on. Do this in the area tagged as "`Preset make macros go here`" in the sample above.

Postset macros

Following the inclusion of **qtargets.mk**, you can override or (more likely) add to the macros set by **qtargets.mk**. Do this in the area tagged as "`Post-set make macros go here`" in the sample above.

`qconfig.mk` macros

Here's a summary of the macros available from **qconfig.mk**:

CP_HOST

Copy files from one spot to another.

LN_HOST

Create a symbolic link from one file to another.

RM_HOST

Remove files from the filesystem.

TOUCH_HOST

Update a file's access and modification times.

PWD_HOST

Print the full path of the current working directory.

CL_ which

Compile and link.

CC_ which

Compile C/C++ source to an object file.

AS_ which

Assemble something to an object file.

AR_which

Generate an object file library (archive).

LR_which

Link a list of objects/libraries to a relocatable object file.

LD_which

Link a list of objects/libraries to a executable/shared object.

UM_which

Add a usage message to an executable.

The *which* parameter can be either the string `HOST` for compiling something for the host system or a triplet of the form *os_cpu_compiler* to specify a combination of target OS and CPU, as well as the compiler to be used.

The *os* is usually the string `nto` to indicate Neutrino (i.e., the QNX Neutrino RTOS). The *cpu* is one of `x86` or `arm`. Finally, the compiler is usually `gcc`.

For example, you could use the macro *CC_nto_x86_gcc* to specify:

- the compilation tool
- a Neutrino target system
- an x86 platform
- the GNU GCC compiler

The following macro contains the command-line sequence required to invoke the GCC compiler:

```
CC_nto_x86_gcc = qcc -Vgcc_ntox86 -c
```

The various makefiles use the *CP_HOST*, *LN_HOST*, *RM_HOST*, *TOUCH_HOST*, and *PWD_HOST* macros to decouple the OS commands from the commands used to perform the given actions. For example, under most POSIX systems, the *CP_HOST* macro expands to the `cp` utility. Under other operating systems, it may expand to something else (e.g., `copy`).

In addition to the macros mentioned above, you can use the following macros to specify options to be placed at the end of the corresponding command lines:

- *CLPOST_which*
- *CCPOST_which*
- *ASPOST_which*
- *ARPOST_which*
- *LRPOST_which*
- *LDPOST_which*
- *UMPOST_which*

The parameter "*which*" is the same as defined above: either the string "`HOST`" or the ordered triplet defining the OS, CPU, and compiler.

For example, specifying the following:

```
CCPOST_nto_x86_gcc = -ansi
```

causes the command line specified by `CC_nto_x86_gcc` to have the additional string "`-ansi`" appended to it.

The `qrules.mk` include file

The **qrules.mk** include file defines the macros used for compiling.

You can inspect—and in some cases, also set—the following macros when you use **qrules.mk**. Since the **qtargets.mk** file includes **qrules.mk**, these are available there as well. Don't modify those that are marked "(read-only)."

VARIANT_LIST **(read-only)**

A space-separated list of the variant names macro. Useful with the `$(filter ...)` `make` function for picking out individual variant names.

CPU

The name of the target CPU. Defaults to the name of the next directory up with all parent directories stripped off.

CPU_ROOT **(read-only)**

The full pathname of the directory tree up to and including the OS level.

OS

The name of the target OS. Defaults to the name of the directory two levels up with all parent directories stripped off.

OS_ROOT **(read-only)**

The full pathname of the directory tree up to and including the OS level.

SECTION

The name of the section. This is set only if there's a section level in the tree.

SECTION_ROOT **(read-only)**

The full pathname of the directory tree up to and including the section level.

PROJECT **(read-only)**

The *basename()* of the directory containing the **common.mk** file.

PROJECT_ROOT **(read-only)**

The full pathname of the directory tree up to and including the project level.

PRODUCT **(read-only)**

The *basename()* of the directory above the project level.

PRODUCT_ROOT **(read-only)**

The full pathname of the directory tree up to and including the product level.

NAME

The *basename()* of the executable or library being built. Defaults to `$(PROJECT)`.

SRCVPATH

A space-separated list of directories to search for source files. Defaults to all the directories from the current working directory up to and including the project root directory. You'd almost never want to set this; use *EXTRA_SRCVPATH* to add paths instead.

EXTRA_SRCVPATH

Added to the end of *SRCVPATH*. Defaults to none.

INCVPATH

A space-separated list of directories to search for include files. Defaults to `$(SRCVPATH)` plus `$(USE_ROOT_INCLUDE)`. You'd almost never want to set this; use *EXTRA_INCVPATH* to add paths instead.

EXTRA_INCVPATH

Added to *INCVPATH* just before the `$(USE_ROOT_INCLUDE)`. Default is none.

LIBVPATH

A space-separated list of directories to search for library files. Defaults to:

```
. $(INSTALL_ROOT_support)/$(OS)/$(CPUDIR)/lib $(USE_ROOT_LIB).
```

You'll almost never want to use this; use *EXTRA_LIBVPATH* to add paths instead.

EXTRA_LIBVPATH

Added to *LIBVPATH* just before **$(INSTALL_ROOT_support)/$(OS)/$(CPUDIR)/lib**. Default is none.

DEFFILE

The name of an assembler define file created by `mkasmoff`. Default is none.

SRCS

A space-separated list of source files to be compiled. Defaults to all ***.s**, ***.S**, ***.c**, and ***.cc** files in *SRCVPATH*.

EXCLUDE_OBJS

A space-separated list of object files *not* to be included in the link/archive step. Defaults to none.

EXTRA_OBJS

A space-separated list of object files to be added to the link/archive step even though they don't have corresponding source files (or have been excluded by *EXCLUDE_OBJS*). Default is none.

OBJPREF_object*, *OBJPOST_object

Options to add before or after the specified object:

```
OBJPREF_object = options
OBJPOST_object = options
```

The *options* string is inserted verbatim. Here's an example:

```
OBJPREF_libc_cut.a = -Wl,--whole-archive
OBJPOST_libc_cut.a = -Wl,--no-whole-archive
```

LIBS

A space-separated list of library stems to be included in the link. Default is none.

LIBPREF_library*, *LIBPOST_library

Options to add before or after the specified library:

```
LIBPREF_library = options
LIBPOST_library = options
```

The *options* string is inserted verbatim.

You can use these macros to link some libraries statically and others dynamically. For example, here's how to bind **libmystat.a** and **libmydyn.so** to the same program:

```
LIBS += mystat mydyn

LIBPREF_mystat = -Bstatic
LIBPOST_mystat = -Bdynamic
```

This places the `-Bstatic` option just before `-lmystat`, and `-Bdynamic` right after it, so that only that library is linked statically.

CCFLAGS

Flags to add to the C compiler command line.

CXXFLAGS

Flags to add to the C++ compiler command line.

ASFLAGS

Flags to add to the assembler command line.

LDFLAGS

Flags to add to the linker command line.

VFLAG_ which

Flags to add to the command line for C compiles, assemblies, and links; see below.

CCVFLAG_ which

Flags to add to C compiles; see below.

ASVFLAG_ which

Flags to add to assemblies; see below.

LDVFLAG_ which

Flags to add to links; see below.

OPTIMIZE_TYPE

The optimization type; one of:

- *OPTIMIZE_TYPE=TIME* — optimize for execution speed (the default for AArch64 and x86 platforms)
- *OPTIMIZE_TYPE=SIZE* — optimize for executable size (the default for ARM platforms)
- *OPTIMIZE_TYPE=NONE* — turn off optimization

Note that for the *VFLAG_ which*, *CCVFLAG_ which*, *ASVFLAG_ which*, and *LDVFLAG_ which* macros, the *which* part is the name of a variant. This combined macro is passed to the appropriate command line. For example, if there were a variant called "`403`," then the macro *VFLAG_403* would be passed to the C compiler, assembler, and linker.

Don't use this mechanism to define a C macro constant that you can test in the source code to see if you're in a particular variant. The makefiles do that automatically for you. Don't set the **VFLAG_** macros for any of the distinguished variant names (listed in the "*Recognized variant names*" section, above). The common makefiles will get confused if you do.

The `qtargets.mk` include file

The **qtargets.mk** include file has the linking and installation rules.

You can inspect and/or set the following macros when you use **qtargets.mk**:

INSTALLDIR

The subdirectory where the executable or library is to be installed. Defaults to **bin** for executables, and **lib/dll** for DLLs. If you set it to **/dev/null**, then no installation is done.

USEFILE

The file containing the usage message for the application. Defaults to none for archives and shared objects and to **$(PROJECT_ROOT)/$(NAME).use** for executables. The application-specific makefile can set the macro to a null string, in which case nothing is added to the executable.

LINKS

A space-separated list of symbolic link names that are aliases for the image being installed. They're placed in the same directory as the image. The default is none.

PRE_TARGET*, *POST_TARGET

Extra targets to add as dependencies to the `all` target before and after the main target.

PRE_CLEAN*, *POST_CLEAN

Extra commands to run before and after the `clean` target.

PRE_ICLEAN*, *POST_ICLEAN

Extra commands to run before and after the `iclean` target.

PRE_HINSTALL*, *POST_HINSTALL

Extra commands to run before and after the `hinstall` target.

PRE_CINSTALL*, *POST_CINSTALL

Extra commands to run before and after the `cinstall` target.

PRE_INSTALL*, *POST_INSTALL

Extra commands to run before and after the `install` target.

PRE_BUILD*, *POST_BUILD

Extra commands to run before and after building the image.

SO_VERSION

The *SONAME* version number to use when building a shared object (the default is 1).

In this release, the version number is required for the internal name of the shared object, so setting this macro is mandatory. For more information, see "*Specifying an internal name*".

PINFO

Information to go into the ***.pinfo** file.

For example, you can use the *PINFO NAME* option to keep a permanent record of the original filename of a binary. If you use this option, the name that you specify appears in the information from the `use -i` *filename* command. Otherwise, the information from `use -i` contains the *NAME* entry specified outside of the *PINFO* define.

For more information about *PINFO*, see the *hook_pinfo()* function described below for the GNU `configure` command.

Advanced topics

In this section, we'll discuss how to:

- *collapse unnecessary directory levels*
- *perform partial builds*
- *perform parallel builds*
- *use GNU `configure`*

Collapsing unnecessary directory levels

You can *collapse* unnecessary components out of the directory tree.

The directory structure shown in the "*Structure of a multiplatform source tree*" section defines the complete tree; every possible directory level is shown. In the real world, however, some of these directory levels aren't required. For example, you may wish to build a particular module for an ARM in little-endian mode and *never* need to build it for anything else (perhaps due to hardware constraints). Therefore, it seems a waste to have a variant level that has only the directory **o.le** and a CPU level that has only the directory **arm**.

In this situation, you can *collapse* unnecessary directory components out of the tree. You do this by simply separating the name of the components with dashes (-) rather than slashes (/).

For example, in our source tree, let's look at the **startup/boards/***my_board***/arm-le** makefile:

```
include ../common.mk
```

In this case, we've specified both the variant (as "`le`" for little-endian) and the CPU (as "`arm`" for ARM) with a single directory.

Why did we do this? Because the *my_board* directory refers to a very specific board—it's not going to be useful for anything other than an ARM running in little-endian mode.

In this case, the makefile macros would have the following values:

Macro	Value
VARIANT1	`arm-le`
CPU	`arm`
OS	`nto` (default)
SECTION	*my_board*
PROJECT	`boards`

The `addvariant` command knows how to create both the squashed and unsquashed versions of the directory tree. You should always use it when creating the OS, CPU, and variant levels of the tree.

Performing partial builds

By using the *LIST* tag in the makefile, you can cause the `make` command to perform a partial build, even if you're at the top of the source tree.

If you were to simply type `make` without having used the *LIST* tag, all directories would be recursed into and everything would be built.

However, by defining a macro on `make`'s command line, you can:

- recurse into only the specified tagged directories

  Or:

- recurse into all of the directories except for the specified tagged ones

Let's consider an example. The following (issued from the top of the source tree):

```
make CPULIST=x86
```

causes only the directories that are at the CPU level and below (and tagged as *LIST=CPU*), *and that are called x86*, to be recursed into.

You can specify a space-separated list of directories (note the use of quoting in the shell to capture the space character):

```
make "CPULIST=x86 arm"
```

This causes the x86 *and* ARM versions to be built.

There's also the inverse form, which causes the specific lists *not* to be built:

```
make EXCLUDE_CPULIST=arm
```

This causes everything *except* the ARM versions to be built.

As you can see from the above examples, the following are all related to each other via the *CPU* portion:

- *LIST=CPU*
- *CPULIST*
- *EXCLUDE_CPULIST*

Performing parallel builds

To get `make` to run more than one command in parallel, use the *JLEVEL* macro.

For example:

```
JLEVEL=4
```

The default value is `1`. If you run parallel builds, the output from different jobs can be interspersed.

For more information, see the `-j` option in the GNU documentation for `make`.

More uses for *LIST*

Besides using the standard *LIST* values that we use, you can also define your own.

In certain makefiles, you'd put the following definition:

```
LIST=CONTROL
```

Then you can decide to build (or prevent from building) various subcomponents marked with `CONTROL`. This might be useful in a very big project, where compilation times are long and you need to test only a particular subsection, even though other subsections may be affected and would ordinarily be made.

For example, if you had marked two directories, **robot_plc** and **pidloop**, with the *LIST=CONTROL* macro within the makefile, you could then make just the **robot_plc** module:

```
make CONTROLLIST=robot_plc
```

or make both (note the use of quoting in the shell to capture the space character):

```
make "CONTROLLIST=robot_plc pidloop"
```

or make everything *except* the **robot_plc** module:

```
make EXCLUDE_CONTROLLIST=robot_plc
```

GNU `configure`

The `addvariant` utility knows how to work with code that uses a GNU `./configure` script for configuration.

If the current working directory contains files named **configure** and **Makefile.in**, `addvariant` automatically squashes the directory levels (as described earlier) into a single OS-CPU-VARIANT level and creates **GNUmakefile** files in the newly created directories along with a recursing **Makefile**.

After you've run `addvariant`, create an executable shell script called **build-hooks** in the root of the project. This file needs to define one or more of the following shell functions (described in more detail below):

- *hook_preconfigure()*
- *hook_postconfigure()*
- *hook_premake()*
- *hook_postmake()*
- *hook_pinfo()*

Every time that you type `make` in one of the newly created directories, the **GNUmakefile** is read (a small trick that works only with GNU `make`). **GNUmakefile** in turn invokes the **$QNX_TARGET/usr/include/mk/build-cfg** script, which notices whether or not `configure` has been run in the directory:

- If it hasn't, `build-cfg` invokes the *hook_preconfigure()* function, then the project's `configure`, and then the *hook_postconfigure()* function.
- If the configure has already been done, or we just did it successfully, `build-cfg` invokes the *hook_premake()*, then does a `make -fMakefile`, then *hook_postmake()*, then *hook_pinfo()*.

If a function isn't defined in **build-hooks**, `build-cfg` doesn't bother trying to invoke it.

Within the **build-hooks** script, the following variables are available:

SYSNAME

The host OS (e.g., `nto`, `linux`) that we're running on. This is automatically set by `build-cfg`, based on the results of `uname`.

TARGET_SYSNAME

The target OS (e.g., `nto`, `win32`) that we're going to be generating executables for. It's set automatically by `build-cfg`, based on the directory that you're in.

make_CC

This variable is used to set the *CC* `make` variable when we invoke `make`. This typically sets the compiler that `make` uses. It's set automatically by `build-cfg`, based on the directory that you're in.

make_opts

Any additional options that you want to pass to `make` (the default is `""`).

make_cmds

The command goals passed to `make` (e.g., `all`). It's set automatically by `build-cfg` what you passed on the original `make` command line.

configure_opts

The list of options that should be passed to `configure`. The default is `""`, but `--srcdir=..` is automatically added just before `configure` is called.

hook_preconfigure()

This function is invoked just before we run the project's `configure` script. Its main job is to set the *configure_opts* variable properly.

Here's a fairly complicated example (this is from GCC):

```
# The "target" variable is the compilation target: "ntoarmv7", "ntox86", etc.
function hook_preconfigure {
    case ${SYSNAME} in
    nto)
        case "${target}" in
        nto*)   basedir=/usr ;;
        *)      basedir=/opt/QNXsdk/host/qnx6/x86/usr ;;
        esac
        ;;
    linux)
        host_cpu=$(uname -p)
        case ${host_cpu} in
        i[34567]86) host_cpu=x86 ;;
        esac
        basedir=/opt/QNXsdk/host/linux/${host_cpu}/usr
        ;;
    *)
```

```
                echo "Don't have config for ${SYSNAME}"
                exit 1
                ;;
            esac
            configure_opts="${configure_opts} --target=${target}"
            configure_opts="${configure_opts} --prefix=${basedir}"
            configure_opts="${configure_opts} --exec-prefix=${basedir}"
            configure_opts="${configure_opts} --with-local-prefix=${basedir}"
            configure_opts="${configure_opts} --enable-haifa"
            configure_opts="${configure_opts} --enable-languages=c++"
            configure_opts="${configure_opts} --enable-threads=posix"
            configure_opts="${configure_opts} --with-gnu-as"
            configure_opts="${configure_opts} --with-gnu-ld"
            configure_opts="${configure_opts} --with-as=${basedir}/bin/${target}-as"
            configure_opts="${configure_opts} --with-ld=${basedir}/bin/${target}-ld"
            if [ ${SYSNAME} == nto ]; then
                configure_opts="${configure_opts} --enable-multilib"
                configure_opts="${configure_opts} --enable-shared"
            else
                configure_opts="${configure_opts} --disable-multilib"
            fi
        }
```

hook_postconfigure()

This is invoked after `configure` has been successfully run. Usually you don't need to define this function, but sometimes you just can't quite convince `configure` to do the right thing, so you can put some hacks in here to fix things appropriately.

For example, again from GCC:

```
function hook_postconfigure {
    echo "s/^GCC_CFLAGS *=/&-I\$\(QNX_TARGET\)\/usr\/include /"  >/tmp/fix.$$
    if [ ${SYSNAME} == nto ]; then
        echo "s/OLDCC = cc/OLDCC = .\/xgcc -B.\/ -I \$\(QNX_TARGET\)\/usr\/include/" >>/tmp/fix.$$
        echo "/^INCLUDES = /s/\$/ -I\$\(QNX_TARGET\)\/usr\/include/" >>/tmp/fix.$$
        if [ ${target} == ntosh ]; then
            # We've set up GCC to support both big and little endian, but
            # we only actually support little endian right now. This will
            # cause the configures for the target libraries to fail, since
            # it will test the compiler by attempting a big endian compile
            # which won't link due to a missing libc & crt?.o files.
            # Hack things by forcing compiles/links to always be little endian
            sed -e "s/^CFLAGS_FOR_TARGET *=/&-ml /"  <Makefile >1.$$
            mv 1.$$ Makefile
        fi
    else
        # Only need to build libstdc++ & friends on one host
        rm -Rf ${target}

        echo "s/OLDCC = cc/OLDCC = .\/xgcc -B.\//" >>/tmp/fix.$$
    fi
    cd gcc
    sed -f/tmp/fix.$$ <Makefile >1.$$
```

```
    mv 1.$$ Makefile
    cd ..
    rm /tmp/fix.$$
}
```

hook_premake()

This function is invoked just before the `make`. You don't usually need it.

hook_postmake()

This function is invoked just after the `make`. We haven't found a use for this one yet, but included it for completeness.

hook_pinfo()

This function is invoked after *hook_postmake()*. Theoretically, we don't need this hook at all and we could do all its work in *hook_postmake()*, but we're keeping it separate in case we get fancier in the future.

This function is responsible for generating all the ***.pinfo** files in the project. It does this by invoking the *gen_pinfo()* function that's defined in `build-cfg`, which generates one **.pinfo**. The command line for *gen_pinfo()* is:

`gen_pinfo [-n`*src_name* `]` *install_name* *install_dir* *pinfo_line*`...`

The arguments are:

src_name

The name of the pinfo file (minus the **.pinfo** suffix). If it's not specified, *gen_pinfo()* uses *install_name*.

install_name

The basename of the executable when it's installed.

install_dir

The directory the executable should be installed in. If it doesn't begin with a `/`, the target CPU directory is prepended to it. For example, if *install_dir* is **usr/bin** and you're generating an x86 executable, the true installation directory is **/x86/usr/bin**.

pinfo_line

Any additional pinfo lines that you want to add. You can repeat this argument as many times as required. Favorites include:

- `DESCRIPTION="This executable performs no useful purpose"`
- `SYMLINK=foobar.so`

Here's an example from the `nasm` project:

```
function hook_pinfo {
    gen_pinfo nasm    usr/bin LIC=NASM DESCRIPTION="Netwide X86 Assembler"
```

```
    gen_pinfo ndisasm usr/bin LIC=NASM DESCRIPTION="Netwide X86 Disassembler"
}
```


Examples of creating Makefiles

If you use our directory structure, you should use the `addvariant` command to create it. This section gives some examples of creating **Makefile**s for a single application, as well as for a library and an application.

A single application

Suppose we have a product (we'll use the archiver, `lha` for this example) that we'd like to make available on all the processors that the QNX Neutrino RTOS supports. Unfortunately, we've been using our own custom Makefiles for `gcc` on x86, and we have no idea how to make binaries for other processors.

The QNX Neutrino **Makefile** system makes it very easy for us to build different processor versions. Instead of writing the entire complicated **Makefile** ourselves, we simply include various QNX Neutrino **Makefile** system files that will do most of the work for us. We just have to make sure the correct variables are defined, and variants are created.

First, let's get the source code for `lha` from *http://www2m.biglobe.ne.jp/~dolphin/lha/prog/lha-114i.tar.gz* and unarchive it:

```
tar -zxvf lha-114i.tar.gz
```

This creates a directory called **lha-114i**. If we run `make` here, everything will compile, and when it's done, we'll have a x86 binary called **lha** in the **src** directory.

A typical compile command for this application using the original **Makefile** looks like:

```
gcc -O2 -DSUPPORT_LH7 -DMKSTEMP -DNEED_INCREMENTAL_INDICATOR \
  -DTMP_FILENAME_TEMPLATE=""/tmp/lhXXXXXX"" \
  -DSYSTIME_HAS_NO_TM -DEUC -DSYSV_SYSTEM_DIR -DMKTIME \
  -c -o lharc.o lharc.c
```

We want to make sure our version compiles with the same options as the original version, so we have to make sure to include those compiler options somewhere.

Let's save the current **Makefile** as a backup:

```
cd src
mv Makefile Makefile.old
```

As mentioned above, we need to define some variables in a file somewhere that our **Makefile**s can include. The usual place to put these defines is in a **common.mk** file. We can use the `addvariant` utility to create our initial **common.mk** and new **Makefile**, like this:

```
addvariant -i OS
```

Let's go through the **common.mk** file line by line to figure out what's going on, and what we need to add:

```
ifndef QCONFIG
QCONFIG=qconfig.mk
endif
include $(QCONFIG)
```

You should never change these four lines. The default **qconfig.mk** defines a number of variables that the **Makefile** system uses.

After these lines, we can define our own variables. Let's start with:

```
INSTALLDIR=usr/bin
```

This defines where to install our binary. Third-party applications should go into **usr/bin** instead of **bin**, which is the default.

Next, we put in some packager info:

```
define PINFO
PINFO DESCRIPTION=Archiver using lha compression.
endef
```

If we define *PINFO* information like this in our **common.mk** file, a **lha.pinfo** file will be created in each of our variant directories. We'll look at this later.

After that, we add:

```
NAME=lha
```

This tells the **Makefile** system what the name of our project is. Since we're building binary executables, this will be the name of our binary.

```
#EXTRA_INCVPATH=$(PROJECT_ROOT)/includes
```

EXTRA_INCVPATH defines where our header files are located. By default, all the directories from our *PROJECT_ROOT* down to our variant directory are added to the main include paths (i.e., where it will look for header files.) In our case, all the project headers are located in the project's root directory, so we don't need an *EXTRA_INCVPATH* line. This commented-out line serves as an example.

```
EXCLUDE_OBJS=lhdir.o makezero.o
```

Ordinarily, all the source code files in the *PROJECT_ROOT* directory are compiled and linked to the final executable. If we want to exclude certain files from being compiled and linked, we specify the object files in *EXCLUDE_OBJS*.

```
CCFLAGS=-O2 -DSUPPORT_LH7 -DMKSTEMP -DNEED_INCREMENTAL_INDICATOR
  -DTMP_FILENAME_TEMPLATE=""/tmp/lhXXXXXX"" -DSYSTIME_HAS_NO_TM
  -DEUC -DSYSV_SYSTEM_DIR -DMKTIME
```

CCFLAGS defines the compiler flags. This is where we put the original compiler flags listed above.

That's all we need to add to get up and running. The last line in our **common.mk** file is:

```
include $(MKFILES_ROOT)/qtargets.mk
```

This does all the magic that figures out which CPU compiler to use, what binary to make, etc. You should never change this line.

Here's what our complete **common.mk** file looks like:

```
ifndef QCONFIG
QCONFIG=qconfig.mk
endif
include $(QCONFIG)

INSTALLDIR=usr/bin
define PINFO
```

```
PINFO DESCRIPTION=Archiver using lha compression.
endef
NAME=lha
#EXTRA_INCVPATH=$(PROJECT_ROOT)/includes
EXCLUDE_OBJS=lhdir.o makezero.o
CCFLAGS=-O2 -DSUPPORT_LH7 -DMKSTEMP -DNEED_INCREMENTAL_INDICATOR
  -DTMP_FILENAME_TEMPLATE=""/tmp/lhXXXXXX"" -DSYSTIME_HAS_NO_TM
  -DEUC -DSYSV_SYSTEM_DIR -DMKTIME

include $(MKFILES_ROOT)/qtargets.mk
```

That's it for the **common.mk** file. We'll see where it is included in **Makefile**s shortly. How about the **Makefile** that was just created for us? We'll very rarely have to change any of the **Makefile**s. Usually they just contain a `LIST=` line, depending on where they are in our directory tree, and some **Makefile** code to include the appropriate file that makes the recursion into subdirectories possible. The exception is the **Makefile** at the very bottom. More on this later.

We'll have to have a usage description for our application as well. In our case, we can get a usage message simply by running `lha` without any parameters, like this:

```
./lha 2> lha.use
```

For our final binaries, when someone types `use lha` (assuming `lha` is in their path), they'll get the proper usage message.

As described earlier in this appendix, we use a lot of subdirectories. Here are the ones we need:

Directory	Level
nto	OS
nto/x86/	CPU
nto/x86/o	Variant

Unless we'll be releasing for QNX 4 as well as the QNX Neutrino RTOS, we'll need only the **nto** directory for the OS level. For the CPU level, we'll have directories for anything we want to support: ARM and/or x86.

The final variant directory depends on what we're building, and what endian-ness we want to compile for:

- Since x86 only has little endian-ness, it doesn't have an extension.
- If there's a choice, the variant level directory name would have a **.be** or **.le** at the end (e.g., **o.le**).
- If we're building shared libraries, we'd replace the **o** variant with a **so** variant.
- If we were building shared objects that aren't meant to be linked directly with applications, we'd use a **dll** variant.
- If we were building static libraries, we'd use an **a** variant.

We're building just an executable binary, so we use the **o** variant. Each directory and subdirectory needs to have a **Makefile**. Again, for most of them we're simply including the **recurse.mk** file, which contains everything needed to recurse down our tree until we get to the **o*** directory, as well as setting a *LIST* variable, which for general use indicates where we are in our **Makefile** tree. For example, if the directory contains variants, *LIST* is set to `VARIANT`.

Let's use the `addvariant` utility to create a directory tree and appropriate **Makefile**s for our various CPUs and variants. The `addvariant` utility can do more than just add variants, but in our case, that's all we need it for. We create a variant by running:

```
addvariant nto
```

Let's do this for each of our CPUs, like this:

```
addvariant nto arm o.le
addvariant nto x86 o
```

If we look at the **Makefile** in the **lha-114i/src/nto/x86/o** directory, we see it just contains:

```
include ../../../common.mk
```

Since this is the bottom directory, we don't need to recurse any further, but rather we want to include the **common.mk** file we created earlier. We also don't need a *LIST* variable, since we have no subdirectories at this point. We now have a complete QNX Neutrino-style **Makefile** tree.

A library and an application

What if we want to distribute shared libraries (again for all the CPUs we can) and a development package as well?

Let's use the `bzip2` distribution as our example. The `bzip2` binary already comes with QNX Neutrino, but the library doesn't. You can download the source code from *http://www.bzip.org*.

This is a good example, because it contains both a library (**libbz2**) and an application (`bzip2`). Once we've downloaded it, we can extract and build it with:

```
tar -zxvf bzip2-1.0.3.tar.gz
cd bzip2-1.0.3
make
```

We notice that a typical compile looks like:

```
gcc -Wall -Winline -O2 -fomit-frame-pointer -fno-strength-reduce
    -D_FILE_OFFSET_BITS=64 -c decompress.c
```

Let's remember those options for later.

The problem with using the QNX Neutrino makefile system in this case, is that we want to make two projects: the **libbz2** library and the `bzip2` application. With the QNX Neutrino **Makefile** system, we usually have a single project.

The best solution is to separate them into different directories. Instead of moving the source code around, we'll just create two subdirectories, one called **lib**, and the other called **app**, in which we'll create the appropriate **Makefile** and **common.mk** files:

```
mkdir app
cd app
addvariant -i OS
addvariant nto arm o.le
addvariant nto x86 o
cd ..
```

```
mkdir lib
cd lib
addvariant -i OS
addvariant nto arm so.le
addvariant nto arm a.le
addvariant nto x86 so
addvariant nto x86 a
```

If we try to build either of these projects now, not much happens. This is because we haven't told the **Makefile** system where our source files are.

Let's start with the library. Its **common.mk** file already contains the default lines:

```
ifndef QCONFIG
QCONFIG=qconfig.mk
endif
include $(QCONFIG)

include $(MKFILES_ROOT)/qtargets.mk
```

Let's add a few more lines just before the line that includes **qtargets.mk**. First, we'll add the compile options it used originally:

```
CCFLAGS+=-Wall -Winline -O2 -fomit-frame-pointer -fno-strength-reduce
  -D_FILE_OFFSET_BITS=64
```

Next, let's tell it where to find the source files. The *PRODUCT_ROOT* directory is the parent directory of the *PROJECT_ROOT* directory, which is where our source code is located. Let's use that to specify where our source code is:

```
EXTRA_SRCVPATH=$(PRODUCT_ROOT)
```

Since the parent directory also contains the source code for the `bzip2` application, and we want only the object files for the **libbz** library, let's weed out the object files we don't need:

```
EXCLUDE_OBJS=bzip2recover.o bzip2.o dlltest.o spewG.o unzcrash.o
```

We should add some *PINFO* definitions and specify where to install the files (**usr/lib** in this case):

```
define PINFO
PINFO DESCRIPTION=bzip2 data compressions library
endef
INSTALLDIR=usr/lib
```

Finally, let's make sure the library has the correct name. By default, it uses the directory name of the *PROJECT_ROOT* directory. Since we don't want to call our library `lib`, let's change it:

```
NAME=bz2
```

If we now run `make` at the terminal, we can watch all of our libraries being built.

You may notice that there are **libbz2S.a** libraries being built in the **so** directories. You can use these libraries if you want to create other shared libraries that require code from this library.

What about our application, `bzip2`? Let's change into the **app** directory we built before and set up our **common.mk** file. This time, though, we exclude everything but the **bzip2.o** from our objects and add a new line:

```
LIBS+=bz2
```

Here's our complete **common.mk** file:

```
ifndef QCONFIG
QCONFIG=qconfig.mk
endif
include $(QCONFIG)

CCFLAGS+=-Wall -Winline -O2 -fomit-frame-pointer -fno-strength-reduce
  -D_FILE_OFFSET_BITS=64
EXTRA_SRCVPATH=$(PRODUCT_ROOT)
EXCLUDE_OBJS= blocksort.o bzip2recover.o bzlib.o compress.o crctable.o
   decompress.o dlltest.o huffman.o randtable.o spewG.o unzcrash.o
LIBS+=bz2
define PINFO
PINFO DESCRIPTION=bzip2 file compressor/decompressor
endef
INSTALLDIR=usr/bin
NAME=bzip2

include $(MKFILES_ROOT)/qtargets.mk
```

We can easily create our **bzip2.use** file by getting help from our previously created `bzip2` executable:

```
../bzip2 --help 2> bzip2.use
```

Now we can build our binaries, and make sure they exist:

```
make
ls -l nto/*/*/bzip2
```

Appendix C
Using GDB

QNX Neutrino-specific extensions

The QNX Neutrino implementation of GDB includes some extensions:

`target qnx`

Set the target; see "*Setting the target*."

`set nto-inherit-env`

Set where the remote process inherits its environment from; see "*Your program's environment*."

`set nto-cwd`

Set the working directory for the remote process; see "*Starting your program*."

`set nto-timeout`

Set the timeout for remote reads; see "*Setting the target*."

`upload` ***local_path remote_path***

Send a file to a remote target system.

`download` ***remote_path local_path***

Retrieve a file from a remote target system.

`info pidlist`

Display a list of processes and their process IDs on the remote system.

`info meminfo`

Display a list of memory-region mappings (shared objects) for the current process being debugged.

A quick overview of starting the debugger

To debug an application, do the following:

1. Start GDB, but don't specify the application as an argument:

   ```
   gdb
   ```

2. Load the symbol information for the application:

   ```
   file my_application
   ```

3. Set the target:

   `target qnx` *com_port_specifier* `|` *host:port*

4. Send the application to the target:

   ```
   upload my_application /tmp/my_application
   ```

5. Set any breakpoints. For example, to set a breakpoint in *main()*:

   ```
   set break main
   ```

6. Start the application:

   ```
   run
   ```

GDB commands

You can abbreviate a GDB command to the first few letters of the command name, if that abbreviation is unambiguous; and you can repeat certain GDB commands by typing just **Enter**. You can also use the **Tab** key to get GDB to fill out the rest of a word in a command (or to show you the alternatives available, if there's more than one possibility).

You may also place GDB commands in an initialization file and these commands will be run before any that have been entered via the command line. For more information, see:

- `gdb` in the *Utilities Reference*
- the GNU documentation for GDB

Command syntax

A GDB command is a single line of input. There's no limit on how long it can be. It starts with a command name, which is followed by arguments whose meaning depends on the command name.

For example, the command `step` accepts an argument that is the number of times to step, as in `step 5`. You can also use the `step` command with no arguments. Some command names don't allow any arguments.

GDB command names may always be truncated if that abbreviation is unambiguous. Other possible command abbreviations are listed in the documentation for individual commands. In some cases, even ambiguous abbreviations are allowed; for example, `s` is specifically defined as equivalent to `step` even though there are other commands whose names start with `s`. You can test abbreviations by using them as arguments to the `help` command.

A blank line as input to GDB (typing just **Enter**) means to repeat the previous command. Certain commands (for example, `run`) don't repeat this way; these are commands whose unintentional repetition might cause trouble and which you're unlikely to want to repeat.

When you repeat the `list` and `x` commands with **Enter**, they construct new arguments rather than repeat exactly as typed. This permits easy scanning of source or memory.

GDB can also use **Enter** in another way: to partition lengthy output, in a way similar to the common utility `more`. Since it's easy to press one **Enter** too many in this situation, GDB disables command repetition after any command that generates this sort of display.

Any text from a `#` to the end of the line is a comment. This is useful mainly in command files.

Command completion

GDB can fill in the rest of a word in a command for you if there's only one possibility; it can also show you what the valid possibilities are for the next word in a command, at any time. This works for GDB commands, GDB subcommands, and the names of symbols in your program.

Press the **Tab** key whenever you want GDB to fill out the rest of a word. If there's only one possibility, GDB fills in the word, and waits for you to finish the command (or press **Enter** to enter it). For example, if you type:

```
(gdb) info bre Tab
```

GDB fills in the rest of the word `breakpoints`, since that is the only `info` subcommand beginning with `bre`:

```
(gdb) info breakpoints
```

You can either press **Enter** at this point, to run the `info breakpoints` command, or backspace and enter something else, if `breakpoints` doesn't look like the command you expected. (If you were sure you wanted `info breakpoints` in the first place, you might as well just type **Enter** immediately after `info bre`, to exploit command abbreviations rather than command completion).

If there's more than one possibility for the next word when you press **Tab**, GDB sounds a bell. You can either supply more characters and try again, or just press **Tab** a second time; GDB displays all the possible completions for that word. For example, you might want to set a breakpoint on a subroutine whose name begins with `make_`, but when you type:

```
b make_Tab
```

GDB just sounds the bell. Typing **Tab** again displays all the function names in your program that begin with those characters, for example:

```
make_a_section_from_file     make_environ
make_abs_section             make_function_type
make_blockvector             make_pointer_type
make_cleanup                 make_reference_type
make_command                 make_symbol_completion_list
(gdb) b make_
```

After displaying the available possibilities, GDB copies your partial input (`b make_` in the example) so you can finish the command.

If you just want to see the list of alternatives in the first place, you can press **Esc** followed by **?** (rather than press **Tab** twice).

Sometimes the string you need, while logically a “word”, may contain parentheses or other characters that GDB normally excludes from its notion of a word. To permit word completion to work in this situation, you may enclose words in **'** (single quote marks) in GDB commands.

The most likely situation where you might need this is in typing the name of a C++ function. This is because C++ allows function overloading (multiple definitions of the same function, distinguished by argument type). For example, when you want to set a breakpoint you may need to distinguish whether you mean the version of `name` that takes an `int` parameter, `name(int)`, or the version that takes a `float` parameter, `name(float)`. To use the word-completion facilities in this situation, type a single quote `'` at the beginning of the function name. This alerts GDB that it may need to consider more information than usual when you press **Tab**, or **Esc** followed by **?**, to request word completion:

```
(gdb) b 'bubble(Esc?
bubble(double,double)    bubble(int,int)
(gdb) b 'bubble(
```

In some cases, GDB can tell that completing a name requires using quotes. When this happens, GDB inserts the quote for you (while completing as much as it can) if you don't type the quote in the first place:

```
(gdb) b bub Tab
```

GDB alters your input line to the following, and rings a bell:

```
(gdb) b 'bubble(
```

In general, GDB can tell that a quote is needed (and inserts it) if you haven't yet started typing the argument list when you ask for completion on an overloaded symbol.

Getting help

You can always ask GDB itself for information on its commands, using the command `help`.

`help` or `h`

You can use `help` (`h`) with no arguments to display a short list of named classes of commands:

```
(gdb) help
List of classes of commands:

running -- Running the program
stack -- Examining the stack
data -- Examining data
breakpoints -- Making program stop at certain
points
files -- Specifying and examining files
status -- Status inquiries
support -- Support facilities
user-defined -- User-defined commands
aliases -- Aliases of other commands
obscure -- Obscure features

Type "help" followed by a class name for a list
of commands in that class.
Type "help" followed by command name for full
documentation.
Command name abbreviations are allowed if
unambiguous.
(gdb)
```

`help` ***class***

Using one of the general help classes as an argument, you can get a list of the individual commands in that class. For example, here's the help display for the class `status`:

```
(gdb) help status
Status inquiries.

List of commands:

show -- Generic command for showing things set
with "set"
info -- Generic command for printing status

Type "help" followed by command name for full
documentation.
Command name abbreviations are allowed if
unambiguous.
(gdb)
```

`help` ***command***

With a command name as `help` argument, GDB displays a short paragraph on how to use that command.

`complete` ***args***

The `complete` *args* command lists all the possible completions for the beginning of a command. Use *args* to specify the beginning of the command you want completed. For example:

```
complete i
```

results in:

```
info
inspect
ignore
```

This is intended for use by GNU Emacs.

In addition to `help`, you can use the GDB commands `info` and `show` to inquire about the state of your program, or the state of GDB itself. Each command supports many topics of inquiry; this manual introduces each of them in the appropriate context. The listings under `info` and `show` in the index point to all the sub-commands.

`info`

This command (abbreviated `i`) is for describing the state of your program. For example, you can list the arguments given to your program with `info args`, list the registers currently in use with `info registers`, or list the breakpoints you've set with `info breakpoints`. You can get a complete list of the `info` sub-commands with `help info`.

set

You can assign the result of an expression to an environment variable with `set`. For example, you can set the GDB prompt to a $-sign with `set prompt $`.

show

In contrast to `info`, `show` is for describing the state of GDB itself. You can change most of the things you can `show`, by using the related command `set`; for example, you can control what number system is used for displays with `set radix`, or simply inquire which is currently in use with `show radix`.

To display all the settable parameters and their current values, you can use `show` with no arguments; you may also use `info set`. Both commands produce the same display.

Here are three miscellaneous `show` subcommands, all of which are exceptional in lacking corresponding `set` commands:

show version

Show what version of GDB is running. You should include this information in GDB bug-reports. If multiple versions of GDB are in use at your site, you may occasionally want to determine which version of GDB you're running; as GDB evolves, new commands are introduced, and old ones may wither away. The version number is also announced when you start GDB.

show copying

Display information about permission for copying GDB.

show warranty

Display the GNU “NO WARRANTY” statement.

Running programs under GDB

To run a program under GDB, you must first generate debugging information when you compile it. You may start GDB with its arguments, if any, in an environment of your choice. You may redirect your program's input and output, debug an already running process, or kill the process being debugged.

Compiling for debugging

Debugging information is stored in the object file; it describes the data type of each variable or function and the correspondence between source line numbers and addresses in the executable code.

To request debugging information, specify the `-g` option when you run the compiler.

GCC, the GNU C compiler, supports `-g` with or without `-O`, making it possible to debug optimized code. We recommend that you *always* use `-g` whenever you compile a program. You may think your program is correct, but there's no sense in pushing your luck.

When you debug a program compiled with `-g -O`, remember that the optimizer is rearranging your code; the debugger shows you what is really there. Don't be too surprised when the execution path doesn't exactly match your source file! An extreme example: if you define a variable, but never use it, GDB never sees that variable—because the compiler optimizes it out of existence.

Some things don't work as well with `-g -O` as with just `-g`, particularly on machines with instruction scheduling. If in doubt, recompile with `-g` alone, and if this fixes the problem, please report it to us—and include a test case.

Setting the target

If you're debugging remotely, you need to specify the target to use:

```
target qnx com_port_specifier | host:port
```

The `devc-pty` manager must be running on the machine that's running `pdebug`, and a ptyp/ttyp pair must be available.

Starting your program

The execution of a program is affected by certain information it receives from its superior. GDB provides ways to specify this information, which you must do *before* starting your program. (You can change it after starting your program, but such changes affect your program the *next* time you start it.)

This information may be divided into the following categories:

set nto-cwd ***path***

Specify the remote process's working directory. You should do this before starting your program.

run or **r**

Use the `run` command to start your program under GDB. You must first specify the program name with an argument to GDB (see the description of the `gdb` utility).

The `run` creates an inferior process and makes that process run your program.

Arguments

Specify the arguments to give your program as the arguments of the `run` command. If a shell is available on your target, the shell is used to pass the arguments, so that you may use normal conventions (such as wildcard expansion or variable substitution) in describing the arguments. You can control which shell is used with the *SHELL* environment variable. See "*Your program's arguments*."

Environment

Your program normally inherits its environment from GDB, but you can use the GDB commands `set environment` and `unset environment` to change parts of the environment that affect your program. See "*Your program's environment*."

While input and output redirection work, you can't use pipes to pass the output of the program you're debugging to another program; if you attempt this, GDB is likely to wind up debugging the wrong program.

If the modification time of your symbol file has changed since the last time GDB read its symbols, GDB discards its symbol table and reads it again. When it does this, GDB tries to retain your current breakpoints.

Here's an example of starting the program:

```
(gdb) target qnx mytst:8000
Remote debugging using mytst:8000
Remote target is little-endian
(gdb) file /tmp/helloworld
Reading symbols from /tmp/helloworld...done.
(gdb) upload /tmp/helloworld /tmp/helloworld
(gdb) b main
Breakpoint 1 at 0x804860c: file ./main.c, line 5.
(gdb) r
Starting program:
Remote: /tmp/helloworld

Breakpoint 1, main () at ./main.c:5
5       {
(gdb)
```

If your communication line is slow, you might need to set the timeout for remote reads:

`set nto-timeout` *time*

where *time* is the timeout, in seconds. The default is 10 seconds.

Your program's arguments

The arguments to your program can be specified by the arguments of the `run` command.

A `run` command with no arguments uses the same arguments used by the previous `run`, or those set by the `set args` command.

`set args`

Specify the arguments to be used the next time your program is run. If `set args` has no arguments, `run` executes your program with no arguments. Once you've run your program with arguments, using `set args` before the next `run` is the only way to run it again without arguments.

`show args`

Show the arguments to give your program when it's started.

Your program's environment

The *environment* consists of a set of environment variables and their values.

Environment variables conventionally record such things as your user name, your home directory, your terminal type, and your search path for programs to run. Usually you set up environment variables with the shell and they're inherited by all the other programs you run. When debugging, it can be useful to try running your program with a modified environment without having to start GDB over again.

`set nto-inherit-env` ***value***

If *value* is 0, the process inherits its environment from GDB. If *value* is 1 (the default), the process inherits its environment from `pdebug`.

`path` ***directory***

Add *directory* to the front of the `PATH` environment variable (the search path for executables), for both GDB and your program. You may specify several directory names, separated by a colon (**`:`**) or whitespace. If *directory* is already in the path, it's moved to the front, so it's searched sooner.

You can use the string `$cwd` to refer to the current working directory at the time GDB searches the path. A period (**`.`**) refers to the directory where you executed the `path` command. GDB replaces the period in the *directory* argument by the current path before adding *directory* to the search path.

`show paths`

Display the list of search paths for executables (the `PATH` environment variable).

`show environment` **[*varname*]**

Print the value of environment variable *varname* to be given to your program when it starts. If you don't supply *varname*, print the names and values of all environment variables to be given to your program. You can abbreviate `environment` as `env`.

`set environment` ***varname*** **[=]** ***value***

Set environment variable *varname* to *value*. The value changes for your program only, not for GDB itself. The *value* may be any string; the values of environment variables are just strings, and any interpretation is supplied by your program itself. The *value* parameter is optional; if it's eliminated, the variable is set to a null value.

For example, this command:

```
set env USER=foo
```

tells a Unix program, when subsequently run, that its user is named `foo`.

`unset environment` ***varname***

Remove variable *varname* from the environment to be passed to your program. This is different from `set env` *varname* `=`, in that `unset environment` removes the variable from the environment, rather than assign it an empty value.

Your program's input and output

By default, the program you run under GDB does input and output to the same terminal that GDB uses. GDB switches the terminal to its own terminal modes to interact with you, but it records the terminal modes your program was using and switches back to them when you continue running your program.

You can redirect your program's input and/or output using shell redirection with the `run` command. For example,

```
run > outfile
```

starts your program, diverting its output to the file **outfile**.

Debugging an already-running process

To use `attach`, you must have permission to send the process a signal.

`attach` ***process-id***

This command attaches to a running process—one that was started outside GDB. (The `info files` command shows your active targets.) The command takes as its argument a process ID. To find out a process ID, use the `pidin` utility (see the *Utilities Reference*), or use GDB's `info pidlist` command.

The `attach` command doesn't repeat if you press **Enter** a second time after executing the command.

When using `attach`, you should first use the `file` command to specify the program running in the process and load its symbol table.

The first thing GDB does after arranging to debug the specified process is to stop it. You can examine and modify an attached process with all the GDB commands that are ordinarily available when you start processes with `run`. You can insert breakpoints; you can step and continue; you can modify storage. If you want the process to continue running, use the `continue` command after attaching GDB to the process.

`detach`

When you've finished debugging the attached process, you can use the `detach` command to release it from GDB control. Detaching the process continues its execution. After the `detach` command, that process and GDB become completely independent once more, and you're ready to `attach` another process or start one with `run`. The `detach` command doesn't repeat if you press **Enter** again after executing the command.

If you exit GDB or use the `run` command while you have an attached process, you kill that process. By default, GDB asks for confirmation if you try to do either of these things; you can control whether or not you need to confirm by using the `set confirm` command.

Killing the process being debugged

This command is useful if you wish to debug a core dump instead of a running process. GDB ignores any core dump file while your program is running.

`kill`

Kill the process being debugged.

The `kill` command is also useful if you wish to recompile and relink your program. With QNX Neutrino, it's possible to modify an executable file while it's running in a process. If you want to run the new version, kill the current process; when you next type `run`, GDB notices that the file has changed, and reads the symbol table again (while trying to preserve your current breakpoint settings).

Debugging programs with multiple threads

In QNX Neutrino, a single program may have more than one *thread* of execution. Each thread has its own registers and execution stack.

GDB provides these facilities for debugging multithreaded programs:

- `thread` *threadno*, a command to switch between threads
- `info threads`, a command to inquire about existing threads
- `thread apply` [*threadno*] [*all*] *args*, a command to apply a command to a list of threads
- thread-specific breakpoints

The GDB thread debugging facility lets you observe all threads while your program runs—but whenever GDB takes control, one thread in particular is always the focus of debugging. This thread is called the *current thread*. Debugging commands show program information from the perspective of the current thread.

GDB associates its own thread number—always a single integer—with each thread in your program.

`info threads`

Display a summary of all threads currently in your program. GDB displays for each thread (in this order):

1. Thread number assigned by GDB
2. Target system's thread identifier (*systag*)
3. Current stack frame summary for that thread.

An asterisk `*` to the left of the GDB thread number indicates the current thread. For example:

```
(gdb) info threads
  3 process 35 thread 27  0x34e5 in sigpause ()
  2 process 35 thread 23  0x34e5 in sigpause ()
* 1 process 35 thread 13  main (argc=1, argv=0x7ffffff8)
    at threadtest.c:68
```

`thread` ***threadno***

Make thread number *threadno* the current thread. The command argument *threadno* is the internal GDB thread number, as shown in the first field of the `info threads` display. GDB responds by displaying the system identifier of the thread you selected and its current stack frame summary:

```
(gdb) thread 2
[Switching to process 35 thread 23]
0x34e5 in sigpause ()
```

`thread apply [`*threadno*`][all]` ***args***

The `thread apply` command lets you apply a command to one or more threads. Specify the numbers of the threads that you want affected with the command argument *threadno*. To apply a command to all threads, use `thread apply all` *args*.

Whenever GDB stops your program because of a breakpoint or a signal, it automatically selects the thread where that breakpoint or signal happened. GDB alerts you to the context switch with a message of the form `[Switching to` *systag*`]` to identify the thread.

See "*Stopping and starting multithreaded programs*" for more information about how GDB behaves when you stop and start programs with multiple threads.

See "*Setting watchpoints*" for information about watchpoints in programs with multiple threads.

Debugging programs with multiple processes

GDB has no special support for debugging programs that create additional processes using the *fork()* function. When a program forks, GDB continues to debug the parent process, and the child process runs unimpeded. If you've set a breakpoint in any code that the child then executes, the child gets a `SIGTRAP` signal, which (unless it catches the signal) causes it to terminate.

However, if you want to debug the child process, there's a workaround that isn't too painful:

1. Put a call to `raise(SIGSTOP)` in the code that the child process executes after the *fork()*. It may be useful to stop only if a certain environment variable is set, or a certain file exists, so that the child doesn't stop when you're running it without GDB.
2. While the child is stopped, get its process ID by using the `pidin` utility (see the *Utilities Reference*) or by using GDB's `info pidlist` command.
3. Tell GDB (a new invocation of GDB if you're also debugging the parent process) to attach to the child process (see "*Debugging an already-running process*"). From that point on you can debug the child process just like any other process that you've attached to.

Stopping and continuing

Inside GDB, your program may stop for any of several reasons, such as a signal, a breakpoint, or reaching a new line after a GDB command such as `step`. You may then examine and change variables, set new breakpoints or remove old ones, and then continue execution. Usually, the messages shown by GDB provide ample explanation of the status of your program—but you can also explicitly request this information at any time.

`info program`

Display information about the status of your program: whether it's running or not, what process it is, and why it stopped.

Breakpoints, watchpoints, and exceptions

A *breakpoint* makes your program stop whenever a certain point in the program is reached. For each breakpoint, you can add conditions to control in finer detail whether your program stops.

You can set breakpoints with the `break` command and its variants (see "*Setting breakpoints*") to specify the place where your program should stop by line number, function name or exact address in the program. In languages with exception handling (such as GNU C++), you can also set breakpoints where an exception is raised (see "*Breakpoints and exceptions*").

A *watchpoint* is a special breakpoint that stops your program when the value of an expression changes. You must use a different command to set watchpoints (see "*Setting watchpoints*"), but aside from that, you can manage a watchpoint like any other breakpoint: you enable, disable, and delete both breakpoints and watchpoints using the same commands.

You can arrange to have values from your program displayed automatically whenever GDB stops at a breakpoint. See "*Automatic display*."

GDB assigns a number to each breakpoint or watchpoint when you create it; these numbers are successive integers starting with 1. In many of the commands for controlling various features of breakpoints you use the breakpoint number to say which breakpoint you want to change. Each breakpoint may be *enabled* or *disabled*; if disabled, it has no effect on your program until you enable it again.

Setting breakpoints

Use the `break` (`b`) command to set breakpoints.

The debugger convenience variable `$bpnum` records the number of the breakpoints you've set most recently; see "*Convenience variables*" for a discussion of what you can do with convenience variables.

You have several ways to say where the breakpoint should go:

`break` ***function***

Set a breakpoint at entry to *function*. When using source languages such as C++ that permit overloading of symbols, *function* may refer to more than one possible place to break. See "*Breakpoint menus*" for a discussion of that situation.

break +*offset* or **break −*offset***

Set a breakpoint some number of lines forward or back from the position at which execution stopped in the currently selected frame.

break *linenum*

Set a breakpoint at line *linenum* in the current source file. That file is the last file whose source text was printed. This breakpoint stops your program just before it executes any of the code on that line.

break *filename*:*linenum*

Set a breakpoint at line *linenum* in source file *filename*.

break *filename*:*function*

Set a breakpoint at entry to *function* found in file *filename*. Specifying a filename as well as a function name is superfluous except when multiple files contain similarly named functions.

break **address*

Set a breakpoint at address *address*. You can use this to set breakpoints in parts of your program that don't have debugging information or source files.

break

When called without any arguments, `break` sets a breakpoint at the next instruction to be executed in the selected stack frame (see "*Examining the Stack*"). In any selected frame but the innermost, this makes your program stop as soon as control returns to that frame. This is similar to the effect of a `finish` command in the frame inside the selected frame—except that `finish` doesn't leave an active breakpoint. If you use `break` without an argument in the innermost frame, GDB stops the next time it reaches the current location; this may be useful inside loops.

GDB normally ignores breakpoints when it resumes execution, until at least one instruction has been executed. If it didn't do this, you wouldn't be able to proceed past a breakpoint without first disabling the breakpoint. This rule applies whether or not the breakpoint already existed when your program stopped.

break ... if *cond*

Set a breakpoint with condition *cond*; evaluate the expression *cond* each time the breakpoint is reached, and stop only if the value is nonzero—that is, if *cond* evaluates as true. The ellipsis (**...**) stands for one of the possible arguments described above (or no argument) specifying where to break. For more information on breakpoint conditions, see "*Break conditions*."

There are several variations on the `break` command, all using the same syntax as above:

tbreak

Set a breakpoint enabled only for one stop. The breakpoint is set in the same way as for the `break` command, except that it's automatically deleted after the first time your program stops there. See "*Disabling breakpoints*."

hbreak

Set a hardware-assisted breakpoint. The breakpoint is set in the same way as for the `break` command, except that it requires hardware support (and some target hardware may not have this support).

The main purpose of this is EPROM/ROM code debugging, so you can set a breakpoint at an instruction without changing the instruction.

thbreak

Set a hardware-assisted breakpoint enabled only for one stop. The breakpoint is set in the same way as for the `break` command. However, like the `tbreak` command, the breakpoint is automatically deleted after the first time your program stops there. Also, like the `hbreak` command, the breakpoint requires hardware support, which some target hardware may not have. See "*Disabling breakpoints*" and "*Break conditions*."

rbreak *regex*

Set breakpoints on all functions matching the regular expression *regex*. This command sets an unconditional breakpoint on all matches, printing a list of all breakpoints it set. Once these breakpoints are set, they're treated just like the breakpoints set with the `break` command. You can delete them, disable them, or make them conditional the same way as any other breakpoint.

When debugging you're C++ programs, `rbreak` is useful for setting breakpoints on overloaded functions that aren't members of any special classes.

The following commands display information about breakpoints and watchpoints:

info breakpoints [*n*] or info break [*n*] or info watchpoints [*n*]

Print a table of all breakpoints and watchpoints set and not deleted, with the following columns for each breakpoint:

- Breakpoint Numbers.
- Type—breakpoint or watchpoint.
- Disposition—whether the breakpoint is marked to be disabled or deleted when hit.
- Enabled or Disabled—enabled breakpoints are marked with `y`, disabled with `n`.
- Address—where the breakpoint is in your program, as a memory address.
- What—where the breakpoint is in the source for your program, as a file and line number.

If a breakpoint is conditional, `info break` shows the condition on the line following the affected breakpoint; breakpoint commands, if any, are listed after that.

An `info break` command with a breakpoint number *n* as argument lists only that breakpoint. The convenience variable `$_` and the default examining-address for the `x` command are set to the address of the last breakpoint listed (see "*Examining memory*").

The `info break` command displays the number of times the breakpoint has been hit. This is especially useful in conjunction with the `ignore` command. You can ignore a large number of breakpoint hits, look at the breakpoint information to see how many times the breakpoint was hit, and then run again, ignoring one less than that number. This gets you quickly to the last hit of that breakpoint.

GDB lets you set any number of breakpoints at the same place in your program. There's nothing silly or meaningless about this. When the breakpoints are conditional, this is even useful (see "*Break conditions*").

GDB itself sometimes sets breakpoints in your program for special purposes, such as proper handling of `longjmp` (in C programs). These internal breakpoints are assigned negative numbers, starting with `-1`; `info breakpoints` doesn't display them.

You can see these breakpoints with the GDB maintenance command, `maint info breakpoints`.

`maint info breakpoints`

Using the same format as `info breakpoints`, display both the breakpoints you've set explicitly and those GDB is using for internal purposes. The type column identifies what kind of breakpoint is shown:

- `breakpoint` — normal, explicitly set breakpoint.
- `watchpoint` — normal, explicitly set watchpoint.
- `longjmp` — internal breakpoint, used to handle correctly stepping through `longjmp` calls.
- `longjmp resume` — internal breakpoint at the target of a `longjmp`.
- `until` — temporary internal breakpoint used by the GDB `until` command.
- `finish` — temporary internal breakpoint used by the GDB `finish` command.

Setting watchpoints

You can use a watchpoint to stop execution whenever the value of an expression changes, without having to predict a particular place where this may happen.

Although watchpoints currently execute two orders of magnitude more slowly than other breakpoints, they can help catch errors where in cases where you have no clue what part of your program is the culprit.

`watch` *expr*

Set a watchpoint for an expression. GDB breaks when *expr* is written into by the program and its value changes.

`rwatch` *arg*

Set a watchpoint that breaks when watch *arg* is read by the program. If you use both watchpoints, both must be set with the `rwatch` command.

awatch ***arg***

Set a watchpoint that breaks when *arg* is read and written into by the program. If you use both watchpoints, both must be set with the `awatch` command.

info watchpoints

This command prints a list of watchpoints and breakpoints; it's the same as `info break`.

In multithreaded programs, watchpoints have only limited usefulness. With the current watchpoint implementation, GDB can watch the value of an expression *in a single thread only*. If you're confident that the expression can change due only to the current thread's activity (and if you're also confident that no other thread can become current), then you can use watchpoints as usual. However, GDB may not notice when a noncurrent thread's activity changes the expression.

Breakpoints and exceptions

Some languages, such as GNU C++, implement exception handling. You can use GDB to examine what caused your program to raise an exception and to list the exceptions your program is prepared to handle at a given point in time.

catch ***exceptions***

You can set breakpoints at active exception handlers by using the `catch` command. The *exceptions* argument is a list of names of exceptions to catch.

You can use `info catch` to list active exception handlers. See "*Information about a frame*."

There are currently some limitations to exception handling in GDB:

- If you call a function interactively, GDB normally returns control to you when the function has finished executing. If the call raises an exception, however, the call may bypass the mechanism that returns control to you and cause your program to continue running until it hits a breakpoint, catches a signal that GDB is listening for, or exits.
- You can't raise an exception interactively.
- You can't install an exception handler interactively.

Sometimes `catch` isn't the best way to debug exception handling: if you need to know exactly where an exception is raised, it's better to stop *before* the exception handler is called, since that way you can see the stack before any unwinding takes place. If you set a breakpoint in an exception handler instead, it may not be easy to find out where the exception was raised.

To stop just before an exception handler is called, you need some knowledge of the implementation. In the case of GNU C++, exceptions are raised by calling a library function named *__raise_exception()*, which has the following ANSI C interface:

```
void __raise_exception (void **addr, void *id);

/* addr is where the exception identifier is stored.
   id is the exception identifier.  */
```


To make the debugger catch all exceptions before any stack unwinding takes place, set a breakpoint on *__raise_exception()*. See "*Breakpoints, watchpoints, and exceptions*."

With a conditional breakpoint (see "*Break conditions*") that depends on the value of *id*, you can stop your program when a specific exception is raised. You can use multiple conditional breakpoints to stop your program when any of a number of exceptions are raised.

Deleting breakpoints

You often need to eliminate a breakpoint or watchpoint once it's done its job and you no longer want your program to stop there. This is called *deleting* the breakpoint. A breakpoint that has been deleted no longer exists and is forgotten.

With the `clear` command you can delete breakpoints according to where they are in your program. With the `delete` command you can delete individual breakpoints or watchpoints by specifying their breakpoint numbers.

You don't have to delete a breakpoint to proceed past it. GDB automatically ignores breakpoints on the first instruction to be executed when you continue execution without changing the execution address.

`clear`

Delete any breakpoints at the next instruction to be executed in the selected stack frame (see "*Selecting a frame*"). When the innermost frame is selected, this is a good way to delete a breakpoint where your program just stopped.

`clear` *function* or `clear` *filename*:*function*

Delete any breakpoints set at entry to *function*.

`clear` *linenum* or `clear` *filename*:*linenum*

Delete any breakpoints set at or within the code of the specified line.

`delete [breakpoints] [`*bnums*...`]`

Delete the breakpoints or watchpoints of the numbers specified as arguments. If no argument is specified, delete all breakpoints (GDB asks for confirmation, unless you've `set confirm off`). You can abbreviate this command as `d`.

Disabling breakpoints

Rather than delete a breakpoint or watchpoint, you might prefer to *disable* it. This makes the breakpoint inoperative as if it had been deleted, but remembers the information on the breakpoint so that you can *enable* it again later.

You disable and enable breakpoints and watchpoints with the `enable` and `disable` commands, optionally specifying one or more breakpoint numbers as arguments. Use `info break` or `info watch` to print a list of breakpoints or watchpoints if you don't know which numbers to use.

A breakpoint or watchpoint can have any of the following states:

Enabled

The breakpoint stops your program. A breakpoint set with the `break` command starts out in this state.

Disabled

The breakpoint has no effect on your program.

Enabled once

The breakpoint stops your program, but then becomes disabled. A breakpoint set with the `tbreak` command starts out in this state.

Enabled for deletion

The breakpoint stops your program, but immediately afterwards it's deleted permanently.

You can use the following commands to enable or disable breakpoints and watchpoints:

`disable [breakpoints][`*bnums*...]

Disable the specified breakpoints—or all breakpoints, if none is listed. A disabled breakpoint has no effect but isn't forgotten. All options such as ignore-counts, conditions and commands are remembered in case the breakpoint is enabled again later. You may abbreviate `disable` as `dis`.

`enable [breakpoints][`*bnums*...]

Enable the specified breakpoints (or all defined breakpoints). They become effective once again in stopping your program.

`enable [breakpoints] once` *bnums*...

Enable the specified breakpoints temporarily. GDB disables any of these breakpoints immediately after stopping your program.

`enable [breakpoints] delete` *bnums*...

Enable the specified breakpoints to work once, then die. GDB deletes any of these breakpoints as soon as your program stops there.

Except for a breakpoint set with `tbreak` (see "*Setting breakpoints*"), breakpoints that you set are initially enabled; subsequently, they become disabled or enabled only when you use one of the commands above. (The command `until` can set and delete a breakpoint of its own, but it doesn't change the state of your other breakpoints; see "*Continuing and stepping*.")

Break conditions

The simplest sort of breakpoint breaks every time your program reaches a specified place. You can also specify a *condition* for a breakpoint.

A condition is just a Boolean expression in your programming language (see "*Expressions*"). A breakpoint with a condition evaluates the expression each time your program reaches it, and your program stops only if the condition is *true*.

This is the converse of using assertions for program validation; in that situation, you want to stop when the assertion is violated—that is, when the condition is false. In C, if you want to test an assertion expressed by the condition *assert*, you should set the condition `!` *assert* on the appropriate breakpoint.

Conditions are also accepted for watchpoints; you may not need them, since a watchpoint is inspecting the value of an expression anyhow—but it might be simpler, say, to just set a watchpoint on a variable name, and specify a condition that tests whether the new value is an interesting one.

Break conditions can have side effects, and may even call functions in your program. This can be useful, for example, to activate functions that log program progress, or to use your own print functions to format special data structures. The effects are completely predictable unless there's another enabled breakpoint at the same address. (In that case, GDB might see the other breakpoint first and stop your program without checking the condition of this one.) Note that breakpoint commands are usually more convenient and flexible for the purpose of performing side effects when a breakpoint is reached (see "*Breakpoint command lists*").

If your program is multithreaded, calling a function in it may allow multiple threads to run, and may result in unpredictable and unwanted results.

Break conditions can be specified when a breakpoint is set, by using `if` in the arguments to the `break` command. See "*Setting breakpoints*." They can also be changed at any time with the `condition` command. The `watch` command doesn't recognize the `if` keyword; `condition` is the only way to impose a further condition on a watchpoint.

`condition` *bnum expression*

Specify *expression* as the break condition for breakpoint or watchpoint number *bnum*. After you set a condition, breakpoint *bnum* stops your program only if the value of *expression* is true (nonzero, in C). When you use `condition`, GDB checks *expression* immediately for syntactic correctness, and to determine whether symbols in it have referents in the context of your breakpoint. GDB doesn't actually evaluate *expression* at the time the `condition` command is given, however. See "*Expressions*."

`condition` *bnum*

Remove the condition from breakpoint number *bnum*. It becomes an ordinary unconditional breakpoint.

A special case of a breakpoint condition is to stop only when the breakpoint has been reached a certain number of times. This is so useful that there's a special way to do it, using the *ignore count* of the breakpoint. Every breakpoint has an ignore count, which is an integer. Most of the time, the ignore count is zero, and therefore has no effect. But if your program reaches a breakpoint whose ignore count is positive, then instead of stopping, it just decrements the ignore count by one and continues. As a result, if the ignore count value is *n*, the breakpoint doesn't stop the next *n* times your program reaches it.

`ignore` *bnum count*

Set the ignore count of breakpoint number *bnum* to *count*. The next *count* times the breakpoint is reached, your program's execution doesn't stop; other than to decrement the ignore count, GDB takes no action.

To make the breakpoint stop the next time it's reached, specify a count of zero.

When you use `continue` to resume execution of your program from a breakpoint, you can specify an ignore count directly as an argument to `continue`, rather than use `ignore`. See "*Continuing and stepping*."

If a breakpoint has a positive ignore count and a condition, the condition isn't checked. Once the ignore count reaches zero, GDB resumes checking the condition.

You could achieve the effect of the ignore count with a condition such as `$foo-- <= 0` using a debugger convenience variable that's decremented each time. See "*Convenience variables*."

Breakpoint command lists

You can give any breakpoint (or watchpoint) a series of commands to execute when your program stops due to that breakpoint. For example, you might want to print the values of certain expressions, or enable other breakpoints.

`commands [`*bnum*`]` ... *command-list* ... `end`

Specify a list of commands for breakpoint number *bnum*. The commands themselves appear on the following lines. Type a line containing just `end` to terminate the commands.

To remove all commands from a breakpoint, type `commands` and follow it immediately with `end`; that is, give no commands.

With no *bnum* argument, `commands` refers to the last breakpoint or watchpoint set (not to the breakpoint most recently encountered).

Pressing **Enter** as a means of repeating the last GDB command is disabled within a *command-list*.

You can use breakpoint commands to start your program up again. Just use the `continue` command, or `step`, or any other command that resumes execution.

Commands in *command-list* that follow a command that resumes execution are ignored. This is because any time you resume execution (even with a simple `next` or `step`), you may encounter another breakpoint—which could have its own command list, leading to ambiguities about which list to execute.

If the first command you specify in a command list is `silent`, the usual message about stopping at a breakpoint isn't printed. This may be desirable for breakpoints that are to print a specific message and then continue. If none of the remaining commands print anything, you see no sign that the breakpoint was reached. The `silent` command is meaningful only at the beginning of a breakpoint command list.

The commands `echo`, `output`, and `printf` allow you to print precisely controlled output, and are often useful in silent breakpoints.

For example, here's how you could use breakpoint commands to print the value of *x* at entry to *foo()* whenever *x* is positive:

```
break foo if x>0
commands
silent
printf "x is %d\n",x
```

```
cont
end
```

One application for breakpoint commands is to compensate for one bug so you can test for another. Put a breakpoint just after the erroneous line of code, give it a condition to detect the case in which something erroneous has been done, and give it commands to assign correct values to any variables that need them. End with the `continue` command so that your program doesn't stop, and start with the `silent` command so that no output is produced. Here's an example:

```
break 403
commands
silent
set x = y + 4
cont
end
```

Breakpoint menus

Some programming languages (notably C++) permit a single function name to be defined several times, for application in different contexts. This is called *overloading*. When a function name is overloaded, `break` *function* isn't enough to tell GDB where you want a breakpoint.

If you realize this is a problem, you can use something like:

`break` *function* `(`*types*`)`

to specify which particular version of the function you want. Otherwise, GDB offers you a menu of numbered choices for different possible breakpoints, and waits for your selection with the prompt `>`. The first two options are always `[0] cancel` and `[1] all`. Typing **1** sets a breakpoint at each definition of *function*, and typing **0** aborts the `break` command without setting any new breakpoints.

For example, the following session excerpt shows an attempt to set a breakpoint at the overloaded symbol *String::after()*. We choose three particular definitions of that function name:

```
(gdb) b String::after
[0] cancel
[1] all
[2] file:String.cc; line number:867
[3] file:String.cc; line number:860
[4] file:String.cc; line number:875
[5] file:String.cc; line number:853
[6] file:String.cc; line number:846
[7] file:String.cc; line number:735
> 2 4 6
Breakpoint 1 at 0xb26c: file String.cc, line 867.
Breakpoint 2 at 0xb344: file String.cc, line 875.
Breakpoint 3 at 0xafcc: file String.cc, line 846.
Multiple breakpoints were set.
Use the "delete" command to delete unwanted
 breakpoints.
(gdb)
```

Continuing and stepping

Continuing means resuming program execution until your program completes normally. In contrast, *stepping* means executing just one more "step" of your program, where "step" may mean either one line of source code, or one machine instruction (depending on what particular command you use).

Either when continuing or when stepping, your program may stop even sooner, due to a breakpoint or a signal. (If due to a signal, you may want to use `handle`, or use `signal 0` to resume execution. See "*Signals*.")

`continue` [*ignore-count*] or `c` [*ignore-count*] or `fg` [*ignore-count*]

Resume program execution, at the address where your program last stopped; any breakpoints set at that address are bypassed. The optional argument *ignore-count* lets you specify a further number of times to ignore a breakpoint at this location; its effect is like that of `ignore` (see "*Break conditions*").

The argument *ignore-count* is meaningful only when your program stopped due to a breakpoint. At other times, the argument to `continue` is ignored.

The synonyms `c` and `fg` are provided purely for convenience, and have exactly the same behavior as `continue`.

To resume execution at a different place, you can use `return` (see "*Returning from a function*") to go back to the calling function; or `jump` (see "*Continuing at a different address*") to go to an arbitrary location in your program.

A typical technique for using stepping is to set a breakpoint (see "*Breakpoints, watchpoints, and exceptions*") at the beginning of the function or the section of your program where a problem is believed to lie, run your program until it stops at that breakpoint, and then step through the suspect area, examining the variables that are interesting, until you see the problem happen.

`step`

Continue running your program until control reaches a different source line, then stop it and return control to GDB. This command is abbreviated as `s`.

If you use the `step` command while control is within a function that was compiled without debugging information, execution proceeds until control reaches a function that does have debugging information. Likewise, it doesn't step into a function that is compiled without debugging information. To step through functions without debugging information, use the `stepi` command, described below.

The `step` command stops only at the first instruction of a source line. This prevents multiple stops in switch statements, for loops, etc. The `step` command stops if a function that has debugging information is called within the line.

Also, the `step` command enters a subroutine only if there's line number information for the subroutine. Otherwise it acts like the `next` command.

`step` ***count***

Continue running as in `step`, but do so *count* times. If a breakpoint is reached, or a signal not related to stepping occurs before *count* steps, stepping stops right away.

`next` **[*count*]**

Continue to the next source line in the current (innermost) stack frame. This is similar to `step`, but function calls that appear within the line of code are executed without stopping. Execution stops when control reaches a different line of code at the original stack level that was executing when you gave the `next` command. This command is abbreviated as `n`.

The *count* argument is a repeat count, as for `step`.

The `next` command stops only at the first instruction of a source line. This prevents the multiple stops in switch statements, for loops, etc.

`finish`

Continue running until just after function in the selected stack frame returns. Print the returned value (if any).

Contrast this with the `return` command (see "*Returning from a function*").

`u` **or** **`until`**

Continue running until a source line past the current line in the current stack frame is reached. This command is used to avoid single-stepping through a loop more than once. It's like the `next` command, except that when `until` encounters a jump, it automatically continues execution until the program counter is greater than the address of the jump.

This means that when you reach the end of a loop after single-stepping though it, `until` makes your program continue execution until it exits the loop. In contrast, a `next` command at the end of a loop simply steps back to the beginning of the loop, which forces you to step through the next iteration.

The `until` command always stops your program if it attempts to exit the current stack frame.

The `until` command may produce somewhat counterintuitive results if the order of machine code doesn't match the order of the source lines. For example, in the following excerpt from a debugging session, the `f` (`frame`) command shows that execution is stopped at line `206`; yet when we use `until`, we get to line `195`:

```
(gdb) f
#0  main (argc=4, argv=0xf7fffae8) at m4.c:206
206                 expand_input();
(gdb) until
195             for ( ; argc > 0; NEXTARG) {
```

This happened because, for execution efficiency, the compiler had generated code for the loop closure test at the end, rather than the start, of the loop—even though the test in a C `for`-loop is written before the body of the loop. The `until` command appeared to step back to the beginning of the loop when it advanced to this expression; however, it hasn't really gone to an earlier statement—not in terms of the actual machine code.

An `until` command with no argument works by means of single instruction stepping, and hence is slower than `until` with an argument.

`until` ***location*** **or** **`u`** ***location***

Continue running your program until either the specified location is reached, or the current stack frame returns. The *location* is any of the forms of argument acceptable to `break` (see "*Setting breakpoints*"). This form of the command uses breakpoints, and hence is quicker than `until` without an argument.

`stepi [`*count*`]` **or** **`si [`*count*`]`**

Execute one machine instruction, then stop and return to the debugger.

It's often useful to do `display/i $pc` when stepping by machine instructions. This makes GDB automatically display the next instruction to be executed, each time your program stops. See "*Automatic display*."

The *count* argument is a repeat count, as in `step`.

`nexti [`*count*`]` **or** **`ni [`*count*`]`**

Execute one machine instruction, but if it's a function call, proceed until the function returns.

The *count* argument is a repeat count, as in `next`.

Signals

A signal is an asynchronous event that can happen in a program. The operating system defines the possible kinds of signals, and gives each kind a name and a number.

The table below gives several examples of signals:

Signal:	Received when:
`SIGINT`	You type an interrupt, **Ctrl–C**
`SIGSEGV`	The program references a place in memory far away from all the areas in use.
`SIGALRM`	The alarm clock timer goes off (which happens only if your program has requested an alarm).

Some signals, including `SIGALRM`, are a normal part of the functioning of your program. Others, such as `SIGSEGV`, indicate errors; these signals are *fatal* (killing your program immediately) if the program hasn't specified in advance some other way to handle the signal. `SIGINT` doesn't indicate an error in your program, but it's normally fatal so it can carry out the purpose of the interrupt: to kill the program.

GDB has the ability to detect any occurrence of a signal in your program. You can tell GDB in advance what to do for each kind of signal. Normally, it's set up to:

- Ignore signals like `SIGALRM` that don't indicate an error so as not to interfere with their role in the functioning of your program.
- Stop your program immediately whenever an error signal happens.

You can change these settings with the `handle` command.

`info signals` or **`info handle`**

Print a table of all the kinds of signals and how GDB has been told to handle each one. You can use this to see the signal numbers of all the defined types of signals.

`handle` *signal keywords*...

Change the way GDB handles signal *signal*. The *signal* can be the number of a signal or its name (with or without the `SIG` at the beginning). The *keywords* say what change to make.

The keywords allowed by the `handle` command can be abbreviated. Their full names are:

`nostop`

GDB shouldn't stop your program when this signal happens. It may still print a message telling you that the signal has come in.

`stop`

GDB should stop your program when this signal happens. This implies the `print` keyword as well.

`print`

GDB should print a message when this signal happens.

`noprint`

GDB shouldn't mention the occurrence of the signal at all. This implies the `nostop` keyword as well.

`pass`

GDB should allow your program to see this signal; your program can handle the signal, or else it may terminate if the signal is fatal and not handled.

`nopass`

GDB shouldn't allow your program to see this signal.

When a signal stops your program, the signal isn't visible until you continue. Your program sees the signal then, if `pass` is in effect for the signal in question *at that time*. In other words, after GDB reports a signal, you can use the `handle` command with `pass` or `nopass` to control whether your program sees that signal when you continue.

You can also use the `signal` command to prevent your program from seeing a signal, or cause it to see a signal it normally doesn't see, or to give it any signal at any time. For example, if your program stopped due to some sort of memory reference error, you might store correct values into the erroneous variables and continue, hoping to see more execution; but your program would probably terminate immediately as a result of the fatal signal once it saw the signal. To prevent this, you can continue with `signal 0`. See "*Giving your program a signal*."

Stopping and starting multithreaded programs

When your program has multiple threads, you can choose whether to set breakpoints on all threads, or on a particular thread.

(See "*Debugging programs with multiple threads*.")

break *linespec* thread *threadno* or break *linespec* thread *threadno* if ...

The *linespec* specifies source lines; there are several ways of writing them, but the effect is always to specify some source line.

Use the qualifier `thread` *threadno* with a breakpoint command to specify that you want GDB to stop the program only when a particular thread reaches this breakpoint. The *threadno* is one of the numeric thread identifiers assigned by GDB, shown in the first column of the `info threads` display.

If you don't specify `thread` *threadno* when you set a breakpoint, the breakpoint applies to *all* threads of your program.

You can use the `thread` qualifier on conditional breakpoints as well; in this case, place `thread` *threadno* before the breakpoint condition, like this:

```
(gdb) break frik.c:13 thread 28 if bartab > lim
```

Thread-specific breakpoints are implemented on the `gdb` side by stopping any thread that hits the instruction, and then determining if that thread is the desired one. This can cause threads to be reordered in scheduling lists, and may cause the desired thread to never reach the breakpoint in question.

Whenever your program stops under GDB for any reason, *all* threads of execution stop, not just the current thread. This lets you examine the overall state of the program, including switching between threads, without worrying that things may change underfoot.

Conversely, whenever you restart the program, *all* threads start executing. *This is true even when single-stepping* with commands like `step` or `next`, or when functions are called in a breakpoint condition.

In particular, GDB can't single-step all threads in lockstep. Since thread scheduling is up to the microkernel (not controlled by GDB), other threads may execute more than one statement while the current thread completes a single step. Moreover, in general, other threads stop in the middle of a statement, rather than at a clean statement boundary, when the program stops.

You might even find your program stopped in another thread after continuing or even single-stepping. This happens whenever some other thread runs into a breakpoint, a signal, or an exception before the first thread completes whatever you requested.

Examining the stack

When your program has stopped, the first thing you need to know is where it stopped and how it got there.

Each time your program performs a function call, information about the call is generated. That information includes the location of the call in your program, the arguments of the call, and the local variables of the function being called. The information is saved in a block of data called a *stack frame*. The stack frames are allocated in a region of memory called the *call stack*.

When your program stops, the GDB commands for examining the stack allow you to see all of this information.

One of the stack frames is *selected* by GDB, and many GDB commands refer implicitly to the selected frame. In particular, whenever you ask GDB for the value of a variable in your program, the value is found in the selected frame. There are special GDB commands to select whichever frame you're interested in. See "*Selecting a frame*."

When your program stops, GDB automatically selects the currently executing frame and describes it briefly, similar to the `frame` command (see "*Information about a frame*").

Stack frames

The call stack is divided up into contiguous pieces called *stack frames*, or *frames* for short; each frame is the data associated with one call to one function. The frame contains the arguments given to the function, the function's local variables, and the address at which the function is executing.

When your program is started, the stack has only one frame, that of the function *main()*. This is called the *initial* frame or the *outermost* frame. Each time a function is called, a new frame is made. Each time a function returns, the frame for that function invocation is eliminated. If a function is recursive, there can be many frames for the same function. The frame for the function in which execution is actually occurring is called the *innermost* frame. This is the most recently created of all the stack frames that still exist.

Inside your program, stack frames are identified by their addresses. A stack frame consists of many bytes, each of which has its own address; each kind of computer has a convention for choosing one byte whose address serves as the address of the frame. Usually this address is kept in a register called the *frame pointer register* while execution is going on in that frame.

GDB assigns numbers to all existing stack frames, starting with 0 for the innermost frame, 1 for the frame that called it, and so on upward. These numbers don't really exist in your program; they're assigned by GDB to give you a way of designating stack frames in GDB commands.

Some compilers provide a way to compile functions so that they operate without stack frames. (For example, the `gcc` option `-fomit-frame-pointer` generates functions without a frame.) This is occasionally done with heavily used library functions to reduce the time required to set up the frame. GDB has limited facilities for dealing with these function invocations. If the innermost function invocation has no stack frame, GDB nevertheless regards it as though it had a separate frame, which is numbered 0 as usual, allowing correct tracing of the function call chain. However, GDB has no provision for frameless functions elsewhere in the stack.

`frame` ***args***

The `frame` command lets you move from one stack frame to another, and to print the stack frame you select. The *args* may be either the address of the frame or the stack frame number. Without an argument, `frame` prints the current stack frame.

`select-frame`

The `select-frame` command lets you move from one stack frame to another without printing the frame. This is the silent version of `frame`.

Backtraces

A backtrace is a summary of how your program got where it is. It shows one line per frame, for many frames, starting with the currently executing frame (frame 0), followed by its caller (frame 1), and on up the stack.

`backtrace` or **`bt`**

Print a backtrace of the entire stack, with one line per frame, for all frames in the stack.

You can stop the backtrace at any time by typing the system interrupt character, normally **Ctrl–C**.

`backtrace` ***n*** or **`bt`** ***n***

Similar, but print only the innermost *n* frames.

`backtrace -`***n*** or **`bt -`*****n***

Similar, but print only the outermost *n* frames.

The names `where` and `info stack` (`info s`) are additional aliases for `backtrace`.

Each line in the backtrace shows the frame number and the function name. The program counter value is also shown—unless you use `set print address off`. The backtrace also shows the source filename and line number, as well as the arguments to the function. The program counter value is omitted if it's at the beginning of the code for that line number.

Here's an example of a backtrace. It was made with the command `bt 3`, so it shows the innermost three frames:

```
#0  m4_traceon (obs=0x24eb0, argc=1, argv=0x2b8c8)
    at builtin.c:993
#1  0x6e38 in expand_macro (sym=0x2b600) at macro.c:242
#2  0x6840 in expand_token (obs=0x0, t=177664, td=0xf7fffb08)
    at macro.c:71
(More stack frames follow...)
```

The display for frame 0 doesn't begin with a program counter value, indicating that your program has stopped at the beginning of the code for line `993` of `builtin.c`.

Selecting a frame

Most commands for examining the stack and other data in your program work on whichever stack frame is selected at the moment. Here are the commands for selecting a stack frame; all of them finish by printing a brief description of the stack frame just selected.

`frame` *n* or `f` *n*

Select frame number *n*. Recall that frame 0 is the innermost (currently executing) frame, frame 1 is the frame that called the innermost one, and so on. The highest-numbered frame is the one for `main`.

`frame` *addr* or `f` *addr*

Select the frame at address *addr*. This is useful mainly if the chaining of stack frames has been damaged by a bug, making it impossible for GDB to assign numbers properly to all frames. In addition, this can be useful when your program has multiple stacks and switches between them.

`up` *n*

Move *n* frames up the stack. For positive numbers, this advances toward the outermost frame, to higher frame numbers, to frames that have existed longer. The default for *n* is `1`.

`down` *n*

Move *n* frames down the stack. For positive numbers, this advances toward the innermost frame, to lower frame numbers, to frames that were created more recently. The default for *n* is `1`. You may abbreviate `down` as `do`.

All of these commands end by printing two lines of output describing the frame. The first line shows the frame number, the function name, the arguments, and the source file and line number of execution in that frame. The second line shows the text of that source line.

For example:

```
(gdb) up
#1  0x22f0 in main (argc=1, argv=0xf7fffbf4, env=0xf7fffbfc)
    at env.c:10
10              read_input_file (argv[i]);
```

After such a printout, the `list` command with no arguments prints ten lines centered on the point of execution in the frame. See "*Printing source lines*."

`up-silently` *n* or `down-silently` *n*

These two commands are variants of `up` and `down`; they differ in that they do their work silently, without causing display of the new frame. They're intended primarily for use in GDB command scripts, where the output might be unnecessary and distracting.

Information about a frame

There are several other commands to print information about the selected stack frame:

`frame` or **`f`**

When used without any argument, this command doesn't change which frame is selected, but prints a brief description of the currently selected stack frame. It can be abbreviated `f`. With an argument, this command is used to select a stack frame. See "*Selecting a frame*."

`info frame` or **`info f`**

This command prints a verbose description of the selected stack frame, including:

- the address of the frame
- the address of the next frame down (called by this frame)
- the address of the next frame up (caller of this frame)
- the language in which the source code corresponding to this frame is written
- the address of the frame's arguments
- the program counter saved in it (the address of execution in the caller frame)
- which registers were saved in the frame

The verbose description is useful when something has gone wrong that has made the stack format fail to fit the usual conventions.

`info frame` ***addr*** or **`info f`** ***addr***

Print a verbose description of the frame at address *addr*, without selecting that frame. The selected frame remains unchanged by this command. This requires the same kind of address (more than one for some architectures) that you specify in the `frame` command. See "*Selecting a frame*."

`info args`

Print the arguments of the selected frame, each on a separate line.

`info locals`

Print the local variables of the selected frame, each on a separate line. These are all variables (declared either static or automatic) accessible at the point of execution of the selected frame.

`info catch`

Print a list of all the exception handlers that are active in the current stack frame at the current point of execution. To see other exception handlers, visit the associated frame (using the `up`, `down`, or `frame` commands); then type `info catch`. See "*Breakpoints and exceptions*."

Examining source files

GDB can print parts of your program's source, since the debugging information recorded in the program tells GDB what source files were used to build it. When your program stops, GDB spontaneously prints the line where it stopped.

Likewise, when you select a stack frame (see "*Selecting a frame*"), GDB prints the line where execution in that frame has stopped. You can print other portions of source files by explicit command.

Printing source lines

To print lines from a source file, use the `list` (`l`) command.

By default, ten lines are printed. There are several ways to specify what part of the file you want to print. Here are the forms of the `list` command most commonly used:

`list` ***linenum***

Print lines centered around line number *linenum* in the current source file.

`list` ***function***

Print lines centered around the beginning of function *function*.

`list`

Print more lines. If the last lines printed were printed with a `list` command, this prints lines following the last lines printed; however, if the last line printed was a solitary line printed as part of displaying a stack frame (see "*Examining the Stack*"), this prints lines centered around that line.

`list -`

Print lines just before the lines last printed.

By default, GDB prints ten source lines with any of these forms of the `list` command. You can change this using `set listsize`:

`set listsize` ***count***

Make the `list` command display *count* source lines (unless the `list` argument explicitly specifies some other number).

`show listsize`

Display the number of lines that `list` prints.

Repeating a `list` command with **Enter** discards the argument, so it's equivalent to typing just `list`. This is more useful than listing the same lines again. An exception is made for an argument of −; that argument is preserved in repetition so that each repetition moves up in the source file.

In general, the `list` command expects you to supply zero, one or two *linespecs*. Linespecs specify source lines; there are several ways of writing them but the effect is always to specify some source line. Here's a complete description of the possible arguments for `list`:

`list` *linespec*

Print lines centered around the line specified by *linespec*.

`list` *first*,*last*

Print lines from *first* to *last*. Both arguments are linespecs.

`list` *, last*

Print lines ending with *last*.

`list` *first ,*

Print lines starting with *first*.

`list +`

Print lines just after the lines last printed.

`list -`

Print lines just before the lines last printed.

`list`

As described in the preceding table.

Here are the ways of specifying a single source line—all the kinds of *linespec*:

number

Specifies line *number* of the current source file. When a `list` command has two linespecs, this refers to the same source file as the first linespec.

+ offset

Specifies the line *offset* lines after the last line printed. When used as the second linespec in a `list` command that has two, this specifies the line *offset* lines down from the first linespec.

– offset

Specifies the line *offset* lines before the last line printed.

filename*:*number

Specifies line *number* in the source file *filename*.

function

Specifies the line that begins the body of the function *function*. For example: in C, this is the line with the open brace, `}`.

filename*:*function

Specifies the line of the open brace that begins the body of *function* in the file *filename*. You need the filename with a function name only to avoid ambiguity when there are identically named functions in different source files.

address

Specifies the line containing the program address *address*. The *address* may be any expression.

Searching source files

The commands for searching through the current source file for a regular expression are:

`forward-search` *regexp* or `search` *regexp* or `fo` *regexp*

Check each line, starting with the one following the last line listed, for a match for *regexp*, listing the line found.

`reverse-search` *regexp* or `rev` *regexp*

Check each line, starting with the one before the last line listed and going backward, for a match for *regexp*, listing the line found.

Specifying source directories

Executable programs sometimes don't record the directories of the source files from which they were compiled, just the names. Even when they do, the directories could be moved between the compilation and your debugging session. GDB has a list of directories to search for source files; this is called the *source path*. Each time GDB wants a source file, it tries all the directories in the list, in the order they're present in the list, until it finds a file with the desired name.

If GDB can't find a source file in the source path, and the object program records a directory, GDB tries that directory too. If the source path is empty, and there's no record of the compilation directory, GDB looks in the current directory as a last resort.

Whenever you reset or rearrange the source path, GDB clears out any information it has cached about where source files are found and where each line is in the file.

When you start GDB, its source path is empty. To add other directories, use the `directory` command.

`directory` *dirname* ... or `dir` *dirname* ...

Add directory *dirname* to the front of the source path. Several directory names may be given to this command, separated by colons (`:`) or whitespace. You may specify a directory that is already in the source path; this moves it forward, so GDB searches it sooner.

You can use the string `$cdir` to refer to the compilation directory (if one is recorded), and `$cwd` to refer to the current working directory. Note that `$cwd` isn't the same as a period (`.`); the former tracks the current working directory as it changes during your GDB session, while the latter is immediately expanded to the current directory at the time you add an entry to the source path.

`directory`

Reset the source path to empty again. This requires confirmation.

show directories

Print the source path: show which directories it contains.

If your source path is cluttered with directories that are no longer of interest, GDB may sometimes cause confusion by finding the wrong versions of source. You can correct the situation as follows:

1. Use `directory` with no argument to reset the source path to empty.
2. Use `directory` with suitable arguments to reinstall the directories you want in the source path. You can add all the directories in one command.

Source and machine code

You can use the command `info line` to map source lines to program addresses (and vice versa), and the command `disassemble` to display a range of addresses as machine instructions. When run under GNU Emacs mode, the `info line` command causes the arrow to point to the line specified. Also, `info line` prints addresses in symbolic form as well as hex.

info line *linespec*

Print the starting and ending addresses of the compiled code for source line *linespec*. You can specify source lines in any of the ways understood by the `list` command (see "*Printing source lines*").

For example, we can use `info line` to discover the location of the object code for the first line of function `m4_changequote:`

```
(gdb) info line m4_changecom
Line 895 of "builtin.c" starts at pc 0x634c and ends at 0x6350.
```

We can also inquire (using ** addr* as the form for *linespec*) what source line covers a particular address:

```
(gdb) info line *0x63ff
Line 926 of "builtin.c" starts at pc 0x63e4 and ends at 0x6404.
```

After `info line`, the default address for the `x` command is changed to the starting address of the line, so that `x/i` is sufficient to begin examining the machine code (see "*Examining memory*"). Also, this address is saved as the value of the convenience variable `$_` (see "*Convenience variables*").

disassemble

This specialized command dumps a range of memory as machine instructions. The default memory range is the function surrounding the program counter of the selected frame. A single argument to this command is a program counter value; GDB dumps the function surrounding this value. Two arguments specify a range of addresses (first inclusive, second exclusive) to dump.

We can use `disassemble` to inspect the object code range shown in the last `info line` example (the example shows SPARC machine instructions):

```
(gdb) disas 0x63e4 0x6404
Dump of assembler code from 0x63e4 to 0x6404:
0x63e4 <builtin_init+5340>:     ble 0x63f8 <builtin_init+5360>
0x63e8 <builtin_init+5344>:     sethi %hi(0x4c00), %o0
```

```
0x63ec <builtin_init+5348>:     ld [%i1+4], %o0
0x63f0 <builtin_init+5352>:     b 0x63fc <builtin_init+5364>
0x63f4 <builtin_init+5356>:     ld [%o0+4], %o0
0x63f8 <builtin_init+5360>:     or %o0, 0x1a4, %o0
0x63fc <builtin_init+5364>:     call 0x9288 <path_search>
0x6400 <builtin_init+5368>:     nop
End of assembler dump.
```

`set assembly-language` ***instruction-set***

This command selects the instruction set to use when disassembling the program via the `disassemble` or `x/i` commands. It's useful for architectures that have more than one native instruction set.

Currently it's defined only for the Intel x86 family. You can set *instruction-set* to either `i386` or `i8086`. The default is `i386`.

Shared libraries

You can use the following commands when working with shared libraries:

`sharedlibrary` **[*regexp*]**

Load shared object library symbols for files matching the given regular expression, *regexp*. If *regexp* is omitted, GDB tries to load symbols for all loaded shared libraries.

`info sharedlibrary`

Display the status of the loaded shared object libraries.

The following parameters apply to shared libraries:

`set solib-search-path` ***dir*[:*dir*...]**

Set the search path for loading shared library symbols files that don't have an absolute path. This path overrides the *PATH* and *LD_LIBRARY_PATH* environment variables.

`set solib-absolute-prefix` ***prefix***

Set the prefix for loading absolute shared library symbol files.

`set auto-solib-add` ***value***

Make the loading of shared library symbols automatic or manual:

- If *value* is nonzero, symbols from all shared object libraries are loaded automatically when the inferior process (i.e., the one being debugged) begins execution, or when the runtime linker informs GDB that a new library has been loaded.
- If *value* is zero, symbols must be loaded manually with the `sharedlibrary` command.

You can query the settings of these parameters with the `show solib-search-path`, `show solib-absolute-prefix`, and `show auto-solib-add` commands.

Examining data

The usual way to examine data in your program is with the `print` (`p`) command or its synonym `inspect`. It evaluates and prints the value of an expression of the language your program is written in.

`print` *exp* or `print /` *f exp*

exp is an expression (in the source language). By default, the value of *exp* is printed in a format appropriate to its data type; you can choose a different format by specifying `/` *f*, where *f* is a letter specifying the format; see "*Output formats*."

`print` or `print /` *f*

If you omit *exp*, GDB displays the last value again (from the *value history*; see "*Value history*"). This lets you conveniently inspect the same value in an alternative format.

A lower-level way of examining data is with the `x` command. It examines data in memory at a specified address and prints it in a specified format. See "*Examining memory*."

If you're interested in information about types, or about how the fields of a structure or class are declared, use the `ptype` *exp* command rather than `print`. See "*Examining the symbol table*."

Expressions

The `print` command and many other GDB commands accept an expression and compute its value. Any kind of constant, variable or operator defined by the programming language you're using is valid in an expression in GDB. This includes conditional expressions, function calls, casts and string constants. It unfortunately doesn't include symbols defined by preprocessor `#define` commands.

GDB supports array constants in expressions input by the user. The syntax is `{` *element, element...* `}`. For example, you can use the command `print {1, 2, 3}` to build up an array in memory that is *malloc*'d in the target program.

Because C is so widespread, most of the expressions shown in examples in this manual are in C. In this section, we discuss operators that you can use in GDB expressions regardless of your programming language.

Casts are supported in all languages, not just in C, because it's useful to cast a number into a pointer in order to examine a structure at that address in memory.

GDB supports these operators, in addition to those common to programming languages:

`@`

Binary operator for treating parts of memory as arrays. See "*Artificial arrays*" for more information.

`::`

Lets you specify a variable in terms of the file or function where it's defined. See "*Program variables*."

{ *type* } *addr*

Refers to an object of type *type* stored at address *addr* in memory. The *addr* may be any expression whose value is an integer or pointer (but parentheses are required around binary operators, just as in a cast). This construct is allowed regardless of what kind of data is normally supposed to reside at *addr*.

Program variables

The most common kind of expression to use is the name of a variable in your program.

Variables in expressions are understood in the selected stack frame (see "*Selecting a frame*"); they must be either:

- global (or static)

  Or:

- visible according to the scope rules of the programming language from the point of execution in that frame

This means that in the function:

```
foo (a)
     int a;
{
  bar (a);
  {
    int b = test ();
    bar (b);
  }
}
```

you can examine and use the variable *a* whenever your program is executing within the function *foo()*, but you can use or examine the variable *b* only while your program is executing inside the block where *b* is declared.

There's an exception: you can refer to a variable or function whose scope is a single source file even if the current execution point isn't in this file. But it's possible to have more than one such variable or function with the same name (in different source files). If that happens, referring to that name has unpredictable effects. If you wish, you can specify a static variable in a particular function or file, using the colon-colon notation:

file`::`*variable*
function`::`*variable*

Here *file* or *function* is the name of the context for the static *variable*. In the case of filenames, you can use quotes to make sure GDB parses the filename as a single word. For example, to print a global value of `x` defined in **f2.c**:

```
(gdb) p 'f2.c'::x
```

This use of `::` is very rarely in conflict with the very similar use of the same notation in C++. GDB also supports use of the C++ scope resolution operator in GDB expressions.

Occasionally, a local variable may appear to have the wrong value at certain points in a function, such as just after entry to a new scope, and just before exit.

You may see this problem when you're stepping by machine instructions. This is because, on most machines, it takes more than one instruction to set up a stack frame (including local variable definitions); if you're stepping by machine instructions, variables may appear to have the wrong values until the stack frame is completely built. On exit, it usually also takes more than one machine instruction to destroy a stack frame; after you begin stepping through that group of instructions, local variable definitions may be gone.

Artificial arrays

It's often useful to print out several successive objects of the same type in memory; a section of an array, or an array of dynamically determined size for which only a pointer exists in the program.

You can do this by referring to a contiguous span of memory as an *artificial array*, using the binary operator `@`. The left operand of `@` should be the first element of the desired array and be an individual object. The right operand should be the desired length of the array. The result is an array value whose elements are all of the type of the left operand. The first element is actually the left operand; the second element comes from bytes of memory immediately following those that hold the first element, and so on. For example, if a program says:

```
int *array = (int *) malloc (len * sizeof (int));
```

you can print the contents of `array` with:

```
p *array@len
```

The left operand of `@` must reside in memory. Array values made with `@` in this way behave just like other arrays in terms of subscripting, and are coerced to pointers when used in expressions. Artificial arrays most often appear in expressions via the value history (see "*Value history*"), after printing one out.

Another way to create an artificial array is to use a cast. This reinterprets a value as if it were an array. The value need not be in memory:

```
(gdb) p/x (short[2])0x12345678
$1 = {0x1234, 0x5678}
```

As a convenience, if you leave the array length out—as in (*type*[])*value*—`gdb` calculates the size to fill the value as `sizeof`(*value*)`/sizeof`(*type*). For example:

```
(gdb) p/x (short[])0x12345678
$2 = {0x1234, 0x5678}
```

Sometimes the artificial array mechanism isn't quite enough; in moderately complex data structures, the elements of interest may not actually be adjacent—for example, if you're interested in the values of pointers in an array. One useful workaround in this situation is to use a convenience variable (see "*Convenience variables*") as a counter in an expression that prints the first interesting value, and then repeat that expression via **Enter**. For instance, suppose you have an array *dtab* of pointers to structures, and you're interested in the values of a field *fv* in each structure. Here's an example of what you might type:

```
set $i = 0
p dtab[$i++]->fv
Enter
Enter
...
```

Output formats

By default, GDB prints a value according to its data type. Sometimes this isn't what you want. For example, you might want to print a number in hex, or a pointer in decimal. Or you might want to view data in memory at a certain address as a character string or as an instruction. To do these things, specify an *output format* when you print a value.

The simplest use of output formats is to say how to print a value already computed. This is done by starting the arguments of the `print` command with a slash and a format letter. The format letters supported are:

x

Regard the bits of the value as an integer, and print the integer in hexadecimal.

d

Print as integer in signed decimal.

u

Print as integer in unsigned decimal.

o

Print as integer in octal.

t

Print as integer in binary. The letter `t` stands for `two`. (The letter `b` can't be used because these format letters are also used with the `x` command, where `b` stands for `byte`. See "*Examining memory*.")

a

Print as an address, both absolute in hexadecimal and as an offset from the nearest preceding symbol. You can use this format used to discover where (in what function) an unknown address is located:

```
(gdb) p/a 0x54320
$3 = 0x54320 <_initialize_vx+396>
```

c

Regard as an integer and print it as a character constant.

f

Regard the bits of the value as a floating point number and print using typical floating point syntax.

For example, to print the program counter in hex (see “*Registers*”), type:

```
p/x $pc
```

No space is required before the slash; this is because command names in GDB can't contain a slash.

To reprint the last value in the value history with a different format, you can use the `print` command with just a format and no expression. For example, `p/x` reprints the last value in hex.

Examining memory

You can use the command `x` (for “examine”) to examine memory in any of several formats, independently of your program's data types.

x/ *nfu addr* **or x *addr*** **or x**

Use the `x` command to examine memory.

The *n*, *f*, and *u* are all optional parameters that specify how much memory to display and how to format it; *addr* is an expression giving the address where you want to start displaying memory. If you use defaults for *nfu*, you need not type the slash `/`. Several commands set convenient defaults for *addr*.

n

The repeat count is a decimal integer; the default is 1. It specifies how much memory (counting by units *u*) to display.

f

The display format is one of the formats used by `print`, `s` (null-terminated string), or `i` (machine instruction). The default is `x` (hexadecimal) initially. The default changes each time you use either `x` or `print`.

u

The unit size is any of:

- `b`—bytes.
- `h`—halfwords (two bytes).
- `w`—words (four bytes). This is the initial default.
- `g`—giant words (eight bytes).

Each time you specify a unit size with `x`, that size becomes the default unit the next time you use `x`. (For the `s` and `i` formats, the unit size is ignored and isn't normally written.)

addr

The address where you want GDB to begin displaying memory. The expression need not have a pointer value (though it may); it's always interpreted as an integer address of a byte of memory. See "*Expressions*" for more information on expressions. The default for *addr* is usually just after the last address examined—but several other commands also set the default address: `info breakpoints` (to the address of the last breakpoint listed), `info line` (to the starting address of a line), and `print` (if you use it to display a value from memory).

For example, `x/3uh 0x54320` is a request to display three halfwords (`h`) of memory, formatted as unsigned decimal integers (`u`), starting at address `0x54320`. The `x/4xw $sp` command prints the four words (`w`) of memory above the stack pointer (here, `$sp`; see "*Registers*") in hexadecimal (`x`).

Since the letters indicating unit sizes are all distinct from the letters specifying output formats, you don't have to remember whether unit size or format comes first; either order works. The output specifications `4xw` and `4wx` mean exactly the same thing. (However, the count *n* must come first; `wx4` doesn't work.)

Even though the unit size *u* is ignored for the formats `s` and `i`, you might still want to use a count *n*; for example, `3i` specifies that you want to see three machine instructions, including any operands. The command `disassemble` gives an alternative way of inspecting machine instructions; see "*Source and machine code*."

All the defaults for the arguments to `x` are designed to make it easy to continue scanning memory with minimal specifications each time you use `x`. For example, after you've inspected three machine instructions with `x/3i` *addr*, you can inspect the next seven with just `x/7`. If you use **Enter** to repeat the `x` command, the repeat count *n* is used again; the other arguments default as for successive uses of `x`.

The addresses and contents printed by the `x` command aren't saved in the value history because there's often too much of them and they would get in the way. Instead, GDB makes these values available for subsequent use in expressions as values of the convenience variables `$_` and `$__`. After an `x` command, the last address examined is available for use in expressions in the convenience variable `$_`. The contents of that address, as examined, are available in the convenience variable `$__`.

If the `x` command has a repeat count, the address and contents saved are from the last memory unit printed; this isn't the same as the last address printed if several units were printed on the last line of output.

Automatic display

If you find that you want to print the value of an expression frequently (to see how it changes), you might want to add it to the *automatic display list* so that GDB prints its value each time your program stops.

Each expression added to the list is given a number to identify it; to remove an expression from the list, you specify that number. The automatic display looks like this:

```
2: foo = 38
3: bar[5] = (struct hack *) 0x3804
```

This display shows item numbers, expressions and their current values. As with displays you request manually using `x` or `print`, you can specify the output format you prefer; in fact, `display` decides whether to use `print` or `x` depending on how elaborate your format specification is—it uses `x` if you specify a unit size, or one of the two formats (`i` and `s`) that are supported only by `x`; otherwise it uses `print`.

`display` ***exp***

Add the expression *exp* to the list of expressions to display each time your program stops. See "*Expressions*." The `display` command doesn't repeat if you press **Enter** again after using it.

`display/` ***fmt exp***

For *fmt* specifying only a display format and not a size or count, add the expression *exp* to the auto-display list but arrange to display it each time in the specified format *fmt*. See "*Output formats*."

`display/` ***fmt addr***

For *fmt* `i` or `s`, or including a unit-size or a number of units, add the expression *addr* as a memory address to be examined each time your program stops. Examining means in effect doing `x/` *fmt addr*. See "*Examining memory*."

For example, `display/i $pc` can be helpful, to see the machine instruction about to be executed each time execution stops (`$pc` is a common name for the program counter; see "*Registers*").

`undisplay` ***dnums***... or **`delete display`** ***dnums***...

Remove item numbers *dnums* from the list of expressions to display.

The `undisplay` command doesn't repeat if you press **Enter** after using it. (Otherwise you'd just get the error `No display number ...`.)

`disable display` ***dnums***...

Disable the display of item numbers *dnums*. A disabled display item isn't printed automatically, but isn't forgotten; it may be enabled again later.

`enable display` ***dnums***...

Enable the display of item numbers *dnums*. It becomes effective once again in auto display of its expression, until you specify otherwise.

display

Display the current values of the expressions on the list, just as is done when your program stops.

info display

Print the list of expressions previously set up to display automatically, each one with its item number, but without showing the values. This includes disabled expressions, which are marked as such. It also includes expressions that wouldn't be displayed right now because they refer to automatic variables not currently available.

If a display expression refers to local variables, it doesn't make sense outside the lexical context for which it was set up. Such an expression is disabled when execution enters a context where one of its variables isn't defined.

For example, if you give the command `display last_char` while inside a function with an argument *last_char*, GDB displays this argument while your program continues to stop inside that function. When it stops where there's no variable *last_char*, the display is disabled automatically. The next time your program stops where *last_char* is meaningful, you can enable the display expression once again.

Print settings

GDB provides the following ways to control how arrays, structures, and symbols are printed.

These settings are useful for debugging programs in any language:

set print address or **set print address on**

GDB prints memory addresses showing the location of stack traces, structure values, pointer values, breakpoints, and so forth, even when it also displays the contents of those addresses. The default is `on`. For example, this is what a stack frame display looks like with `set print address on`:

```
(gdb) f
#0  set_quotes (lq=0x34c78 "<<", rq=0x34c88 ">>")
    at input.c:530
530         if (lquote != def_lquote)
```

set print address off

Don't print addresses when displaying their contents. For example, this is the same stack frame displayed with `set print address off`:

```
(gdb) set print addr off
(gdb) f
#0  set_quotes (lq="<<", rq=">>") at input.c:530
530         if (lquote != def_lquote)
```

You can use `set print address off` to eliminate all machine-dependent displays from the GDB interface. For example, with `print address off`, you should get the same text for backtraces on all machines—whether or not they involve pointer arguments.

show print address

Show whether or not addresses are to be printed.

When GDB prints a symbolic address, it normally prints the closest earlier symbol plus an offset. If that symbol doesn't uniquely identify the address (for example, it's a name whose scope is a single source file), you may need to clarify. One way to do this is with `info line`, for example `info line *0x4537`. Alternately, you can set GDB to print the source file and line number when it prints a symbolic address:

set print symbol-filename on

Tell GDB to print the source filename and line number of a symbol in the symbolic form of an address.

set print symbol-filename off

Don't print source filename and line number of a symbol. This is the default.

show print symbol-filename

Show whether or not GDB prints the source filename and line number of a symbol in the symbolic form of an address.

Another situation where it's helpful to show symbol filenames and line numbers is when disassembling code; GDB shows you the line number and source file that correspond to each instruction.

Also, you may wish to see the symbolic form only if the address being printed is reasonably close to the closest earlier symbol:

set print max-symbolic-offset *max-offset*

Tell GDB to display the symbolic form of an address only if the offset between the closest earlier symbol and the address is less than *max-offset*. The default is 0, which tells GDB to always print the symbolic form of an address if any symbol precedes it.

show print max-symbolic-offset

Ask how large the maximum offset is that GDB prints in a symbolic address.

If you have a pointer and you aren't sure where it points, try `set print symbol-filename on`. Then you can determine the name and source file location of the variable where it points, using `p/a` *pointer*. This interprets the address in symbolic form. For example, here GDB shows that a variable *ptt* points at another variable *t*, defined in **hi2.c**:

```
(gdb) set print symbol-filename on
(gdb) p/a ptt
$4 = 0xe008 <t in hi2.c>
```

For pointers that point to a local variable, `p/a` doesn't show the symbol name and filename of the referent, even with the appropriate `set print` options turned on.

Other settings control how different kinds of objects are printed:

set print array or **set print array on**

Pretty print arrays. This format is more convenient to read, but uses more space. The default is off.

set print array off

Return to compressed format for arrays.

show print array

Show whether compressed or pretty format is selected for displaying arrays.

set print elements *number-of-elements*

Set a limit on how many elements of an array GDB prints. If GDB is printing a large array, it stops printing after it has printed the number of elements set by the `set print elements` command. This limit also applies to the display of strings. Setting *number-of-elements* to zero means that the printing is unlimited.

show print elements

Display the number of elements of a large array that GDB prints. If the number is 0, the printing is unlimited.

set print null-stop

Cause GDB to stop printing the characters of an array when the first NULL is encountered. This is useful when large arrays actually contain only short strings.

set print pretty on

Cause GDB to print structures in an indented format with one member per line, like this:

```
$1 = {
  next = 0x0,
  flags = {
    sweet = 1,
    sour = 1
  },
  meat = 0x54 "Pork"
}
```

set print pretty off

Cause GDB to print structures in a compact format, like this:

```
$1 = {next = 0x0, flags = {sweet = 1, sour = 1}, \
meat = 0x54 "Pork"}
```

This is the default format.

show print pretty

Show which format GDB is using to print structures.

set print sevenbit-strings on

Print using only seven-bit characters; if this option is set, GDB displays any eight-bit characters (in strings or character values) using the notation `\`*nnn*. This setting is best if you're working in English (ASCII) and you use the high-order bit of characters as a marker or “meta” bit.

set print sevenbit-strings off

Print full eight-bit characters. This lets you use more international character sets, and is the default.

show print sevenbit-strings

Show whether or not GDB is printing only seven-bit characters.

set print union on

Tell GDB to print unions that are contained in structures. This is the default setting.

set print union off

Tell GDB not to print unions that are contained in structures.

show print union

Ask GDB whether or not it prints unions that are contained in structures. For example, given the declarations:

```
typedef enum {Tree, Bug} Species;
typedef enum {Big_tree, Acorn, Seedling} Tree_forms;
typedef enum {Caterpillar, Cocoon, Butterfly}
              Bug_forms;

struct thing {
  Species it;
  union {
    Tree_forms tree;
    Bug_forms bug;
  } form;
};

struct thing foo = {Tree, {Acorn}};
```

with `set print union on` in effect, `p foo` prints:

```
$1 = {it = Tree, form = {tree = Acorn, bug = Cocoon}}
```

and with `set print union off` in effect, it prints:

```
$1 = {it = Tree, form = {...}}
```

These settings are of interest when you're debugging C++ programs:

`set print demangle` or **`set print demangle on`**

Print C++ names in their source form rather than in the encoded (“mangled”) form passed to the assembler and linker for type-safe linkage. The default is `on`.

`show print demangle`

Show whether C++ names are printed in mangled or demangled form.

`set print asm-demangle` or **`set print asm-demangle on`**

Print C++ names in their source form rather than their mangled form, even in assembler code printouts such as instruction disassemblies. The default is off.

`show print asm-demangle`

Show whether C++ names in assembly listings are printed in mangled or demangled form.

`set demangle-style` ***style***

Choose among several encoding schemes used by different compilers to represent C++ names. The choices for *style* are:

`auto`

Allow GDB to choose a decoding style by inspecting your program.

`gnu`

Decode based on the GNU C++ compiler (`g++`) encoding algorithm. This is the default.

`lucid`

Decode based on the Lucid C++ compiler (`lcc`) encoding algorithm.

`arm`

Decode using the algorithm in the *C++ Annotated Reference Manual*.

This setting alone isn't sufficient to allow debugging `cfront`-generated executables. GDB would require further enhancement to permit that.

`foo`

Show the list of formats.

`show demangle-style`

Display the encoding style currently in use for decoding C++ symbols.

`set print object` or **`set print object on`**

When displaying a pointer to an object, identify the *actual* (derived) type of the object rather than the *declared* type, using the virtual function table.

`set print object off`

Display only the declared type of objects, without reference to the virtual function table. This is the default setting.

show print object

Show whether actual, or declared, object types are displayed.

set print static-members or **set print static-members on**

Print static members when displaying a C++ object. The default is on.

set print static-members off

Don't print static members when displaying a C++ object.

show print static-members

Show whether C++ static members are printed, or not.

set print vtbl or **set print vtbl on**

Pretty print C++ virtual function tables. The default is off.

set print vtbl off

Don't pretty print C++ virtual function tables.

show print vtbl

Show whether C++ virtual function tables are pretty printed, or not.

Value history

Values printed by the `print` command are saved in the GDB *value history*.

This lets you refer to them in other expressions. Values are kept until the symbol table is reread or discarded (for example with the `file` or `symbol-file` commands). When the symbol table changes, the value history is discarded, since the values may contain pointers back to the types defined in the symbol table.

The values printed are given *history numbers*, which you can use to refer to them. These are successive integers starting with 1. The `print` command shows you the history number assigned to a value by printing `$`*num* `=` before the value; here *num* is the history number.

To refer to any previous value, use `$` followed by the value's history number. The way `print` labels its output is designed to remind you of this. Just `$` refers to the most recent value in the history, and `$$` refers to the value before that. `$$`*n* refers to the *n*th value from the end; `$$2` is the value just prior to `$$`, `$$1` is equivalent to `$$`, and `$$0` is equivalent to `$`.

For example, suppose you have just printed a pointer to a structure and want to see the contents of the structure. It suffices to type:

```
p *$
```

If you have a chain of structures where the component `next` points to the next one, you can print the contents of the next one with this:

```
p *$.next
```

You can print successive links in the chain by repeating this command—which you can do by just typing **Enter**.

The history records values, not expressions. If the value of `x` is 4 and you type these commands:

```
print x
set x=5
```

then the value recorded in the value history by the `print` command remains 4 even though the value of `x` has changed.

`show values`

Print the last ten values in the value history, with their item numbers. This is like `p $$9` repeated ten times, except that `show values` doesn't change the history.

`show values` *n*

Print ten history values centered on history item number *n*.

`show values +`

Print ten history values just after the values last printed. If no more values are available, `show values +` produces no display.

Pressing **Enter** to repeat `show values` *n* has exactly the same effect as `show values +`.

Convenience variables

GDB provides *convenience variables* that you can use within GDB to hold on to a value and refer to it later. These variables exist entirely within GDB; they aren't part of your program, and setting a convenience variable has no direct effect on further execution of your program. That's why you can use them freely.

Convenience variables are prefixed with `$`. Any name preceded by `$` can be used for a convenience variable, unless it's one of the predefined machine-specific register names (see "*Registers*"). Value history references, in contrast, are *numbers* preceded by `$`. See "*Value history*."

You can save a value in a convenience variable with an assignment expression, just as you'd set a variable in your program. For example:

```
set $foo = *object_ptr
```

saves in *$foo* the value contained in the object pointed to by *object_ptr*.

Using a convenience variable for the first time creates it, but its value is `void` until you assign a new value. You can alter the value with another assignment at any time.

Convenience variables have no fixed types. You can assign to a convenience variable any type of value, including structures and arrays, even if that variable already has a value of a different type. The convenience variable, when used as an expression, has the type of its current value.

`show convenience`

Print a list of convenience variables used so far, and their values. Abbreviated as `show con`.

One of the ways to use a convenience variable is as a counter to be incremented or a pointer to be advanced. For example, to print a field from successive elements of an array of structures:

```
set $i = 0
print bar[$i++]->contents
```

Repeat that command by pressing **Enter**.

Some convenience variables are created automatically by GDB and given values likely to be useful:

$_

The variable `$_` is automatically set by the `x` command to the last address examined (see "*Examining memory*"). Other commands that provide a default address for `x` to examine also set `$_` to that address; these commands include `info line` and `info breakpoint`. The type of `$_` is `void *` except when set by the `x` command, in which case it's a pointer to the type of `$__`.

$__

The variable `$__` is automatically set by the `x` command to the value found in the last address examined. Its type is chosen to match the format in which the data was printed.

$_exitcode

The variable `$_exitcode` is automatically set to the exit code when the program being debugged terminates.

Registers

You can refer to machine register contents, in expressions, as variables with names starting with `$`. The names of registers are different for each machine; use `info registers` to see the names used on your machine.

info registers

Print the names and values of all registers except floating-point registers (in the selected stack frame).

info all-registers

Print the names and values of all registers, including floating-point registers.

info registers *regname* ...

Print the value of each specified register *regname*. As discussed in detail below, register values are normally relative to the selected stack frame. The *regname* may be any register name valid on the machine you're using, with or without the initial `$`.

GDB has four "standard" register names that are available (in expressions) on most machines—whenever they don't conflict with an architecture's canonical mnemonics for registers:

$pc

Program counter.

$sp

Stack pointer.

$fp

A register that contains a pointer to the current stack frame.

$ps

A register that contains the processor status.

For example, you could print the program counter in hex with:

```
p/x $pc
```

or print the instruction to be executed next with:

```
x/i $pc
```

or add four to the stack pointer with:

```
set $sp += 4
```

This is a way of removing one word from the stack, on machines where stacks grow downward in memory (most machines, nowadays). This assumes that the innermost stack frame is selected; setting `$sp` isn't allowed when other stack frames are selected. To pop entire frames off the stack, regardless of machine architecture, use the **Enter** key.

Whenever possible, these four standard register names are available on your machine even though the machine has different canonical mnemonics, so long as there's no conflict. The `info registers` command shows the canonical names.

GDB always considers the contents of an ordinary register as an integer when the register is examined in this way. Some machines have special registers that can hold nothing but floating point; these registers are considered to have floating point values. There's no way to refer to the contents of an ordinary register as floating point value (although you can *print* it as a floating point value with `print/f $`*regname*).

Some registers have distinct “raw” and “virtual” data formats. This means that the data format in which the register contents are saved by the operating system isn't the same one that your program normally sees. For example, the registers of the 68881 floating point coprocessor are always saved in “extended” (raw) format, but all C programs expect to work with “double” (virtual) format. In such cases, GDB normally works with the virtual format only (the format that makes sense for your program), but the `info registers` command prints the data in both formats.

Normally, register values are relative to the selected stack frame (see “*Selecting a frame*”). This means that you get the value that the register would contain if all stack frames farther in were exited and their saved registers restored. In order to see the true contents of hardware registers, you must select the innermost frame (with `frame 0`).

However, GDB must deduce where registers are saved, from the machine code generated by your compiler. If some registers aren't saved, or if GDB is unable to locate the saved registers, the selected stack frame makes no difference.

Floating point hardware

Depending on the configuration, GDB may be able to give you more information about the status of the floating point hardware.

`info float`

Display hardware-dependent information about the floating point unit. The exact contents and layout vary depending on the floating point chip. Currently, `info float` is supported on ARM and x86 machines.

Examining the symbol table

The commands described in this section allow you to inquire about the symbols (names of variables, functions and types) defined in your program. This information is inherent in the text of your program and doesn't change as your program executes. GDB finds it in your program's symbol table, in the file indicated when you started GDB (see the description of the `gdb` utility).

Occasionally, you may need to refer to symbols that contain unusual characters, which GDB ordinarily treats as word delimiters. The most frequent case is in referring to static variables in other source files (see "*Program variables*"). Filenames are recorded in object files as debugging symbols, but GDB ordinarily parses a typical filename, like **foo.c**, as the three words `foo`, `.`, and `c`. To allow GDB to recognize `foo.c` as a single symbol, enclose it in single quotes. For example:

```
p 'foo.c'::x
```

looks up the value of *x* in the scope of the file **foo.c**.

`info address` ***symbol***

Describe where the data for *symbol* is stored. For a register variable, this says which register it's kept in. For a nonregister local variable, this prints the stack-frame offset at which the variable is always stored.

Note the contrast with `print &` *symbol*, which doesn't work at all for a register variable, and for a stack local variable prints the exact address of the current instantiation of the variable.

`whatis` ***exp***

Print the data type of expression *exp*. The *exp* expression isn't actually evaluated, and any side-effecting operations (such as assignments or function calls) inside it don't take place. See "*Expressions*."

`whatis`

Print the data type of `$`, the last value in the value history.

`ptype` ***typename***

Print a description of data type *typename*, which may be the name of a type, or for C code it may have the form:

- `class` *class-name*
- `struct` *struct-tag*
- `union` *union-tag*
- `enum` *enum-tag*

`ptype` *exp* or `ptype`

Print a description of the type of expression *exp*. The `ptype` command differs from `whatis` by printing a detailed description, instead of just the name of the type. For example, for this variable declaration:

```
struct complex {double real; double imag;} v;
```

the two commands give this output:

```
(gdb) whatis v
type = struct complex
(gdb) ptype v
type = struct complex {
    double real;
    double imag;
}
```

As with `whatis`, using `ptype` without an argument refers to the type of `$`, the last value in the value history.

`info types` *regexp* or `info types`

Print a brief description of all types whose name matches *regexp* (or all types in your program, if you supply no argument). Each complete typename is matched as though it were a complete line; thus, `i type value` gives information on all types in your program whose name includes the string `value`, but `i type ^value$` gives information only on types whose complete name is `value`.

This command differs from `ptype` in two ways: first, like `whatis`, it doesn't print a detailed description; second, it lists all source files where a type is defined.

`info source`

Show the name of the current source file—that is, the source file for the function containing the current point of execution—and the language it was written in.

`info sources`

Print the names of all source files in your program for which there is debugging information, organized into two lists: files whose symbols have already been read, and files whose symbols are read when needed.

`info functions`

Print the names and data types of all defined functions.

`info functions` *regexp*

Print the names and data types of all defined functions whose names contain a match for regular expression *regexp*. Thus, `info fun step` finds all functions whose names include `step`; `info fun ^step` finds those whose names start with `step`.

`info variables`

Print the names and data types of all variables that are declared outside of functions (i.e., excluding local variables).

`info variables` ***regexp***

Print the names and data types of all variables (except for local variables) whose names contain a match for regular expression *regexp*.

Some systems allow individual object files that make up your program to be replaced without stopping and restarting your program. If you're running on one of these systems, you can allow GDB to reload the symbols for automatically relinked modules:

- `set symbol-reloading on` — replace symbol definitions for the corresponding source file when an object file with a particular name is seen again.
- `set symbol-reloading off` — don't replace symbol definitions when reencountering object files of the same name. This is the default state; if you aren't running on a system that permits automatically relinking modules, you should leave `symbol-reloading` off, since otherwise GDB may discard symbols when linking large programs, that may contain several modules (from different directories or libraries) with the same name.
- `show symbol-reloading` — show the current `on` or `off` setting.

`maint print symbols` ***filename*** **or `maint print psymbols`** ***filename*** **or `maint print msymbols`** ***filename***

Write a dump of debugging symbol data into the file *filename*. These commands are used to debug the GDB symbol-reading code. Only symbols with debugging data are included.

- If you use `maint print symbols`, GDB includes all the symbols for which it has already collected full details: that is, *filename* reflects symbols for only those files whose symbols GDB has read. You can use the command `info sources` to find out which files these are.
- If you use `maint print psymbols` instead, the dump shows information about symbols that GDB only knows partially—that is, symbols defined in files that GDB has skimmed, but not yet read completely.
- Finally, `maint print msymbols` dumps just the minimal symbol information required for each object file from which GDB has read some symbols.

Altering execution

Once you think you've found an error in your program, you might want to find out for certain whether correcting the apparent error would lead to correct results in the rest of the run. You can find the answer by experimenting, using the GDB features for altering execution of the program.

For example, you can store new values in variables or memory locations, give your program a signal, restart it at a different address, or even return prematurely from a function.

Assignment to variables

To alter the value of a variable, evaluate an assignment expression.

See "*Expressions*". For example,

```
print x=4
```

stores the value 4 in the variable *x* and then prints the value of the assignment expression (which is 4).

If you aren't interested in seeing the value of the assignment, use the `set` command instead of the `print` command. The `set` command is really the same as `print` except that the expression's value isn't printed and isn't put in the value history (see "*Value history*"). The expression is evaluated only for its effects.

If the beginning of the argument string of the `set` command appears identical to a `set` subcommand, use the `set variable` command instead of just `set`. This command is identical to `set` except for its lack of subcommands. For example, if your program has a variable *width*, you get an error if you try to set a new value with just `set width=13`, because GDB has the command `set width`:

```
(gdb) whatis width
type = double
(gdb) p width
$4 = 13
(gdb) set width=47
Invalid syntax in expression.
```

The invalid expression, of course, is `=47`. In order to actually set the program's variable *width*, use:

```
(gdb) set var width=47
```

GDB allows more implicit conversions in assignments than C; you can freely store an integer value into a pointer variable or vice versa, and you can convert any structure to any other structure that is the same length or shorter.

To store values into arbitrary places in memory, use the `{...}` construct to generate a value of specified type at a specified address (see "*Expressions*"). For example, `{int}0x83040` refers to memory location `0x83040` as an integer (which implies a certain size and representation in memory), and:

```
set {int}0x83040 = 4
```

stores the value 4 in that memory location.

Continuing at a different address

Ordinarily, when you continue your program, you do so at the place where it stopped, with the `continue` command. You can instead continue at an address of your own choosing, with the following commands:

`jump` ***linespec***

Resume execution at line *linespec*. Execution stops again immediately if there's a breakpoint there. See "*Printing source lines*" for a description of the different forms of *linespec*.

The `jump` command doesn't change the current stack frame, or the stack pointer, or the contents of any memory location or any register other than the program counter. If line *linespec* is in a different function from the one currently executing, the results may be bizarre if the two functions expect different patterns of arguments or of local variables. For this reason, the `jump` command requests confirmation if the specified line isn't in the function currently executing. However, even bizarre results are predictable if you're well acquainted with the machine-language code of your program.

`jump *` ***address***

Resume execution at the instruction at *address*.

You can get much the same effect as the `jump` command by storing a new value in the register `$pc`. The difference is that this doesn't start your program running; it only changes the address of where it *will* run when you continue. For example:

```
set $pc = 0x485
```

makes the next `continue` command or stepping command execute at address `0x485`, rather than at the address where your program stopped. See "*Continuing and stepping*."

The most common occasion to use the `jump` command is to back up—perhaps with more breakpoints set—over a portion of a program that has already executed, in order to examine its execution in more detail.

Giving your program a signal

Invoking the `signal` command isn't the same as invoking the `kill` utility from the shell.

Sending a signal with `kill` causes GDB to decide what to do with the signal depending on the signal handling tables (see "*Signals*"). The `signal` command passes the signal directly to your program.

`signal` ***signal***

Resume execution where your program stopped, but immediately give it the given *signal*. The *signal* can be the name or number of a signal. For example, on many systems `signal 2` and `signal SIGINT` are both ways of sending an interrupt signal.

Alternatively, if *signal* is zero, continue execution without giving a signal. This is useful when your program stopped on account of a signal and would ordinary see the signal when resumed with the `continue` command; `signal 0` causes it to resume without a signal.

The `signal` command doesn't repeat when you press **Enter** a second time after executing the command.

Returning from a function

When you use `return`, GDB discards the selected stack frame (and all frames within it). You can think of this as making the discarded frame return prematurely. If you wish to specify a value to be returned, give that value as the argument to `return`.

`return` or **`return`** ***expression***

You can cancel the execution of a function call with the `return` command. If you give an *expression* argument, its value is used as the function's return value.

This pops the selected stack frame (see "*Selecting a frame*") and any other frames inside it, leaving its caller as the innermost remaining frame. That frame becomes selected. The specified value is stored in the registers used for returning values of functions.

The `return` command doesn't resume execution; it leaves the program stopped in the state that would exist if the function had just returned. In contrast, the `finish` command (see "*Continuing and stepping*") resumes execution until the selected stack frame returns naturally.

Calling program functions

You can use this variant of the `print` command if you want to execute a function from your program, but without cluttering the output with `void` returned values. If the result isn't void, it's printed and saved in the value history.

`call` ***expr***

Evaluate the expression *expr* without displaying `void` returned values.

A user-controlled variable, *call_scratch_address*, specifies the location of a scratch area to be used when GDB calls a function in the target. This is necessary because the usual method of putting the scratch area on the stack doesn't work in systems that have separate instruction and data spaces.

In a multithreaded programs, calling a function may allow multiple threads to run.

Patching programs

By default, GDB opens the file containing your program's executable code (or the core file) read-only. This prevents accidental alterations to machine code, but it also prevents you from intentionally patching your program's binary.

If you'd like to be able to patch the binary, you can specify that explicitly with the `set write` command. For example, you might want to turn on internal debugging flags, or even to make emergency repairs.

set write on or **set write off**

If you specify `set write on`, GDB opens executable and core files for both reading and writing; if you specify `set write off` (the default), GDB opens them read-only.

If you've already loaded a file, you must load it again (using the `exec-file` or `core-file` command) after changing `set write` for your new setting to take effect.

show write

Display whether executable files and core files are opened for writing as well as reading.

Appendix D
Glossary

adaptive

Scheduling policy whereby a thread's priority is decayed by 1. See also *FIFO*, *round robin*, and *sporadic*.

adaptive partitioning

A method of dividing, in a flexible manner, CPU time, memory, file resources, or kernel resources with some policy of minimum guaranteed usage.

application ID

A number that identifies all processes that are part of an application. Like process group IDs, the application ID value is the same as the process ID of the first process in the application. A new application is created by spawning with the POSIX_SPAWN_NEWAPP or SPAWN_NEWAPP flag. A process created without one of those inherits the application ID of its parent. A process needs the PROCMGR_AID_CHILD_NEWAPP ability in order to set those flags.

The *SignalKill()* kernel call accepts a SIG_APPID flag ORed into the signal number parameter. This tells it to send the signal to all the processes with an application ID that matches the *pid* argument. The DCMD_PROC_INFO *devctl()* returns the application ID in a structure field.

asymmetric multiprocessing (AMP)

A multiprocessing system where a separate OS, or a separate instantiation of the same OS, runs on each CPU.

atomic

Of or relating to atoms. :-)

In operating systems, this refers to the requirement that an operation, or sequence of operations, be considered *indivisible*. For example, a thread may need to move a file position to a given location and read data. These operations must be performed in an atomic manner; otherwise, another thread could preempt the original thread and move the file position to a different location, thus causing the original thread to read data from the second thread's position.

attributes structure

Structure containing information used on a per-resource basis (as opposed to the *OCB*, which is used on a per-open basis).

This structure is also known as a *handle*. The structure definition is fixed (`iofunc_attr_t`), but may be extended. See also *mount structure*.

bank-switched

A term indicating that a certain memory component (usually the device holding an *image*) isn't entirely addressable by the processor. In this case, a hardware component manifests a small portion (or "window") of the device onto the processor's address bus. Special commands have to be issued to the hardware to move the window to different locations in the device. See also *linearly mapped*.

base layer calls

Convenient set of library calls for writing resource managers. These calls all start with *resmgr_*()*. Note that while some base layer calls are unavoidable (e.g., *resmgr_attach()*), we recommend that you use the *POSIX layer calls* where possible.

BIOS/ROM Monitor extension signature

A certain sequence of bytes indicating to the BIOS or ROM Monitor that the device is to be considered an "extension" to the BIOS or ROM Monitor—control is to be transferred to the device by the BIOS or ROM Monitor, with the expectation that the device will perform additional initializations.

On the x86 architecture, the two bytes 0x55 and 0xAA must be present (in that order) as the first two bytes in the device, with control being transferred to offset 0x0003.

block-integral

The requirement that data be transferred such that individual structure components are transferred in their entirety—no partial structure component transfers are allowed.

In a resource manager, directory data must be returned to a client as *block-integral* data. This means that only complete `struct dirent` structures can be returned—it's inappropriate to return partial structures, assuming that the next _IO_READ request will "pick up" where the previous one left off.

bootable

An image can be either bootable or *nonbootable*. A bootable image is one that contains the startup code that the IPL can transfer control to.

bootfile

The part of an OS image that runs the *startup code* and the microkernel.

bound multiprocessing (BMP)

A multiprocessing system where a single instantiation of an OS manages all CPUs simultaneously, but you can lock individual applications or threads to a specific CPU.

budget

In *sporadic* scheduling, the amount of time a thread is permitted to execute at its normal priority before being dropped to its low priority.

buildfile

A text file containing instructions for `mkifs` specifying the contents and other details of an *image*, or for `mkefs` specifying the contents and other details of an embedded filesystem image.

canonical mode

Also called edited mode or “cooked” mode. In this mode, the character device library performs line-editing operations on each received character. Only when a line is “completely entered”—typically when a carriage return (CR) is received—will the line of data be made available to application processes. Contrast *raw mode*.

channel

A kernel object used with message passing.

In QNX Neutrino, message passing is directed towards a *connection* (made to a channel); threads can receive messages from channels. A thread that wishes to receive messages creates a channel (using *ChannelCreate()*), and then receives messages from that channel (using *MsgReceive()*). Another thread that wishes to send a message to the first thread must make a connection to that channel by “attaching” to the channel (using *ConnectAttach()*) and then sending data (using *MsgSend()*).

chid

An abbreviation for *channel ID*.

CIFS

Common Internet File System (also known as SMB)—a protocol that allows a client workstation to perform transparent file access over a network to a Windows 95/98/NT server. Client file access calls are converted to CIFS protocol requests and are sent to the server over the network. The server receives the request, performs the actual filesystem operation, and sends a response back to the client.

CIS

Card Information Structure—a data block that maintains information about flash configuration. The CIS description includes the types of memory devices in the regions, the physical geometry of these devices, and the partitions located on the flash.

coid

An abbreviation for *connection ID*.

combine message

A resource manager message that consists of two or more messages. The messages are constructed as combine messages by the client's C library (e.g., *stat()*, *readblock()*), and then handled as individual messages by the resource manager.

The purpose of combine messages is to conserve network bandwidth and/or to provide support for atomic operations. See also *connect message* and *I/O message*.

connect message

In a resource manager, a message issued by the client to perform an operation based on a pathname (e.g., an `io_open` message). Depending on the type of connect message sent, a context block (see *OCB*) may be associated with the request and will be passed to subsequent I/O messages. See also *combine message* and *I/O message*.

connection

A kernel object used with message passing.

Connections are created by client threads to "connect" to the channels made available by servers. Once connections are established, clients can *MsgSendv()* messages over them. If a number of threads in a process all attach to the same channel, then the one connection is shared among all the threads. Channels and connections are identified within a process by a small integer.

The key thing to note is that connections and file descriptors (*FD*) are one and the same object. See also *channel* and *FD*.

context

Information retained between invocations of functionality.

When using a resource manager, the client sets up an association or *context* within the resource manager by issuing an *open()* call and getting back a file descriptor. The resource manager is responsible for storing the information required by the context (see *OCB*). When the client issues further file-descriptor based messages, the resource manager uses the OCB to determine the context for interpretation of the client's messages.

cooked mode

See *canonical mode*.

core dump

A file describing the state of a process that terminated abnormally.

critical section

A code passage that *must* be executed "serially" (i.e., by only one thread at a time). The simplest from of critical section enforcement is via a *mutex*.

deadlock

A condition in which one or more threads are unable to continue due to resource contention. A common form of deadlock can occur when one thread sends a message to another, while the other thread sends a message to the first. Both threads are now waiting for each other to reply to the message. Deadlock can be avoided by good design practices or massive kludges—we recommend the good design approach.

device driver

A process that allows the OS and application programs to use the underlying hardware in a generic way (e.g., a disk drive, a network interface). Unlike OSs that require device drivers to be tightly bound into the OS itself, device drivers for the QNX Neutrino RTOS are standard processes that can be started and stopped dynamically. As a result, adding device drivers doesn't affect any other part of the OS—drivers can be developed and debugged like any other application. Also, device drivers are in their own protected address space, so a bug in a device driver won't cause the entire OS to shut down.

discrete (or traditional) multiprocessor system

A system that has separate physical processors hooked up in multiprocessing mode over a board-level bus.

DNS

Domain Name Service—an Internet protocol used to convert ASCII domain names into IP addresses. In QNX Neutrino native networking, `dns` is one of *Qnet*'s built-in resolvers.

dynamic bootfile

An OS image built on the fly. Contrast *static bootfile*.

dynamic linking

The process whereby you link your modules in such a way that the Process Manager will link them to the library modules before your program runs. The word "dynamic" here means that the association between your program and the library modules that it uses is done *at load time*, not at link time. Contrast *static linking*. See also *runtime loading*.

edge-sensitive

One of two ways in which a *PIC* (Programmable Interrupt Controller) can be programmed to respond to interrupts. In edge-sensitive mode, the interrupt is "noticed" upon a transition to/from the rising/falling edge of a pulse. Contrast *level-sensitive*.

edited mode

See *canonical mode*.

EOI

End Of Interrupt—a command that the OS sends to the PIC after processing all Interrupt Service Routines (ISR) for that particular interrupt source so that the PIC can reset the processor's In Service Register. See also *PIC* and *ISR*.

EPROM

Erasable Programmable Read-Only Memory—a memory technology that allows the device to be programmed (typically with higher-than-operating voltages, e.g., 12 V), with the characteristic that any bit (or bits) may be individually programmed from a 1 state to a 0 state. Changing a bit from a 0 state into a 1 state can be accomplished only by erasing the *entire* device, setting *all* of the bits to a 1 state. Erasing is accomplished by shining an ultraviolet light through the erase window of the device for a fixed period of time (typically 10-20 minutes). The device is further characterized by having a limited number of erase cycles (typically 10e5 - 10e6). Contrast *flash* and *RAM*.

event

A notification scheme used to inform a thread that a particular condition has occurred. Events can be signals or pulses in the general case; they can also be unblocking events or interrupt events in the case of kernel timeouts and interrupt service routines. An event is delivered by a thread, a timer, the kernel, or an interrupt service routine when appropriate to the requestor of the event.

FD

File Descriptor—a client must open a file descriptor to a resource manager via the *open()* function call. The file descriptor then serves as a handle for the client to use in subsequent messages. Note that a file descriptor is the exact same object as a connection ID (*coid*, returned by *ConnectAttach()*).

FIFO

First In First Out—a scheduling policy whereby a thread is able to consume CPU at its priority level without bounds. See also *adaptive*, *round robin*, and *sporadic*.

flash memory

A memory technology similar in characteristics to *EPROM* memory, with the exception that erasing is performed electrically instead of via ultraviolet light, and, depending upon the organization of the flash memory device, erasing may be accomplished in blocks (typically 64 KB at a time) instead of the entire device. Contrast *EPROM* and *RAM*.

FQNN

Fully Qualified Node Name—a unique name that identifies a QNX Neutrino node on a network. The FQNN consists of the nodename plus the node domain tacked together.

garbage collection

Also known as space reclamation, the process whereby a filesystem manager recovers the space occupied by deleted files and directories.

HA

High Availability—in telecommunications and other industries, HA describes a system's ability to remain up and running without interruption for extended periods of time.

handle

A pointer that the resource manager base library binds to the pathname registered via *resmgr_attach()*. This handle is typically used to associate some kind of per-device information. Note that if you use the *iofunc_*() POSIX layer calls*, you must use a particular *type* of handle—in this case called an *attributes structure*.

hard thread affinity

A user-specified binding of a thread to a set of processors, done by means of a *runmask*. Contrast *soft thread affinity*.

image

In the context of embedded QNX Neutrino systems, an “image” can mean either a structure that contains files (i.e., an OS image) or a structure that can be used in a read-only, read/write, or read/write/reclaim FFS-2-compatible filesystem (i.e., a flash filesystem image).

inherit mask

A bitmask that specifies which processors a thread's children can run on. Contrast *runmask*.

interrupt

An event (usually caused by hardware) that interrupts whatever the processor was doing and asks it do something else. The hardware will generate an interrupt whenever it has reached some state where software intervention is required.

interrupt handler

See *ISR*.

interrupt latency

The amount of elapsed time between the generation of a hardware interrupt and the first instruction executed by the relevant interrupt service routine. Also designated as "T_{il}". Contrast *scheduling latency*.

interrupt service routine

See *ISR*.

interrupt service thread

A thread that is responsible for performing thread-level servicing of an interrupt.

Since an *ISR* can call only a very limited number of functions, and since the amount of time spent in an ISR should be kept to a minimum, generally the bulk of the interrupt servicing work should be done by a thread. The thread attaches the interrupt (via *InterruptAttach()* or *InterruptAttachEvent()*) and then blocks (via *InterruptWait()*), waiting for the ISR to tell it to do something (by returning an event of type SIGEV_INTR). To aid in minimizing *scheduling latency*, the interrupt service thread should raise its priority appropriately.

I/O message

A message that relies on an existing binding between the client and the resource manager. For example, an _IO_READ message depends on the client's having previously established an association (or *context*) with the resource manager by issuing an *open()* and getting back a file descriptor. See also *connect message*, *context*, *combine message*, and *message*.

I/O privileges

Particular rights, that, if enabled for a given thread, allow the thread to perform I/O instructions (such as the x86 assembler `in` and `out` instructions). By default, I/O privileges are disabled, because a program with them enabled can wreak havoc on a system. To enable I/O privileges, the process must have the PROCMGR_AID_IO ability enabled (see *procmgr_ability()*), and the thread must call *ThreadCtl()*.

IPC

Interprocess Communication—the ability for two processes (or threads) to communicate. The QNX Neutrino RTOS offers several forms of IPC, most notably native messaging (synchronous, client/server relationship), POSIX message queues and pipes (asynchronous), as well as signals.

IPL

Initial Program Loader—the software component that either takes control at the processor's reset vector (e.g., location 0xFFFFFFF0 on the x86), or is a BIOS extension. This component is responsible for setting up the machine into a usable state, such that the startup program can then perform further initializations. The IPL is written in assembler and C. See also *BIOS extension signature* and *startup code*.

IRQ

Interrupt Request—a hardware request line asserted by a peripheral to indicate that it requires servicing by software. The IRQ is handled by the *PIC*, which then interrupts the processor, usually causing the processor to execute an *Interrupt Service Routine (ISR)*.

ISR

Interrupt Service Routine—a routine responsible for servicing hardware (e.g., reading and/or writing some device ports), for updating some data structures shared between the ISR and the thread(s) running in the application, and for signalling the thread that some kind of event has occurred.

kernel

See *microkernel*.

level-sensitive

One of two ways in which a *PIC* (Programmable Interrupt Controller) can be programmed to respond to interrupts. If the PIC is operating in level-sensitive mode, the IRQ is considered active whenever the corresponding hardware line is active. Contrast *edge-sensitive*.

linearly mapped

A term indicating that a certain memory component is entirely addressable by the processor. Contrast *bank-switched*.

message

A parcel of bytes passed from one process to another. The OS attaches no special meaning to the content of a message—the data in a message has meaning for the sender of the message and for its receiver, but for no one else.

Message passing not only allows processes to pass data to each other, but also provides a means of synchronizing the execution of several processes. As they send, receive, and reply to messages, processes undergo various "changes of state" that affect when, and for how long, they may run.

microkernel

A part of the operating system that provides the minimal services used by a team of optional cooperating processes, which in turn provide the higher-level OS functionality. The microkernel itself lacks filesystems and many other services normally expected of an OS; those services are provided by optional processes.

mount structure

An optional, well-defined data structure (of type `iofunc_mount_t`) within an *iofunc_*()* structure, which contains information used on a per-mountpoint basis (generally used only for filesystem resource managers). See also *attributes structure* and *OCB*.

mountpoint

The location in the pathname space where a resource manager has "registered" itself. For example, the serial port resource manager registers mountpoints for each serial device (**/dev/ser1**, **/dev/ser2**, etc.), and a CD-ROM filesystem may register a single mountpoint of **/cdrom**.

multicore system

A chip that has one physical processor with multiple CPUs interconnected over a chip-level bus.

mutex

Mutual exclusion lock, a simple synchronization service used to ensure exclusive access to data shared between threads. It is typically acquired (*pthread_mutex_lock()*) and released (*pthread_mutex_unlock()*) around the code that accesses the shared data (usually a *critical section*). See also *critical section*.

name resolution

In a QNX Neutrino network, the process by which the *Qnet* network manager converts an *FQNN* to a list of destination addresses that the transport layer knows how to get to.

name resolver

Program code that attempts to convert an *FQNN* to a destination address.

nd

An abbreviation for *node descriptor*, a numerical identifier for a node *relative to the current node*. Each node's node descriptor for itself is 0 (ND_LOCAL_NODE).

NDP

Node Discovery Protocol—proprietary QNX Software Systems protocol for broadcasting name resolution requests on a QNX Neutrino LAN.

network directory

A directory in the pathname space that's implemented by the *Qnet* network manager.

NFS

Network FileSystem—a TCP/IP application that lets you graft remote filesystems (or portions of them) onto your local pathname space. Directories on the remote systems appear as part of your local filesystem and all the utilities you use for listing and managing files (e.g., `ls`, `cp`, `mv`) operate on the remote files exactly as they do on your local files.

NMI

Nonmaskable Interrupt—an interrupt that can't be masked by the processor. We don't recommend using an NMI!

Node Discovery Protocol

See *NDP*.

node domain

A character string that the *Qnet* network manager tacks onto the nodename to form an *FQNN*.

nodename

A unique name consisting of a character string that identifies a node on a network.

nonbootable

A nonbootable OS image is usually provided for larger embedded systems or for small embedded systems where a separate, configuration-dependent setup may be required. Think of it as a second "filesystem" that has some additional files on it. Since it's nonbootable, it typically won't contain the OS, startup file, etc. Contrast *bootable*.

OCB

Open Control Block (or Open Context Block)—a block of data established by a resource manager during its handling of the client's *open()* function. This context block is bound by the resource manager to this particular request, and is then automatically passed to all subsequent I/O functions generated by the client on the file descriptor returned by the client's *open()*.

partition

A division of CPU time, memory, file resources, or kernel resources with some policy of minimum guaranteed usage.

pathname prefix

See *mountpoint*.

pathname space mapping

The process whereby the Process Manager maintains an association between resource managers and entries in the pathname space.

persistent

When applied to storage media, the ability for the medium to retain information across a power-cycle. For example, a hard disk is a persistent storage medium, whereas a ramdisk is not, because the data is lost when power is lost.

PIC

Programmable Interrupt Controller—hardware component that handles IRQs. See also *edge-sensitive*, *level-sensitive*, and *ISR*.

PID

Process ID. Also often *pid* (e.g., as an argument in a function call).

POSIX

An IEEE/ISO standard. The term is an acronym (of sorts) for Portable Operating System Interface—the “X” alludes to “UNIX”, on which the interface is based.

POSIX layer calls

Convenient set of library calls for writing resource managers. The POSIX layer calls can handle even more of the common-case messages and functions than the *base layer calls*. These calls are identified by the *iofunc_*()* prefix. In order to use these (and we strongly recommend that you do), you must also use the well-defined POSIX-layer *attributes* (`iofunc_attr_t`), *OCB* (`iofunc_ocb_t`), and (optionally) *mount* (`iofunc_mount_t`) structures.

preemption

The act of suspending the execution of one thread and starting (or resuming) another. The suspended thread is said to have been “preempted” by the new thread. Whenever a lower-priority thread is actively consuming the CPU, and a higher-priority thread becomes READY, the lower-priority thread is immediately preempted by the higher-priority thread.

prefix tree

The internal representation used by the Process Manager to store the pathname table.

priority inheritance

The characteristic of a thread that causes its priority to be raised or lowered to that of the thread that sent it a message. Also used with mutexes. Priority inheritance is a method used to prevent *priority inversion*.

priority inversion

A condition that can occur when a low-priority thread consumes CPU at a higher priority than it should. This can be caused by not supporting priority inheritance, such that when the lower-priority thread sends a message to a higher-priority thread, the higher-priority thread consumes CPU *on behalf of* the lower-priority thread. This is solved by having the higher-priority thread inherit the priority of the thread on whose behalf it's working.

process

A nonschedulable entity, which defines the address space and a few data areas. A process must have at least one *thread* running in it—this thread is then called the first thread.

process group

A collection of processes that permits the signalling of related processes. Each process in the system is a member of a process group identified by a process group ID. A newly created process joins the process group of its creator.

process group ID

The unique identifier representing a process group during its lifetime. A process group ID is a positive integer. The system may reuse a process group ID after the process group dies.

process group leader

A process whose ID is the same as its process group ID.

process ID (PID)

The unique identifier representing a process. A PID is a positive integer. The system may reuse a process ID after the process dies, provided no existing process group has the same ID. Only the Process Manager can have a process ID of `1`.

pty

Pseudo-TTY—a character-based device that has two “ends”: a master end and a slave end. Data written to the master end shows up on the slave end, and vice versa. These devices are typically used to interface between a program that expects a character device and another program that wishes to use that device (e.g., the shell and the `telnet` daemon process, used for logging in to a system over the Internet).

pulses

In addition to the synchronous Send/Receive/Reply services, QNX Neutrino also supports fixed-size, nonblocking messages known as pulses. These carry a small payload (four bytes of data plus a single byte code). A pulse is also one form of *event* that can be returned from an ISR or a timer. See *MsgDeliverEvent()* for more information.

Qnet

The native network manager in the QNX Neutrino RTOS.

QoS

Quality of Service—a policy (e.g., `loadbalance`) used to connect nodes in a network in order to ensure highly dependable transmission. QoS is an issue that often arises in high-availability (*HA*) networks as well as realtime control systems.

RAM

Random Access Memory—a memory technology characterized by the ability to read and write any location in the device without limitation. Contrast *flash* and *EPROM*.

raw mode

In raw input mode, the character device library performs no editing on received characters. This reduces the processing done on each character to a minimum and provides the highest performance interface for reading data. Also, raw mode is used with devices that typically generate binary data—you don't want any translations of the raw binary stream between the device and the application. Contrast *canonical mode*.

replenishment

In *sporadic* scheduling, the period of time during which a thread is allowed to consume its execution *budget*.

reset vector

The address at which the processor begins executing instructions after the processor's reset line has been activated. On the x86, for example, this is the address 0xFFFFFFF0.

resource manager

A user-level server program that accepts messages from other programs and, optionally, communicates with hardware. QNX Neutrino resource managers are responsible for presenting an interface to various types of devices, whether actual (e.g., serial ports, parallel ports, network cards, disk drives) or virtual (e.g., **/dev/null**, a network filesystem, and pseudo-ttys).

In other operating systems, this functionality is traditionally associated with *device drivers*. But unlike device drivers, QNX Neutrino resource managers don't require any special arrangements with the kernel. In fact, a resource manager looks just like any other user-level program. See also *device driver*.

RMA

Rate Monotonic Analysis—a set of methods used to specify, analyze, and predict the timing behavior of realtime systems.

round robin

A scheduling policy whereby a thread is given a certain period of time to run. Should the thread consume CPU for the entire period of its timeslice, the thread will be placed at the end of the ready queue for its priority, and the next available thread will be made READY. If a thread is the only thread READY at its priority level, it will be able to consume CPU again immediately. See also *adaptive*, *FIFO*, and *sporadic*.

runmask

A bitmask that indicates which processors a thread can run on. Contrast *inherit mask*.

runtime loading

The process whereby a program decides *while it's actually running* that it wishes to load a particular function from a library. Contrast *static linking*.

scheduling latency

The amount of time that elapses between the point when one thread makes another thread READY and when the other thread actually gets some CPU time. Note that this latency is almost always at the control of the system designer.

Also designated as "T_{sl}". Contrast *interrupt latency*.

scoid

An abbreviation for *server connection ID*.

session

A collection of process groups established for job control purposes. Each process group is a member of a session. A process belongs to the session that its process group belongs to. A newly created process joins the session of its creator. A process can alter its session membership via *setsid()*. A session can contain multiple process groups.

session leader

A process whose death causes all processes within its process group to receive a SIGHUP signal.

soft thread affinity

The scheme whereby the microkernel tries to dispatch a thread to the processor where it last ran, in an attempt to reduce thread migration from one processor to another, which can affect cache performance. Contrast *hard thread affinity*.

software interrupts

Similar to a hardware interrupt (see *interrupt*), except that the source of the interrupt is software.

sporadic

A scheduling policy whereby a thread's priority can oscillate dynamically between a “foreground” or normal priority and a “background” or low priority. A thread is given an execution *budget* of time to be consumed within a certain *replenishment* period. See also *adaptive*, *FIFO*, and *round robin*.

startup code

The software component that gains control after the IPL code has performed the minimum necessary amount of initialization. After gathering information about the system, the startup code transfers control to the OS.

static bootfile

An image created at one time and then transmitted whenever a node boots. Contrast *dynamic bootfile*.

static linking

The process whereby you combine your modules with the modules from the library to form a single executable that's entirely self-contained. The word “static” implies that it's not going to change—*all* the required modules are already combined into one.

symmetric multiprocessing (SMP)

A multiprocessor system where a single instantiation of an OS manages all CPUs simultaneously, and applications can float to any of them.

system page area

An area in the kernel that is filled by the startup code and contains information about the system (number of bytes of memory, location of serial ports, etc.) This is also called the SYSPAGE area.

thread

The schedulable entity under the QNX Neutrino RTOS. A thread is a flow of execution; it exists within the context of a *process*.

tid

An abbreviation for *thread ID*.

timer

A kernel object used in conjunction with time-based functions. A timer is created via *timer_create()* and armed via *timer_settime()*. A timer can then deliver an *event*, either periodically or on a one-shot basis.

timeslice

A period of time assigned to a *round-robin* or *adaptive* scheduled thread. This period of time is small (on the order of tens of milliseconds); the actual value shouldn't be relied upon by any program (it's considered bad design).

TLB

An abbreviation for *translation look-aside buffer*. To maintain performance, the processor caches frequently used portions of the external memory page tables in the TLB.

TLS

An abbreviation for *thread local storage*.

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