Multithreaded Programming Guide

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Preface

The *Multithreaded Programming Guide* describes the multithreaded programming interfaces for POSIX and Solaris threads in the Solaris™ 2.5 system. This guide shows application programmers how to create new multithreaded programs and how to add multithreading to existing programs.

Although this guide covers both the POSIX and Solaris threads implementations, most topics assume a POSIX threads interest. Information applying to only Solaris threads is covered in a special chapter.

To understand this guide, a reader must be familiar with

- A UNIX® SVR4 system—preferably the Solaris 2.5 system
- The C programming language—multithreading is implemented through the `libthread` library
- The principles of concurrent programming (as opposed to sequential programming)—multithreading requires a different way of thinking about function interactions. Some books you might want to read are:
    - *Algorithms for Mutual Exclusion* by Michel Raynal (MIT Press, 1986)
    - *Concurrent Programming* by Alan Burns & Geoff Davies (Addison-Wesley, 1993)
    - *Distributed Algorithms and Protocols* by Michel Raynal (Wiley, 1988)
    - *Operating System Concepts* by Silberschatz, Peterson, & Galvin (Addison-Wesley, 1991)
    - *Principles of Concurrent Programming* by M. Ben-Ari (Prentice-Hall, 1982)

How This Guide Is Organized

Chapter 1, "Covering Multithreading Basics," gives a structural overview of threads implementation in this release.

Chapter 2, "Basic Threads Programming," discusses the general POSIX threads library routines, emphasizing creating a thread with default attributes.

Chapter 3, "Thread Create Attributes," covers creating a thread with nondefault attributes.

Chapter 4, "Programming With Synchronization Objects," covers the threads library synchronization routines.

Chapter 5, "Programming With the Operating System," discusses changes to the operating system to support multithreading.

Chapter 6, "Safe and Unsafe Interfaces," covers multithreading safety issues.

Chapter 7, "Compiling and Debugging," covers the basics of compiling and debugging multithreaded applications.

Chapter 8, "Tools for Enhancing MT Programs," describes some of the tools available for gathering performance and debugging information about your multithreaded programs.

Chapter 9, "Programming with Solaris Threads," covers the Solaris threads (as opposed to POSIX threads) interfaces.

Chapter 10, "Programming Guidelines," discusses issues that affect programmers writing multithreaded applications.

Appendix A, "Sample Application – Multithreaded grep," shows how code can be designed for POSIX threads.

Appendix B, "Solaris Threads Example: barrier.c" shows an example of building a barrier in Solaris threads.

Appendix C, "MT Safety Levels: Library Interfaces" lists the safety levels of library routines.

You might be able to find additional useful information about multithreaded programming by browsing the following World Wide Web (WWW) site:

`http://www.sun.com/sunsoft/Products/Developer-products/sig/threads`

What Typographic Changes and Symbols Mean

Table P-1 describes the type changes and symbols used in this guide.

Table P-1 Typographic Conventions

Typeface or Symbol	**Meaning**	**Example**
`AaBbCc123`	Commands, files, directories, and C functions; code examples	The `fork1`() function is new. Use `ls -a` to list all files.
AaBbCc123	Variables, titles, and emphasized words	The *stack_size* value is set by... You *must* specify a zero value.
`AaBbCc123`	What you type, contrasted with on-screen computer output	`system%` **`cc prog.c`**
`page(#)`	The man page name and section in the *Solaris Reference Manual*	See `thr_create`(3T).

Sections of program code in the main text are enclosed in boxes:

```
nt test (100);

main()
{
    register int a, b, c, d, e, f;

    test(a) = b & test(c & 0x1) & test(d & 0x1);
```

Covering Multithreading Basics 1

The word *multithreading* can be translated as *multiple threads of control* or *multiple flows of control*. While a traditional UNIX process always has contained and still does contain a single thread of control, multithreading (MT) separates a process into many execution threads, each of which runs independently.

Multithreading your code can

- Improve application responsiveness
- Use multiprocessors more efficiently
- Improve program structure
- Use fewer system resources

This chapter explains some multithreading terms, benefits, and concepts. If you are ready to start using multithreading, skip to the chapter “Basic Threads Programming” on page 11.

Defining Multithreading Terms

Table 1-1 introduces some of the terms used in this book.

Table 1-1 Multithreading Terms

Term	Definition
Process	The UNIX environment (context like file descriptors, user ID, and so on) created with the `fork`(2) system call, which is set up to run a program.
Thread	A sequence of instructions executed within the context of a process.
pthreads (POSIX threads)	A POSIX 1003.1c compliant threads interface.
Solaris threads	A SunSoft™ threads interface that is not POSIX compliant. A predecessor of pthreads.
Single-threaded	Restricting access to a single thread.
Multithreaded	Allowing access to two or more threads.
User- or Application-level threads	Threads managed by the threads library routines in user (as opposed to kernel) space.
Lightweight processes	Threads in the kernel that execute kernel code and system calls (also called LWPs).
Bound threads	Threads that are permanently bound to LWPs.
Unbound threads	A default Solaris thread that context switches very quickly without kernel support.
Attribute object	Contains opaque data types and related manipulation functions used to standardize some of the configurable aspects of POSIX threads, mutexes, and condition variables.
Mutual exclusion locks	Functions that lock and unlock access to shared data
Condition variables	Functions that block threads until a change of state.
Counting semaphore	A memory-based synchronization mechanism.
Parallelism	A condition that arises when at least two threads are *executing* simultaneously.
Concurrency	A condition that exists when at least two threads are *making progress*. A more generalized form of parallelism that can encompass time-slicing as a form of virtual parallelism.

Meeting Multithreading Standards

The concept of multithreaded programming goes back to at least the 1960s. Its development on UNIX systems goes back to the mid-1980s. While there is agreement about what multithreading is and the features necessary to support it, the interfaces used to implement multithreading have varied greatly.

For several years a group called POSIX (Portable Operating System Interface) 1003.4a has been working on standards for multithreaded programming. The standard has now been ratified. This guide is based on the POSIX standards: P1003.1b final draft 14 (realtime), and P1003.1c final draft 10 (multithreading).

This book now covers both POSIX threads (also called *pthreads*) and Solaris threads. Solaris threads were available in the Solaris 2.4 release, and are not functionally different from POSIX threads. However, because POSIX threads are more portable than Solaris threads, this book covers multithreading from the POSIX perspective. Subjects specific to Solaris threads, only, are covered in the chapter “Programming with Solaris Threads.”

Benefiting From Multithreading

Improving Application Responsiveness

Any program in which many activities are not dependent upon each other can be redesigned so that each activity is defined as a thread. For example, the user of a multithreaded GUI does not have to wait for one activity to complete before starting another.

Using Multiprocessors Efficiently

Typically, applications that express concurrency requirements with threads need not take into account the number of available processors. The performance of the application improves transparently with additional processors.

Numerical algorithms and applications with a high degree of parallelism, such as matrix multiplications, can run much faster when implemented with threads on a multiprocessor.

Improving Program Structure

Many programs are more efficiently structured as multiple independent or semi-independent units of execution instead of as a single, monolithic thread. Multithreaded programs can be more adaptive to variations in user demands than single threaded programs.

Using Fewer System Resources

Programs that use two or more processes that access common data through shared memory are applying more than one thread of control.

However, each process has a full address space and operating systems state. The cost of creating and maintaining this large amount of state makes each process much more expensive than a thread in both time and space.

In addition, the inherent separation between processes can require a major effort by the programmer to communicate between the threads in different processes or to synchronize their actions.

Combining Threads and RPC

By combining threads and a remote procedure call (RPC) package, you can exploit nonshared-memory multiprocessors (such as a collection of workstations). This combination distributes your application relatively easily and treats the collection of workstations as a multiprocessor.

For example, one thread might create child threads. Each of these children could then place a remote procedure call, invoking a procedure on another workstation. Although the original thread has merely created threads that are now running in parallel, this parallelism involves other computers.

Understanding Basic Multithreading Concepts

Concurrency and Parallelism

In a multithreaded process on a single processor, the processor can switch execution resources between threads, resulting in concurrent execution.

In the same multithreaded process in a shared-memory multiprocessor environment, each thread in the process can run on a separate processor at the same time, resulting in parallel execution.

When the process has as many threads as, or fewer threads than, there are processors, the threads support system and the operating system ensure that each thread runs on a different processor.

For example, in a matrix multiplication that has the same number of threads and processors, each thread (and each processor) computes a row of the result.

Looking at Multithreading Structure

Traditional UNIX already supports the concept of threads—each process contains a single thread, so programming with multiple processes is programming with multiple threads. But a process is also an address space, and creating a process involves creating a new address space.

Creating a thread is much less expensive when compared to creating a new process, because the newly created thread uses the current process address space. The time it takes to switch between threads is much less than the time it takes to switch between processes, partly because switching between threads does not involve switching between address spaces.

Communicating between the threads of one process is simple because the threads share everything—address space, in particular. So, data produced by one thread is immediately available to all the other threads.

The interface to multithreading support is through a subroutine library, `libpthread` for POSIX threads, and `libthread` for Solaris threads. Multithreading provides flexibility by decoupling kernel-level and user-level resources.

User-level Threads

Threads are the primary programming interface in multithreaded programming. User-level threads[1] are handled in user space and avoid kernel context switching penalties. An application can have hundreds of threads and still not consume many kernel resources. How many kernel resources the application uses is largely determined by the application.

Threads are visible only from within the process, where they share all process resources like address space, open files, and so on. The following state is unique to each thread.

- Thread ID
- Register state (including PC and stack pointer)
- Stack
- Signal mask
- Priority
- Thread-private storage

Because threads share the process instructions and most of the process data, a change in shared data by one thread can be seen by the other threads in the process. When a thread needs to interact with other threads in the same process, it can do so without involving the operating system.

By default, threads are very lightweight. But, to get more control over a thread (for instance, to control scheduling policy more), the application can bind the thread. When an application binds threads to execution resources, the threads become kernel resources (see “System Scope (Bound Threads)” on page 8 for more information).

To summarize, user-level threads are:

- Inexpensive to create because they do not need to create their own address space. They are bits of virtual memory that are allocated from your address space at run time.
- Fast to synchronize because synchronization is done at the application level, not at the kernel level.
- Easily managed by the threads library, `libpthread` or `libthread`.

1. User-level threads are named to distinguish them from kernel-level threads, which are the concern of systems programmers, only. Because this book is for application programmers, kernel-level threads are not discussed.

Lightweight Processes

The threads library uses underlying threads of control called *lightweight processes* that are supported by the kernel. You can think of an LWP as a virtual CPU that executes code or system calls.

You usually do not need to concern yourself with LWPs to program with threads. The information here about LWPs is provided as background, so you can understand the differences in scheduling scope, described on page 8.

Note – The LWPs in the Solaris 2.x system are *not* the same as the LWPs in the SunOS™ 4.0 LWP library, which are not supported in the Solaris 2.x system.

Much as the `stdio` library routines such as `fopen(3S)` and `fread(3S)` use the `open(2)` and `read(2)` functions, the threads interface uses the LWP interface, and for many of the same reasons.

Lightweight processes (LWPs) bridge the user level and the kernel level. Each process contains one or more LWPs, each of which runs one or more user threads. The creation of a thread usually involves just the creation of some user context, but not the creation of an LWP.

Each LWP is a kernel resource in a kernel pool, and is allocated (attached) and de-allocated (detached) to a thread on a per thread basis. This happens as threads are scheduled or are created and destroyed.

Scheduling

POSIX specifies three scheduling policies: first-in-first-out (`SCHED_FIFO`), round-robin (`SCHED_RR`), and custom (`SCHED_OTHER`). `SCHED_FIFO` is a queue-based scheduler with different queues for each priority level. `SCHED_RR` is like FIFO except that each thread has a execution time quota.

Both `SCHED_FIFO` and `SCHED_RR` are POSIX Realtime extensions. `SCHED_OTHER` is the default scheduling policy.

See “LWPs and Scheduling Classes” on page 127“ for information about the `SCHED_OTHER` policy, and about emulating some properties of the POSIX `SCHED_FIFO` and `SCHED_RR` policies.

Two scheduling scopes are available: process scope for unbound threads and system scope for bound threads. Threads with differing scope states can coexist on the same system and even in the same process. In general, the scope sets the range in which the threads policy is in effect.

Process Scope (Unbound Threads)

Unbound threads are created `PTHREAD_SCOPE_PROCESS` and are private to a process.These threads are scheduled in user space to attach and detach from available LWPs in the LWP pool.

In most cases, threads should be `PTHREAD_SCOPE_PROCESS`. This allows the threads to float among the LWPs, and this improves threads performance (and is equivalent to creating a Solaris thread in the `THR_UNBOUND` state).

System Scope (Bound Threads)

Bound threads are created `PTHREAD_SCOPE_SYSTEM`. A thread with a scope of `PTHREAD_SCOPE_SYSTEM` is global to the system.

Each bound thread is bound to an LWP for the lifetime of the thread. This is equivalent to creating a Solaris thread in the `THR_BOUND` state. You can bind a thread to give it an alternate signal stack or to use special scheduling attributes with Realtime scheduling.

Cancellation

Thread cancellation allows a thread to terminate the execution of any other thread in the process. The target thread (the one being cancelled) can keep cancellation requests pending and can perform application-specific cleanup when it acts upon the cancellation notice.

The pthreads cancellation feature permits either asynchronous or deferred termination of a thread. Asynchronous cancellation can occur at any time; deferred cancellation can occur only at defined points. Deferred cancellation is the default type.

Synchronization

Synchronization allows you to control program flow and access to shared data for concurrently executing threads.

The three synchronization models are mutex locks, condition variables, and semaphores.

- Mutex locks allow only one thread at a time to execute a specific section of code, or to access specific data.
- Condition variables block threads until a particular condition is true.
- Counting semaphores typically coordinate access to resources. The count is the limit on how many threads can have access to a semaphore. When the count is reached, the semaphore blocks.

Basic Threads Programming 2

The Threads Library

This chapter introduces the basic threads programming routines from the POSIX threads library, `libpthread(3T)`. This chapter covers *default threads*, or threads with default attribute values, which are the kinds of threads that are most often used in multithreaded programming.

The next chapter, “Thread Create Attributes,” explains how to create and use threads with nondefault attributes.

The POSIX (`libpthread`) routines introduced here have programming interfaces that are similar to the original (`libthread`) Solaris multithreading library.

Create a Default Thread	*pthread_create(3T)*	*page 13*
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Yield Thread Execution	*sched_yield(3R)*	*page 28*
Get the Thread Priority	*pthread_getschedparam(3T)*	*page 30*
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Send a Signal to a Thread	*pthread_kill(3T)*	*page 31*
Access the Signal Mask of the Calling Thread	*pthread_sigmask(3T)*	*page 32*
Re-create and Reinitialize Critical Threads	*pthread_atfork(3T)*	*page 33*
Terminate a Thread	*pthread_exit(3T)*	*page 33*
Cancel a Thread	*pthread_cancel(3T)*	*page 36*
Enable or Disable Cancellation	*pthread_setcancelstate(3T)*	*page 37*
Set Cancellation Type	*pthread_setcanceltype(3T)*	*page 38*
Create a Cancellation Point	*pthread_testcancel(3T)*	*page 39*
Push a Handler Onto the Stack	*pthread_cleanup_push(3T)*	*page 40*
Pull a Handler Off the Stack	*pthread_cleanup_pop(3T)*	*page 40*

Create a Default Thread

When an attribute object is not specified, it is NULL, and the default thread is created with the following attributes:

- Unbound
- Nondetached
- With a default stack and stack size
- With the parent's priority

You can also create a default attribute object with `pthread_attr_init()`, and then use this attribute object to create a default thread. See the section "Initialize Attributes" on page 45 for details.

pthread_create(3T)

Use `pthread_create()` to add a new thread of control to the current process.

Prototype:

```
int pthread_create(pthread_t *tid, const pthread_attr_t *tattr,
    void*(*start_routine)(void *), void *arg);
```

```
#include <pthread.h>

pthread_attr_t tattr;
pthread_t tid;
extern *void start_routine(void *arg);
void *arg;
int ret;

/* default behavior*/
ret = pthread_create(&tid, NULL, start_routine, arg);

/* initialized with default attributes */
ret = pthread_attr_init(&tattr);
/* default behavior specified*/
ret = pthread_create(&tid, &tattr, start_routine, arg);
```

The `pthread_create()` function is called with the *attr* having the necessary state behavior. *start_routine* is the function with which the new thread begins execution. When *start_routine* returns, the thread exits with the exit status set to the value returned by *start_routine* (see "pthread_exit(3T)" on page 33).

When `pthread_create()` is successful, the ID of the thread created is stored in the location referred to by *tid*.

Creating a thread using a NULL attribute argument has the same effect as using a default attribute. Both create a default thread. When *tattr* is initialized, it acquires the default behavior.

Return Values

Returns a zero and exits when it completes successfully. Any other returned value indicates that an error occurred. When any of the following conditions are detected, `pthread_create()` fails and returns the corresponding value.

`EAGAIN` – A system limit is exceeded, such as when too many LWPs have been created.

`EINVAL` – The value of *tattr* is invalid.

Wait for Thread Termination

pthread_join(3T)

Use the `pthread_join()` function to wait for a thread to terminate.

```
Prototype:
int pthread_join(thread_t tid, void **status);
```

```
#include <phread.h>

pthread_t tid;
int ret;
int status;

/* waiting to join thread "tid" with status */
ret = pthread_join(tid, &status);

/* waiting to join thread "tid" without status */
ret = pthread_join(tid, NULL);
```

The `pthread_join()` function blocks the calling thread until the specified thread terminates.

The specified thread must be in the current process and must not be detached. For information on thread detachment, see “Set Detach State” on page 47.

When *status* is not NULL, it points to a location that is set to the exit status of the terminated thread when `pthread_join()` returns successfully.

Multiple threads cannot wait for the same thread to terminate. If they try to, one thread returns successfully and the others fail with an error of ESRCH.

After `pthread_join` returns, any stack storage associated with the thread can be reclaimed by the application.

Return Values

Returns a zero when it completes successfully. Any other returned value indicates that an error occurred. When any of the following conditions are detected, `pthread_join()` fails and returns the corresponding value.

`ESRCH` – *tid* is not a valid, undetached thread in the current process.

`EDEADLK` – *tid* specifies the calling thread.

`EINVAL` – The value of *tid* is invalid.

The `pthread_join()` routine takes two arguments, giving you some flexibility in its use. When you want the caller to wait until a specific thread terminates, supply that thread's ID as the first argument.

If you are interested in the exit code of the defunct thread, supply the address of an area to receive it.

Remember that `pthread_join()` works only for target threads that are nondetached. When there is no reason to synchronize with the termination of a particular thread, then that thread should be detached.

Think of a detached thread as being the usual sort of thread and reserve nondetached threads for only those situations that require them.

A Simple Threads Example

In Code Example 2-1, one thread executes the procedure at the top, creating a helper thread that executes the procedure `fetch`, which involves a complicated database lookup and might take some time.

The main thread wants the results of the lookup but has other work to do in the meantime. So it does those other things and then waits for its helper to complete its job by executing `pthread_join()`.

The result is passed as a stack parameter, which can be done here because the main thread waits for the spun-off thread to terminate. In general, though, it is better to malloc(3C) storage from the heap instead of passing an address to thread stack storage, which can disappear or be reassigned if the thread terminated.

Code Example 2-1 A Simple Threads Program

```
void mainline (...)
{
        char int result;
        pthread_attr_t tattr;
        pthread_t helper;
        int status;

        pthread_create(&helper, NULL, fetch, &result);

            /* do something else for a while */

        pthread_join(helper, &status);
        /* it's now safe to use result */
}

void fetch(int *result)
{
        /* fetch value from a database */

        *result = value;
        pthread_exit(0);
}
```

Detaching a Thread

pthread_detach(3T)

pthread_detach(3T) is an alternate way (as opposed to pthread_join(3T)) to reclaim storage for a thread that is created with a *detachstate* attribute set to PTHREAD_CREATE_JOINABLE.

Prototype:

```
int pthread_detach(thread_t tid);
```

```
#include <phread.h>

pthread_t tid;
int ret;

/* detach thread tid */
ret = pthread_detach(tid);
```

The pthread_detach(3T) function is used to indicate to the implementation that storage for the thread *tid* can be reclaimed when the thread terminates. If *tid* has not terminated, pthread_detach(3T) does not cause it to terminate. The effect of multiple pthread_detach(3T) calls on the same target thread is unspecified.

Return Values

Returns a zero when it completes successfully. Any other returned value indicates that an error occurred. When any of the following conditions are detected, pthread_join() fails and returns the corresponding value.

EINVAL – *tid* is not a valid thread.

ESRCH – *tid* is not a valid, undetached thread in the current process.

Create a Key for Thread-Specific Data

Single-threaded C programs have two basic classes of data—local data and global data. For multithreaded C programs a third class is added—thread-specific data (TSD). This is very much like global data, except that it is private to a thread.

Thread-specific data is maintained on a per-thread basis. TSD is the only way to define and refer to data that is private to a thread. Each thread-specific data item is associated with a key that is global to all threads in the process. Using the key, a thread can access a pointer (`void *`) that is maintained per-thread.

pthread_keycreate(3T)

Use `pthread_keycreate()` to allocate a key that is used to identify thread-specific data in a process. The key is global to all threads in the process, and all threads initially have the value NULL associated with the key when it is created.

`pthread_keycreate()` is called once for each key before the key is used. There is no implicit synchronization.

Once a key has been created, each thread can bind a value to the key. The values are specific to the thread and are maintained for each thread independently. The per-thread binding is deallocated when a thread terminates if the key was created with a destructor function.

Prototype:

```
int pthread_key_create(pthread_key_t *key,
    void (*destructor) (void *));
```

```
#include <pthread.h>

pthread_key_t key;
int ret;

/* key create without destructor */
ret = pthread_key_create(&key, NULL);

/* key create with destructor */
ret = pthread_key_create(&key, destructor);
```

When `pthread_keycreate()` returns successfully, the allocated key is stored in the location pointed to by *key*. The caller must ensure that the storage and access to this key are properly synchronized.

An optional destructor function, `destructor`, can be used to free stale storage. When a key has a non-NULL `destructor` function and the thread has a non-NULL value associated with that key, the `destructor` function is called with the current associated value when the thread exits. The order in which the `destructor` functions are called is unspecified.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, `pthread_keycreate()` fails and returns the corresponding value.

`EAGAIN` – The *key* name space is exhausted.

`ENOMEM` – Not enough virtual memory is available in this process to create a new key.

Delete the Thread-Specific Data Key

pthread_keydelete(3T)

Use `pthread_keydelete()` to destroy an existing thread-specific data key. This can be used to cause an error return when trying to access some thread-specific data set that is no longer valid. (Read the POSIX standard document for the rationale.) There is no comparable function in Solaris threads.

```
Prototype:
int pthread_key_delete(pthread_key_t *key);
```

```
#include <pthread.h>

pthread_key_t key;
int ret;

/* key previously created */
ret = pthread_key_delete(&key);
```

Once a key has been deleted, any reference to it with the `pthread_setspecific()` or `pthread_getspecific()` calls results in the `EINVAL` error.

It is the responsibility of the programmer to free any thread-specific resources before calling the delete function. This function does not invoke any of the destructors.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, `pthread_keycreate()` fails and returns the corresponding value.

`EINVAL` – The *key* value is invalid.

Set the Thread-Specific Data Key

pthread_setspecific(3T)

Use `pthread_setspecific()` for a thread that has not yet established a binding to the specified thread-specific data key.

```
Prototype:
int pthread_setspecific(pthread_key_t key, const void *value);
```

```
#include <pthread.h>

pthread_key_t key;
void *value;
int ret;

/* key previously created */
ret = pthread_setspecific(key, value);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, `pthread_setspecific()` fails and returns the corresponding value.

`ENOMEM` – Not enough virtual memory is available.

`EINVAL` – *key* is invalid.

Note – A memory leak can occur if you set a new binding for a thread to a key that the thread has already used.

Get the Thread-Specific Data Key

pthread_getspecific(3T)

Use `pthread_getspecific()` to get the calling thread's binding for *key*, and store it in the location pointed to by *value*.

```
Prototype:
int pthread_getspecific(pthread_key_t key);
```

```
#include <pthread.h>

pthread_key_t key;
void *value;

/* key previously created */
value = pthread_getspecific(key);
```

Return Values

No errors are returned.

Global and Private Thread-Specific Data Example

Code Example 2-2 shows an excerpt from a multithreaded program. This code is executed by any number of threads, but it has references to two global variables, `errno` and `mywindow`, that really should be references to items private to each thread.

Code Example 2-2 Thread-Specific Data—Global but Private

```
body() {
    ...

    while (write(fd, buffer, size) == -1) {
        if (errno != EINTR) {
            fprintf(mywindow, "%s\n", strerror(errno));
            exit(1);
        }
    }

    ...

}
```

References to `errno` should get the system error code from the routine called by this thread, not by some other thread. So, references to `errno` by one thread refer to a different storage location than references to `errno` by other threads.

The `mywindow` variable is intended to refer to a `stdio` stream connected to a window that is private to the referring thread. So, as with `errno`, references to `mywindow` by one thread should refer to a different storage location (and, ultimately, a different window) than references to `mywindow` by other threads. The only difference here is that the threads library takes care of `errno`, but the programmer must somehow make this work for `mywindow`.

The next example shows how the references to `mywindow` work. The preprocessor converts references to `mywindow` into invocations of the `_mywindow` procedure.

This routine in turn invokes pthread_getspecific(3T), passing it the mywindow_key global variable (it really is a global variable) and an output parameter, win, that receives the identity of this thread's window.

Code Example 2-3 Turning Global References Into Private References

```
#define mywindow _mywindow()

thread_key_t mywindow_key;

FILE *_mywindow(void) {
    FILE *win;

    pthread_getspecific(mywindow_key, &win);
    return(win);
}


void thread_start(...) {
    ...
    make_mywindow();
    ...
}
```

The mywindow_key variable identifies a class of variables for which each thread has its own private copy; that is, these variables are thread-specific data. Each thread calls make_mywindow() to initialize its window and to arrange for its instance of mywindow to refer to it.

Once this routine is called, the thread can safely refer to mywindow and, after _mywindow, the thread gets the reference to its private window. So, references to mywindow behave as if they were direct references to data private to the thread.

Code Example 2-4 shows how to set this up.

Code Example 2-4 Initializing the Thread-Specific Data

```
void make_mywindow(void) {
    FILE **win;
    static pthread_once_t mykeycreated = PTHREAD_ONCE_INIT;

    pthread_once(&mykeycreated, mykeycreate);

    win = malloc(sizeof(*win));
    create_window(win, ...);

    pthread_setspecific(mywindow_key, win);
}

void mykeycreate(void) {
    pthread_keycreate(&mywindow_key, free_key);
}

void free_key(void *win) {
    free(win);
}
```

First, get a unique value for the key, `mywindow_key`. This key is used to identify the thread-specific class of data. So, the first thread to call `make_mywindow` eventually calls `pthread_keycreate(3T)`, which assigns to its first argument a unique key. The second argument is a destructor function that is used to deallocate a thread's instance of this thread-specific data item once the thread terminates.

The next step is to allocate the storage for the caller's instance of this thread-specific data item. Having allocated the storage, a call is made to the `create_window` routine, which sets up a window for the thread and sets the storage pointed to by `win` to refer to it. Finally, a call is made to `pthread_setspecific`, which associates the value contained in `win` (that is, the location of the storage containing the reference to the window) with the key.

After this, whenever this thread calls `pthread_getspecific()`, passing the global key, it gets the value that was associated with this key by this thread when it called `pthread_setspecific()`.

When a thread terminates, calls are made to the destructor functions that were set up in `pthread_key_create()`. Each destructor function is called only if the terminating thread established a value for the key by calling `pthread_setspecific()`.

Get the Thread Identifier

pthread_self(3T)

Use `pthread_self()` to get the ID of the calling thread.

```
Prototype:
pthread_t pthread_self(void);
```

```
#include <pthread.h>

pthread_t tid;

tid = pthread_self();
```

Return Values

Returns the ID of the calling thread.

Compare Thread IDs

pthread_equal(3T)

Use `pthread_equal()` to compare the thread identification numbers of two threads.

```
Prototype:
int  pthread_equal(pthread_t tid1, pthread_t tid2);
```

```
#include <pthread.h>

pthread_t tid1, tid2;
int ret;

ret = pthread_equal(tid1, tid2);
```

Return Values

Returns a non-zero value when *tid1* and *tid2* are equal; otherwise, zero is returned. When either *tid1* or *tid2* is an invalid thread identification number, the result is unpredictable.

Initializing Threads

pthread_once(3T)

Use pthread_once(3T) to call an initialization routine the first time pthread_once(3T) is called. Subsequent calls to pthread_once(3T) have no effect..

```
Prototype:
int  pthread_once(pthread_once_ *once_control,
    void (*init_routine)(void));
```

```
#include <pthread.h>

pthread_once_t once_control = PTHREAD_ONCE_INIT;
int ret;

ret = pthread_once(&once_control, init_routine);
```

The *once_control* parameter determines whether the associated initialization routine has been called.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, pthread_once() fails and returns the corresponding value.

EINVAL – *once_control* or *init_routine* is NULL.

Yield Thread Execution

sched_yield(3R)

Use sched_yield() to cause the current thread to yield its execution in favor of another thread with the same or greater priority.

```
Prototype:
int  sched_yield(void);
```

```
#include <sched.h>

int ret;

ret = sched_yield();
```

Return Values

Returns zero after completing successfully. Otherwise -1 is returned and errno is set to indicate the error condition.

ENOSYS – sched_yield(3R) is not supported in this implementation.

Set the Thread Priority

pthread_setschedparam(3T)

Use `pthread_setschedparam()` to modify the priority of an existing thread.This function has no effect on scheduling policy.

```
Prototype:
int  pthread_setschedparam(pthread_t tid, int policy,
    const struct schedparam *param);
```

```
#include <pthread.h>

pthread_t tid;
int ret;
sched_param param;
int priority;

/* sched_priority will be the priority of the thread */
schedparam.sched_priority = priority;

/* only supported policy, others will result in ENOTSUP */
policy = SCHED_OTHER;

/* scheduling parameters of target thread */
ret = pthread_setschedparam(tid, policy, param);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When either of the following conditions occurs, the function fails and returns the corresponding value.

`EINVAL` – The value of the attribute being set is not valid.

`ENOTSUP` – An attempt was made to set the attribute to an unsupported value.

Get the Thread Priority

pthread_getschedparam(3T)

Gets the priority of the existing thread.

```
Prototype:
int  pthread_getschedparam(pthread_t tid, int policy,
    struct schedparam *param);
```

```
#include <pthread.h>

pthread_t tid;
sched_param param;
int priority;
int policy;
int ret;

/* scheduling parameters of target thread */
ret = pthread_getschedparam (tid, &policy, &param);

/* sched_priority contains the priority of the thread */
priority = schedparam.sched_priority;
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

`ESRCH` – The value specified by *tid* does not refer to an existing thread.

Send a Signal to a Thread

pthread_kill(3T)

Use `pthread_kill()` to send a signal to a thread.

```
Prototype:
int  pthread_kill(thread_t tid,  int sig);
```

```
#include <pthread.h>
#include <signal.h>

int sig;
pthread_t tid;
int ret;

ret = pthread_kill(tid, sig);
```

`pthread_kill()` sends the signal *sig* to the thread specified by *tid*. *tid* must be a thread within the same process as the calling thread. The *sig* argument must be from the list given in `signal(5)`.

When *sig* is zero, error checking is performed but no signal is actually sent. This can be used to check the validity of *tid*.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When either of the following conditions occurs, `pthread_kill()` fails and returns the corresponding value.

`EINVAL` – *sig* is not a valid signal number.

`ESRCH` – *tid* cannot be found in the current process.

Access the Signal Mask of the Calling Thread

pthread_sigmask(3T)

Use pthread_sigmask() to change or examine the signal mask of the calling thread.

```
Prototype:
int pthread_sigmask(int how, const sigset_t *new, sigset_t *old);
```

```
#include <pthread.h>
#include <signal.h>

int ret;
sigset_t old, new;

ret = pthread_sigmask(SIG_SETMASK, &new, &old); /* set new mask */
ret = pthread_sigmask(SIG_BLOCK, &new, &old); /* blocking mask */
ret = pthread_sigmask(SIG_UNBLOCK, &new, &old); /* unblocking */
```

how determines how the signal set is changed. It can have one of the following values:

- SIG_BLOCK—Add *new* to the current signal mask, where *new* indicates the set of signals to block.
- SIG_UNBLOCK—Delete *new* from the current signal mask, where *new* indicates the set of signals to unblock.
- SIG_SETMASK—Replace the current signal mask with *new*, where *new* indicates the new signal mask.

When the value of *new* is NULL, the value of *how* is not significant and the signal mask of the thread is unchanged. So, to inquire about currently blocked signals, assign a NULL value to the *new* argument.

The *old* variable points to the space where the previous signal mask is stored, unless it is NULL.

Return Values

Returns a zero when it completes successfully. Any other returned value indicates that an error occurred. When the following condition occurs, `pthread_sigmask()` fails and returns the corresponding value.

`EINVAL` – The value of *how* is not defined.

Re-create and Reinitialize Critical Threads

pthread_atfork(3T)

See the discussion about `pthread_atfork()` on page 123.

```
Prototype:

int pthread_atfork(void (*prepare) (void), void (*parent) (void),
    void (*child) (void) );
```

Terminate a Thread

pthread_exit(3T)

Use `pthread_exit()` to terminate a thread.

```
Prototype:
void pthread_exit(void *status);
```

```
#include <pthread.h>

int status;

pthread_exit(&status); /* exit with status */
```

The `pthread_exit()` function terminates the calling thread. All thread-specific data bindings are released. If the calling thread is not detached, then the thread’s ID and the exit status specified by *status* are retained until the thread is waited for. Otherwise, *status* is ignored and the thread's ID can be reclaimed immediately. For information on thread detachment, see "Set Detach State" on page 47.

Return Values

The calling thread terminates with its exit status set to the contents of *status* if *status* is not NULL.

Finishing Up

A thread can terminate its execution in the following ways:

- By returning from its first (outermost) procedure, the threads start routine; see `pthread_create(3T)`
- By calling `pthread_exit(3T)`, supplying an exit status
- By termination with POSIX cancel functions; see `pthread_cancel(3T)`

The default behavior of a thread is to remain until some other thread has acknowledged its demise by "joining" with it. This is the same as the default pthread create attribute being non-detached; see `pthread_detach(3T)`. The result of the join is that the joining thread picks up the exit status of the dying thread and the dying thread vanishes.

An important special case arises when the main thread, the one that existed initially, returns from the main procedure or calls `exit(3C)`. This action causes the entire process to be terminated, along with all its threads. So take care to ensure that the main thread does not return from `main` prematurely.

Note that when the main thread merely calls `pthread_exit(3T)`, it terminates only itself—the other threads in the process, as well as the process, continue to exist. (The process terminates when all threads terminate.)

Cancellation

POSIX threads introduces the notion of cancellability to threads programming. Cancellation allows a thread to terminate the execution of any other thread, or all threads, in the process. Cancellation is an option when all further operations of a related set of threads are undesirable or unnecessary. A good method is to cancel all threads, restore the process to a consistent state, and then return to the point of origin.

One example is an asynchronously generated cancel condition such as a user requesting to close or exit some running application. Another example is the completion of a task undertaken by a number of threads. One of the threads might ultimately complete the task while the others continue to operate. Since they are serving no purpose at that point, they all should be cancelled.

There are dangers in performing cancellations. Most deal with properly restoring invariants and freeing shared resources. A thread that is cancelled without care might leave a mutex in a locked state, leading to a deadlock. Or it might leave a region of memory allocated with no way to identify it and therefore no way to free it.

pthreads specifies a cancellation interface that permits or forbids cancellation programmatically. pthreads defines the set of points at which cancellation can occur *(cancellation points)*. It also allows the scope of cancellation handlers, which provide clean up services, to be defined so that they are sure to operate when and where intended.

Placement of cancellation points and the effects of cancellation handlers must be based on an understanding of the application. A mutex is explicitly not a cancellation point and should be held only the minimal essential time.

Limit regions of asynchronous cancellation to sequences with no external dependencies that could result in dangling resources or unresolved state conditions. Take care to restore cancellation state when returning from some alternate, nested cancellation state. The interface provides features to facilitate restoration: `pthread_setcancelstate(3T)` preserves the current cancel state in a referenced variable; `pthread_setcanceltype(3T)` preserves the current cancel type in the same way.

Cancellations can occur under three different circumstances:

- Asynchronously
- At various points in the execution sequence as defined by the standard
- At discrete points specified by the application

By default, cancellation can occur only at well-defined points as defined by the POSIX standard.

In all cases, take care that resources and state are restored to a condition consistent with the point of origin.

Cancellation Points

Be careful to cancel a thread only when cancellation is safe. The pthreads standard specifies several cancellation points, including:

- The programmatically-determined `pthread_testcancel(3T)` call
- Threads waiting in `pthread_cond_wait(3T)` or `pthread_cond_timedwait(3T)`.
- Threads waiting for termination of another thread in `pthread_join(3T)`.
- Threads blocked on `sigwait(2)`.
- Some standard library calls. In general, these are functions in which threads can block; see the man page `cancellation(3T)` for a list.

By default cancellation is enabled. At times you might want an application to disable cancellation. This has the result of deferring all cancellation requests until they are enabled again. Note that enabling cancellation constitutes a cancellation point.

See `pthread_setcancelstate()` for information about disabling cancellation.

Cancel a Thread

pthread_cancel(3T)

Use `pthread_cancel()` to cancel a thread.

```
Prototype:
int pthread_cancel(pthread_t thread);
```

```
#include <pthread.h>

pthread_t thread;
int ret;

ret = pthread_cancel(thread);
```

How the cancellation request is treated depends on the state of the target thread. Two functions, `pthread_setcancelstate(3T)` and `pthread_setcanceltype(3T)`, determine that state.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

`ESRCH` – No thread could be found corresponding to that specified by the given thread ID.

Enable or Disable Cancellation

pthread_setcancelstate(3T)

Use `pthread_setcancelstate()` to enable or disable cancellability of a thread. When a thread is created, cancellability is enabled by default.

```
Prototype:
int pthread_setcancelstate(int state, int *oldstate);
```

```
#include <pthread.h>

int oldstate;
int ret;

/* enabled */
ret = pthread_setcancelstate(PTHREAD_CANCEL_ENABLE, &oldstate);

/* disabled */
ret = pthread_setcancelstate(PTHREAD_CANCEL_DISABLE, &oldstate);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The state is not `PTHREAD_CANCEL_ENABLE` or `PTHREAD_CANCEL_DISABLE`.

Set Cancellation Type

`pthread_setcanceltype(3T)`

Use `pthread_setcanceltype()` to set the cancellation type to either deferred or asynchronous mode. When a thread is created, the cancellation type is set to deferred mode by default. In deferred mode, the thread can be cancelled only at cancellation points. In asynchronous mode, a thread can be cancelled any point during its execution. Using asynchronous mode is discouraged.

Prototype:

```
int pthread_setcanceltype(int type, int *oldtype);
```

```
#include <pthread.h>

int oldtype;
int ret;

/* deferred mode */
ret = pthread_setcanceltype(PTHREAD_CANCEL_DEFERED, &oldtype);

/* async mode*/
ret = pthread_setcanceltype(PTHREAD_CANCEL_ASYNCHRONOUS, &oldtype);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The type is not `PTHREAD_CANCEL_DEFERRED` or `PTHREAD_CANCEL_ASYNCHRONOUS`.

Create a Cancellation Point

pthread_testcancel(3T)

Use `pthread_testcancel()` to establish a cancellation point for a thread.

```
Prototype:
void pthread_testcancel(void);
```

```
#include <pthread.h>

pthread_testcancel();
```

The `pthread_testcancel()` function is effective when cancellability is enabled and in deferred mode. Calling this function while cancellability is disabled has no effect.

Be careful to insert `pthread_testcancel()` only in sequences where it is safe to cancel a thread. In addition to the programmatically determined `pthread_testcancel()` call, the pthreads standard specifies several cancellation points. See “Cancellation Points” on page 36 for more details.

There is no return value.

Push a Handler Onto the Stack

Use cleanup handlers to restore conditions to a state consistent with that at the point of origin, such as cleaning up allocated resources and restoring invariants. Use the `pthread_cleanup_push(3T)` and `pthread_cleanup_pop(3T)` functions to manage the handlers.

Cleanup handlers are pushed and popped in the same lexical scope of a program. They should always match; otherwise compiler errors will be generated.

pthread_cleanup_push(3T)

Use the `pthread_cleanup_push()` function to push a cleanup handler onto a cleanup stack (FIFO).

Prototype:
```
void pthread_cleanup_push(void(*routine)(void *), void *args);
```

```
#include <pthread.h>

/* push the handler "routine" on cleanup stack */
pthread_cleanup_push (routine, arg);
```

Pull a Handler Off the Stack

pthread_cleanup_pop(3T)

Use the `pthread_cleanup_pop()` function to pull the cleanup handler off the cleanup stack.

A nonzero argument in the pop function removes the handler from the stack and executes it. An argument of zero pops the handler without executing it.

`pthread_cleanup_pop()` is effectively called with a nonzero argument if a thread either explicitly or implicitly calls `pthread_exit(3T)` or if the thread accepts a cancel request.

Prototype:
`void pthread_cleanup_pop(int` *execute*`);`

```
#include <pthread.h>

/* pop the "func" out of cleanup stack and execute "func" */
pthread_cleanup_pop (1);

/* pop the "func" and DONT execute "func" */
pthread_cleanup_pop (0);
```

There are no return values.

Thread Create Attributes 3

The previous chapter covered the basics of threads creation using default attributes. This chapter discusses setting attributes at thread creation time.

Note that only pthreads uses attributes and cancellation, so the API covered in this chapter is for POSIX threads only. Otherwise, the *functionality* for Solaris threads and pthreads is largely the same. (See Chapter 9, "Programming with Solaris Threads" for more information about similarities and differences.)

Attributes

Attributes are a way to specify behavior that is different from the default. When a thread is created with `pthread_create(3T)` or when a synchronization variable is initialized, an attribute object can be specified. The defaults are usually sufficient.

An attribute object is opaque, and cannot be directly modified by assignments. A set of functions is provided to initialize, configure, and destroy each object type.

Once an attribute is initialized and configured, it has process-wide scope. The suggested method for using attributes is to configure all required state specifications at one time in the early stages of program execution. The appropriate attribute object can then be referred to as needed.

Using attribute objects has two primary advantages.

- First, it adds to code portability.

  Even though supported attributes might vary between implementations, you need not modify function calls that create thread entities because the attribute object is hidden from the interface.

  If the target port supports attributes that are not found in the current port, provision must be made to manage the new attributes. This is an easy porting task though, because attribute objects need only be initialized once in a well-defined location.

- Second, state specification in an application is simplified.

  As an example, consider that several sets of threads might exist within a process, each providing a separate service, and each with its own state requirements.

  At some point in the early stages of the application, a thread attribute object can be initialized for each set. All future thread creations will then refer to the attribute object initialized for that type of thread. The initialization phase is simple and localized, and any future modifications can be made quickly and reliably.

Attribute objects require attention at process exit time. When the object is initialized, memory is allocated for it. This memory must be returned to the system. Attribute destroy function calls are provided to do this.

Initialize Attributes

pthread_attr_init(3T)

Use pthread_attr_init() to initialize the attributes associated with the object to the default values. The storage is allocated by the thread system during execution.

```
Prototype:
int pthread_attr_init(pthread_attr_t *tattr);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int ret;

/* initialize an attribute to the default value */
ret = pthread_attr_init(&tattr);
```

The default values for attributes (*tattr*) are:

Table 3-1 Default Attribute Values

Attribute	Value	Result
scope	PTHREAD_SCOPE_PROCESS	New thread is unbound – not permanently attached to LWP
detachstate	PTHREAD_CREATE_JOINABLE	Exit status and thread are preserved after the thread terminates.
stackaddr	NULL	New thread has system-allocated stack address
stacksize	1 megabyte	New thread has system-defined stack size

Table 3-1 Default Attribute Values

Attribute	Value	Result
`priority`		New thread inherits parent thread priority
`inheritsched`	`PTHREAD_INHERIT_SCHED`	New thread inherits parent thread scheduling priority
`schedpolicy`	`SCHED_OTHER`	New thread uses Solaris-defined fixed priority scheduling; threads run until preempted by a higher-priority thread or until they block or yield.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`ENOMEM` – Returned when there is not enough memory to initialize the thread attributes object.

Destroy Attributes

pthread_attr_destroy(3T)

Use `pthread_attr_destroy()` to remove the storage allocated during initialization. The attribute object becomes invalid.

```
Prototype:
int pthread_attr_destroy(pthread_attr_t *tattr);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int ret;

/* destroy an attribute */
ret = pthread_attr_destroy(&tattr);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – Indicates that the value of *tattr* was not valid.

Set Detach State

pthread_attr_setdetachstate(3T)

When a thread is created detached (PTHREAD_CREATE_DETACHED), its thread ID and other resources can be reused as soon as the thread terminates. Use pthread_attr_setdetachstate() when you do not want to wait for the thread to terminate.

When a thread is created nondetached (PTHREAD_CREATE_JOINABLE), it is assumed that the you will be waiting for it. That is, it is assumed that you will be executing a pthread_join(3T) on the thread.

Prototype:
```
int pthread_attr_setdetachstate(pthread_attr_t *tattr,int detachstate);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int ret;

/* set the thread detach state */
ret = pthread_attr_setdetachstate(&tattr,PTHREAD_CREATE_DETACHED);
```

Note – When there is no explicit synchronization to prevent it, a newly created, detached thread can die and have its thread ID reassigned to another new thread before its creator returns from pthread_create().

For nondetached (PTHREAD_CREATE_JOINABLE) threads, it is very important that some thread join with it after it terminates—otherwise the resources of that thread are not released for use by new threads. This commonly results in a memory leak. So when you do not want a thread to be joined, create it as a detached thread.

Code Example 3-1 Creating a Detached Thread

```
#include <pthread.h>

pthread_attr_t tattr;
pthread_t tid;
void *start_routine;
void arg
int ret;

/* initialized with default attributes */
ret = pthread_attr_init(&tattr);
ret = pthread_attr_setdetachstate(&tattr,PTHREAD_CREATE_DETACHED);
ret = pthread_create(&tid, &tattr, start_routine, arg);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – Indicates that the value of *detachstate* or *tattr* was not valid.

Get Detach State

pthread_attr_getdetachstate(3T)

Use `pthread_attr_getdetachstate()` to retrieve the thread create state, which can be either detached or joined.

```
Prototype:
int pthread_attr_getdetachstate(const pthread_attr_t *tattr,
    int *detachstate;
```

```
#include <pthread.h>

pthread_attr_t tattr;
int detachstate;
int ret;

/* get detachstate of thread */
ret = pthread_attr_getdetachstate (&tattr, &detachstate);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – Indicates that the value of *detachstate* is NULL or *tattr* is invalid.

Set Scope

pthread_attr_setscope(3T)

Use `pthread_attr_setscope()` to create a bound thread (PTHREAD_SCOPE_SYSTEM) or an unbound thread (PTHREAD_SCOPE_PROCESS).

Prototype:
```
int pthread_attr_setscope(pthread_attr_t *tattr,int scope);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int ret;

/* bound thread */
ret = pthread_attr_setscope(&tattr, PTHREAD_SCOPE_SYSTEM);

/* unbound thread */
ret = pthread_attr_setscope(&tattr, PTHREAD_SCOPE_PROCESS);
```

Notice that there are three function calls in this example: one to initialize the attributes, one to set any variations from the default attributes, and one to create the pthreads.

Table 3-2 Creating a Bound Thread

```
#include <pthread.h>

pthread_attr_t tattr;
pthread_t tid;
void start_routine;
void arg;
int ret;

/* initialized with default attributes */
ret = pthread_attr_init(&tattr);

/* BOUND behavior */
ret = pthread_attr_setscope(&tattr, PTHREAD_SCOPE_SYSTEM);
ret = pthread_create(&tid, &tattr, start_routine, arg);
```

Return Values

Returns zero after completing *successfully*. Any other returned value indicates that an error occurred. If the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` – An attempt was made to set *tattr* to a value that is not valid.

Get Scope

pthread_attr_getscope(3T)

Use this routine to retrieve the thread scope, which can be process or system.

```
Prototype:
int pthread_attr_getscope(pthread_attr_t *tattr, int scope);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int scope;
int ret;

/* get scope of thread */
ret = pthread_attr_getscope(&tattr, &scope);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The value of *scope* is NULL or *tattr* is invalid.

Set Scheduling Policy

pthread_attr_setschedpolicy(3T)

Use `pthread_attr_setschedpolicy()` to set the scheduling policy. The POSIX draft standard specifies scheduling policy attributes of `SCHED_FIFO` (first-in-first-out), `SCHED_RR` (round-robin), or `SCHED_OTHER` (an implementation-defined method).

`SCHED_FIFO` and `SCHED_RR` are optional in POSIX, and are supported for Realtime bound threads, only.

Currently, only the Solaris-based SCHED_OTHER is supported in pthreads. For a discussion of scheduling, see the section “Scheduling” on page 7.

Prototype:
```
int pthread_attr_setschedpolicy(pthread_attr_t *tattr, int policy);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int policy;
int ret;

/* set the scheduling policy to SCHED_OTHER */
ret = pthread_attr_setschedpolicy(&tattr, SCHED_OTHER);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When either of the following conditions occurs, the function fails and returns the corresponding value.

EINVAL – An attempt was made to set *tattr* to a value that is not valid.

ENOTSUP – An attempt was made to set the attribute to an unsupported value.

Get Scheduling Policy

pthread_attr_getschedpolicy(3T)

Use `pthread_attr_getschedpolicy()` to retrieve the scheduling policy.

```
Prototype:
int pthread_attr_getschedpolicy(pthread_attr_t *tattr, int policy);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int policy;
int ret;

/* get scheduling policy of thread */
ret = pthread_attr_getschedpolicy (&tattr, &policy);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The parameter *policy* is NULL or *tattr* is invalid.

Set Inherited Scheduling Policy

pthread_attr_setinheritsched(3T)

An *inherit* value of PTHREAD_INHERIT_SCHED (the default) means that the scheduling policies defined in the creating thread are to be used, and any scheduling attributes defined in the pthread_create() call are to be ignored. If PTHREAD_EXPLICIT_SCHED is used, the attributes from the pthread_create() call are to be used.

Prototype:

```
int pthread_attr_setinheritsched(pthread_attr_t *tattr, int inherit);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int inherit;
int ret;

/* use the current scheduling policy */
ret = pthread_attr_setinheritsched(&tattr, PTHREAD_EXPLICIT_SCHED);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When either of the following conditions occurs, the function fails and returns the corresponding value.

EINVAL – An attempt was made to set *tattr* to a value that is not valid.

ENOTSUP – An attempt was made to set the attribute to an unsupported value.

Get Inherited Scheduling Policy

pthread_attr_getinheritsched(3T)

```
Prototype:
int pthread_attr_getinheritsched(pthread_attr_t *tattr, int inherit);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int inherit;
int ret;

/* get scheduling policies of the creating thread */
ret = pthread_attr_getinheritsched (&tattr, &inherit);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The parameter *inherit* is NULL or *tattr* is invalid.

Set Scheduling Parameters

pthread_attr_setschedparam(3T)

Scheduling parameters are defined in the `param` structure; only priority is supported. Newly created threads run with this priority.

```
Prototype:
int pthread_attr_setschedparam(pthread_attr_t *tattr,
    const struct sched_param *param);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int newprio;
sched_param param;
newprio = 30;

/* set the priority; others are unchanged */
param.sched_priority = newprio;

/* set the new scheduling param */
ret = pthread_attr_setschedparam (&tattr, &param);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` – The value of *param* is NULL or *tattr* is invalid.

You can manage pthreads priority two ways. You can set the priority attribute before creating a child thread, or you can change the priority of the parent thread and then change it back.

Get Scheduling Parameters

pthread_attr_getschedparam(3T)

```
Prototype:
int pthread_attr_getschedparam(pthread_attr_t *tattr,
    const struct sched_param *param);
```

```
#include <pthread.h>

pthread_attr_t attr;
sched_param param;
int ret;

/* get the existing scheduling param */
ret = pthread_attr_getschedparam (&tattr, &param);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value of *param* is NULL or *tattr* is invalid.

Creating a Thread With a Specified Priority

You can set the priority attribute before creating the thread. The child thread is created with the new priority that is specified in the `sched_param` structure (this structure also contains other scheduling information).

It is always a good idea to get the existing parameters, change the priority, and then set it. Code Example 3-2 shows an example of this.

Code Example 3-2 Creating a Prioritized Thread

```
#include <pthread.h>
#include <sched.h>

pthread_attr_t tattr;
pthread_t tid;
int ret;
int newprio = 20;
sched_param param;

/* initialized with default attributes */
ret = pthread_attr_init (&tattr);

/* safe to get existing scheduling param */
ret = pthread_attr_getschedparam (&tattr, &param);

/* set the priority; others are unchanged */
param.sched_priority = newprio;

/* setting the new scheduling param */
ret = pthread_attr_setschedparam (&tattr, &param);

/* with new priority specified */
ret = pthread_create (&tid, &tattr, func, arg);
```

Set Stack Size

pthread_attr_setstacksize(3T)

The stacksize attribute defines the size of the stack (in bytes) that the system will allocate. The size should not be less than the system-defined minimum stack size. See “About Stacks” on page 61 for more information.

Prototype:

```
int pthread_attr_setstacksize(pthread_attr_t *tattr, int size);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int size;
int ret;

size = (PTHREAD_STACK_MIN + 0x4000);

/* setting a new size */
ret = pthread_attr_setstacksize(&tattr, size);
```

In the example above, *size* contains the size, in number of bytes, for the stack that the new thread uses. If *size* is zero, a default size is used. In most cases, a zero value works best.

PTHREAD_STACK_MIN is the amount of stack space required to start a thread. This does not take into consideration the threads routine requirements that are needed to execute application code.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value returned is less than the value of PTHREAD_STACK_MIN, or exceeds a system-imposed limit, or *tattr* is not valid.

Get Stack Size

pthread_attr_getstacksize(3T)

Prototype:

```
int pthread_attr_getstacksize(pthread_attr_t *tattr, int size);
```

```
#include <pthread.h>

pthread_attr_t tattr;
int size;
int ret;

size = (PTHREAD_STACK_MIN + 0x1000);

/* getting the stack size */
ret = pthread_attr_getstacksize(&tattr, &size);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The value returned is less than the value of `PTHREAD_STACK_MIN`, or exceeds a system-imposed limit.

About Stacks

Typically, thread stacks begin on page boundaries and any specified size is rounded up to the next page boundary. A page with no access permission is appended to the top of the stack so that most stack overflows result in sending a `SIGSEGV` signal to the offending thread. Thread stacks allocated by the caller are used as is.

When a stack is specified, the thread should also be created `PTHREAD_CREATE_JOINABLE`. That stack cannot be freed until the `pthread_join(3T)` call for that thread has returned, because the thread's stack cannot be freed until the thread has terminated. The only reliable way to know if a thread has terminated is through `pthread_join(3T)`.

Generally, you do not need to allocate stack space for threads. The threads library allocates one megabyte of virtual memory for each thread's stack with no swap space reserved. (The library uses the `MAP_NORESERVE` option of `mmap(2)` to make the allocations.)

Each thread stack created by the threads library has a red zone. The library creates the red zone by appending a page to the top of a stack to catch stack overflows. This page is invalid and causes a memory fault if it is accessed. Red zones are appended to all automatically allocated stacks whether the size is specified by the application or the default size is used.

Note – Because runtime stack requirements vary, you should be absolutely certain that the specified stack will satisfy the runtime requirements needed for library calls and dynamic linking.

There are very few occasions when it is sensible to specify a stack, its size, or both. It is difficult even for an expert to know if the right size was specified. This is because even an ABI-compliant program can't determine its stack size statically. Its size is dependent on the needs of the particular runtime environment in which it executes.

Building Your Own Stack

When you specify the size of a thread stack, be sure to account for the allocations needed by the invoked function and by each function called. The accounting should include calling sequence needs, local variables, and information structures.

Occasionally you want a stack that is a bit different from the default stack. An obvious situation is when the thread needs more than one megabyte of stack space. A less obvious situation is when the default stack is too large. You might be creating thousands of threads and not have enough virtual memory to handle the gigabytes of stack space that this many default stacks require.

The limits on the maximum size of a stack are often obvious, but what about the limits on its minimum size? There must be enough stack space to handle all of the stack frames that are pushed onto the stack, along with their local variables and so on.

You can get the absolute minimum limit on stack size by calling the macro PTHREAD_STACK_MIN(), which returns the amount of stack space required for a thread that executes a null procedure. Useful threads need more than this, so be very careful when reducing the stack size.

When you allocate your own stack, be sure to append a red zone to its end by calling mprotect(2).

```
#include <pthread.h>

pthread_attr_t tattr;
pthread_t tid;
int ret;

int size = PTHREAD_STACK_MIN + 0x4000;

/* initialized with default attributes */
ret = pthread_attr_init(&tattr);

/* setting the size of the stack also */
ret = pthread_attr_setstacksize(&tattr, size);

/* only size specified in tattr*/
ret = pthread_create(&tid, &tattr, start_routine, arg);
```

Set Stack Address

pthread_attr_setstackaddr(3T)

The stackaddr attribute defines the base of the thread's stack. If this is set to non-null (NULL is the default) the system initializes the stack at that address.

```
Prototype:
int pthread_attr_setstackaddr(pthread_attr_t *tattr,void **stackaddr);
```

```
#include <pthread.h>

pthread_attr_t tattr;
void *base;
int ret;

base = (void *) malloc(PTHREAD_STACK_MIN + 0x4000);

/* setting a new address */
ret = pthread_attr_setstackaddr(&tattr, base);
```

In the example above, *base* contains the address for the stack that the new thread uses. If *base* is NULL, then pthread_create(3T) allocates a stack for the new thread with at least PTHREAD_STACK_MIN bytes.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value or *base* or *tattr* is incorrect.

This example shows how to create a thread with a custom stack address.

```
#include <pthread.h>

pthread_attr_t tattr;
pthread_t tid;
int ret;
void *stackbase;

stackbase = (void *) malloc(size);

/* initialized with default attributes */
ret = pthread_attr_init(&tattr);

/* setting the base address in the attribute */
ret = pthread_attr_setstackaddr(&tattr, stackbase);

/* only address specified in attribute tattr */
ret = pthread_create(&tid, &tattr, func, arg);
```

This example shows how to create a thread with both a custom stack address and a custom stack size.

```
#include <pthread.h>

pthread_attr_t tattr;
pthread_t tid;
int ret;
void *stackbase;

int size = PTHREAD_STACK_MIN + 0x4000;
stackbase = (void *) malloc(size);

/* initialized with default attributes */
ret = pthread_attr_init(&tattr);

/* setting the size of the stack also */
ret = pthread_attr_setstacksize(&tattr, size);

/* setting the base address in the attribute */
ret = pthread_attr_setstackaddr(&tattr, stackbase);

/*address and size specified */
ret = pthread_create(&tid, &tattr, func, arg);
```

Get Stack Address

pthread_attr_getstackaddr(3T)

Prototype:

```
int pthread_attr_getstackaddr(pthread_attr_t *tattr,void **stackaddr);
```

```
#include <pthread.h>

pthread_attr_t tattr;
void *base;
int ret;

base = (void *) malloc(PTHREAD_STACK_MIN + 0x1000);

/* getting a new address */
ret = pthread_attr_getstackaddr (&tattr, base);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The value or *base* or *tattr* is incorrect.

Programming With Synchronization Objects 4

This chapter describes the synchronization types available with threads and discusses synchronization concerns.

Synchronization objects are variables in memory that you access just like data. Threads in different processes can communicate with each other through synchronization objects placed in threads-controlled shared memory, even though the threads in different processes are generally invisible to each other.

Synchronization objects can also be placed in files and can have lifetimes beyond that of the creating process.

The available types of synchronization objects are:

- Mutex Locks
- Condition Variables
- Semaphores

Here are situations that can profitably use synchronization:

- When synchronization is the only way to ensure consistency of shared data.
- When threads in two or more processes can use a single synchronization object jointly. Note that the synchronization object should be initialized by only one of the cooperating processes, because reinitializing a synchronization object sets it to the *unlocked* state.
- When synchronization can ensure the safety of mutable data.
- When a process can map a file and have a thread in this process get a record's lock. Once the lock is acquired, any other thread in any process mapping the file that tries to acquire the lock is blocked until the lock is released.
- Even when accessing a single primitive variable, such as an integer. On machines where the integer is not aligned to the bus data width or is larger than the data width, a single memory load can use more than one memory cycle. While this cannot happen on the SPARC® architecture, portable programs cannot rely on this.

Note – On 32-bit architectures a `long long` is not atomic[1] and is read and written as two 32-bit quantities. The types `int`, `char`, `float`, and pointers are atomic on SPARC and x86 machines.

Mutual Exclusion Lock Attributes

Use mutual exclusion locks (mutexes) to serialize thread execution. Mutual exclusion locks synchronize threads, usually by ensuring that only one thread at a time executes a critical section of code. Mutex locks can also preserve single-threaded code.

1. An *atomic* operation cannot be divided into smaller operations.

To change the default mutex attributes, you can declare and initialize an attribute object. Often, the mutex attributes are set in one place at the beginning of the application so they can be located quickly and modified easily. The following table lists the functions discussed in this section that manipulate mutex attributes.

Table 4-1 Mutex Attributes Routines

Initialize a Mutex Attribute Object	*pthread_mutexattr_init(3T)*	*page 72*
Destroy a Mutex Attribute Object	*pthread_mutexattr_destroy(3T)*	*page 73*
Set the Scope of a Mutex	*pthread_mutexattr_setpshared(3T)*	*page 74*
Get the Scope of a Mutex	*pthread_mutexattr_getpshared(3T)*	*page 75*

The differences in defining the scope of a mutex from the original Solaris threads are shown in Table 4-2.

Table 4-2 Mutex Scope Comparison

Solaris	**POSIX**	**Definition**
USYNC_PROCESS	PTHREAD_PROCESS_SHARED	Use to synchronize threads in this and other processes
USYNC_THREAD	PTHREAD_PROCESS_PRIVATE	Use to synchronize threads in this process only

Initialize a Mutex Attribute Object

pthread_mutexattr_init(3T)

Use pthread_mutexattr_init() to initialize attributes associated with this object to their default values. Storage for each attribute object is allocated by the threads system during execution.

The default value of the *pshared* attribute when this function is called is PTHREAD_PROCESS_PRIVATE, which means that the initialized mutex can be used within a process.

```
Prototype:
int pthread_mutexattr_init(pthread_mutexattr_t *mattr);
```

```
#include <pthread.h>

pthread_mutexattr_t mattr;
int ret;

/* initialize an attribute to default value */
ret = pthread_mutexattr_init(&mattr);
```

mattr is an opaque type that contains a system-allocated attribute object. The possible values of *mattr*'s scope are PTHREAD_PROCESS_PRIVATE (the default) and PTHREAD_PROCESS_SHARED.

Before a mutex attribute object can be reused, it must first be destroyed by pthread_mutexattr_destroy(3T). The pthread_mutexattr_init() call returns a pointer to an opaque object. If the object is not destroyed, a memory leak will result.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If either of the following conditions occurs, the function fails and returns the corresponding value.

ENOMEM – There is not enough memory to initialize the thread attributes object.

EINVAL – The value specified by *mattr* is invalid.

Destroy a Mutex Attribute Object

pthread_mutexattr_destroy(3T)

`pthread_mutexattr_destroy()` deallocates the storage space used to maintain the attribute object created by `pthread_mutexattr_init()`.

Prototype:
```
int pthread_mutexattr_destroy(pthread_mutexattr_t *mattr)
```

```
#include <pthread.h>

pthread_mutexattr_t mattr;
int ret;

/* destroy an attribute */
ret = pthread_mutexattr_destroy(&mattr);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The value specified by *mattr* is invalid.

Set the Scope of a Mutex

pthread_mutexattr_setpshared(3T)

The scope of a mutex variable can be either process private (intraprocess) or system wide (interprocess). If the mutex is created with the *pshared* attribute set to the PTHREAD_PROCESS_SHARED state, and it exists in shared memory, it can be shared among threads from more than one process. This is equivalent to the USYNC_PROCESS flag in mutex_init() in the original Solaris threads.

```
Prototype:
int pthread_mutexattr_setpshared(pthread_mutexattr_t *mattr,
    int pshared);
```

```
#include <pthread.h>

pthread_mutexattr_t mattr;
int pshared;
int ret;

ret = pthread_mutexattr_init(&mattr);
/*
 * resetting to its default value
 */
ret = pthread_mutexattr_setpshared(&mattr,
    PTHREAD_PROCESS_PRIVATE);
```

If the mutex *pshared* attribute is set to PTHREAD_PROCESS_PRIVATE, only those threads created by the same process can operate on the mutex.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value specified by *mattr* is invalid.

Get the Scope of a Mutex

pthread_mutexattr_getpshared(3T)

```
Prototype:
int pthread_mutexattr_getpshared(pthread_mutexattr_t *mattr,
    int pshared);
```

```
#include <pthread.h>

pthread_mutexattr_t mattr;
int pshared, ret;

/* get pshared of mutex */
ret = pthread_mutexattr_getpshared(&mattr, &pshared);
```

Get the current value of *pshared* for the attribute object *mattr*. It is either PTHREAD_PROCESS_SHARED or PTHREAD_PROCESS_PRIVATE.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value specified by *mattr* is invalid.

Using Mutual Exclusion Locks

After the attributes for a mutex are configured, you initialize the mutex itself. The following functions are used to initialize or destroy, lock or unlock, or try to lock a mutex. Table 4-3 lists the functions discussed in this chapter that manipulate mutex locks.

Table 4-3 Routines for Mutual Exclusion Locks

Initialize a Mutex	*pthread_mutex_init(3T)*	*page 76*
Lock a Mutex	*pthread_mutex_lock(3T)*	*page 78*
Unlock a Mutex	*pthread_mutex_unlock(3T)*	*page 79*
Lock With a Nonblocking Mutex	*pthread_mutex_trylock(3T)*	*page 80*
Destroy a Mutex	*pthread_mutex_destroy(3T)*	*page 81*

The default scheduling policy, `SCHED_OTHER`, does not specify the order in which threads can acquire a lock. When multiple threads are waiting for a mutex, the order of acquisition is undefined. When there is contention, the default behavior is to unblock threads in priority order.

Initialize a Mutex

pthread_mutex_init(3T)

Use `pthread_mutex_init()` to initialize the mutex pointed at by *mp* to its default value (*mattr* is NULL), or to specify mutex attributes that have already been set with `pthread_mutexattr_init()`.

```
Prototype:
int pthread_mutex_init(pthread_mutex_t *mp,
    const pthread_mutexattr_t *mattr);
```

```
#include <pthread.h>

pthread_mutex_t mp = PTHREAD_MUTEX_INITIALIZER;
pthread_mutexattr_t mattr;
int ret;

/* initialize a mutex to its default value */
ret = pthread_mutex_init(&mp, NULL);

/* initialize a mutex */
ret = pthread_mutex_init(&mp, &mattr);
```

When the mutex is initialized, it is in an unlocked state.

The effect of *mattr* being NULL is the same as passing the address of a default mutex attribute object, but without the memory overhead.

Statically defined mutexes can be initialized directly to have default attributes with the macro PTHREAD_MUTEX_INITIALIZER.

If a mutex is dynamically allocated and was initialized with an attribute object, its attribute object should be freed with pthread_mutexattr_destroy() before the mutex itself is freed.

A mutex lock must not be reinitialized or destroyed while other threads might be using it. Program failure will result if either action is not done correctly. If a mutex is reinitialized or destroyed, the application must be sure the mutex is not currently in use.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EBUSY – The mutex cannot be reinitialized or modified because it still exists.

EINVAL – The attribute value is invalid. The mutex has not been modified.

EAGAIN – There are not enough resources to initialize another mutex.

ENOMEM – There is not enough memory to initialize another mutex.

Lock a Mutex

pthread_mutex_lock(3T)

```
Prototype:
int pthread_mutex_lock(pthread_mutex_t *mp);
```

```
#include <pthread.h>

pthread_mutex_t mp;
int ret;

ret = pthread_ mutex_lock(&mp); /* acquire the mutex */
```

Use `pthread_mutex_lock()` to lock the mutex pointed to by *mp*. When the mutex is already locked, the calling thread blocks and the mutex waits on a prioritized queue. When `pthread_mutex_lock()` returns, the mutex is locked and the calling thread is the owner.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` – The value specified by *mp* does not refer to an initialized mutex object.

`EDEADLK` – The current thread already owns the mutex.

Unlock a Mutex

pthread_mutex_unlock(3T)

Use `pthread_mutex_unlock()` to unlock the mutex pointed to by *mp*.

```
Prototype:
int pthread_mutex_unlock(pthread_mutex_t *mp);
```

```
#include <pthread.h>

pthread_mutex_t mp;
int ret;

ret = pthread_ mutex_unlock(&mp); /* release the mutex */
```

The mutex must be locked and the calling thread must be the one that last locked the mutex (the owner). When any other threads are waiting for the mutex to become available, the thread at the head of the queue is unblocked.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` – The value specified by *mp* does not refer to an initialized mutex object.

`EPERM` – The current thread does not own the mutex.

Lock With a Nonblocking Mutex

pthread_mutex_trylock(3T)

Use `pthread_mutex_trylock()` to attempt to lock the mutex pointed to by *mp*.

```
Prototype:
int pthread_mutex_trylock(pthread_mutex_t *mp);
```

```
#include <pthread.h>

pthread_mutex_t mp;
int ret;

ret = pthread_ mutex_trylock(&mp); /* try to lock the mutex */
```

This function is a nonblocking version of `pthread_mutex_lock()`. When the mutex is already locked, this call returns with an error. Otherwise, the mutex is locked and the calling thread is the owner.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EBUSY` – The mutex pointed to by *mp* was already locked.

`EINVAL` – The value specified by *mp* does not refer to an initialized mutex object.

Destroy a Mutex

pthread_mutex_destroy(3T)

Use pthread_mutex_destroy() to destroy any state associated with the mutex pointed to by *mp*.

```
Prototype:
int pthread_mutex_destroy(pthread_mutex_t *mp);
```

```
#include <pthread.h>

mutex_t mp;
int ret;

ret = pthread_mutex_destroy(&mp); /* mutex is destroyed */
```

Note that the space for storing the mutex is not freed.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EBUSY – The mutex you are trying to destroy is locked or in use.

EINVAL – The value specified by *mp* does not refer to an initialized mutex object.

Mutex Lock Code Examples

Here are some code fragments showing mutex locking.

Code Example 4-1 Mutex Lock Example

```
#include <pthread.h>

pthread_mutex_t count_mutex;
long long count;

void
increment_count()
{
    pthread_mutex_lock(&count_mutex);
    count = count + 1;
    pthread_mutex_unlock(&count_mutex);
}

long long
get_count()
{
    long long c;

    pthread_mutex_lock(&count_mutex);
    c = count;
    pthread_mutex_unlock(&count_mutex);
    return (c);
}
```

The two functions in Code Example 4-1 use the mutex lock for different purposes. The `increment_count` function uses the mutex lock simply to assure an atomic update of the shared variable. The `get_count` function uses the mutex lock to guarantee that the 64-bit quantity `count` is read atomically. On a 32-bit architecture, a `long long` is really two 32-bit quantities.

Note that if `count` were an `int`, `get_count` would not need a mutex lock to read the value of `count`, because integer operations are atomic.

Using Locking Hierarchies

You will occasionally want to access two resources at once. Perhaps you are using one of the resources, and then discover that the other resource is needed as well. As shown in Code Example 4-2, there could be a problem if two threads attempt to claim both resources but lock the associated mutexes in different orders. In this example, if the two threads lock mutexes 1 and 2 respectively, then a deadlock occurs when each attempts to lock the other mutex.

Code Example 4-2 Deadlock

Thread 1	Thread 2

`pthread_mutex_lock(&m1);`
 	
`/* use resource 1 */`
 	
`pthread_mutex_lock(&m2);`
 	
`/* use resources 1 and 2 */`
 	
`pthread_mutex_unlock(&m2);`
`pthread_mutex_unlock(&m1);`
	`pthread_mutex_lock(&m2);`
	
	`/* use resource 2 */`
	
	`pthread_mutex_lock(&m1);`
	
	`/* use resources 1 and 2 */`
	
	`pthread_mutex_unlock(&m1);`
	`pthread_mutex_unlock(&m2);`

The best way to avoid this problem is to make sure that whenever threads lock multiple mutexes, they do so in the same order. This technique is known as *lock hierarchies*: order the mutexes by logically assigning numbers to them.

Also, honor the restriction that you cannot take a mutex that is assigned *i* when you are holding any mutex assigned a number greater than *i*.

Note – The `lock_lint` tool can detect the sort of deadlock problem shown in this example. The best way to avoid such deadlock problems is to use lock hierarchies. When locks are always taken in a prescribed order, deadlock should not occur.

However, this technique cannot always be used—sometimes you must take the mutexes in an order other than prescribed. To prevent deadlock in such a situation, use `pthread_mutex_trylock()`. One thread must release its mutexes when it discovers that deadlock would otherwise be inevitable.

Code Example 4-3 shows how this is done.

Code Example 4-3 Conditional Locking

Thread 1	**Thread 2**

`pthread_mutex_lock(&m1);`
`  pthread_mutex_lock(&m2);`
 	
`  pthread_mutex_unlock(&m2);`
 	
`pthread_mutex_unlock(&m1);`
	`for (;;) {`
	`  pthread_mutex_lock(&m2);`
	`  if (pthread_mutex_trylock(&m1)==0)`
	`    /* got it! */`
	`    break;`
	
	`  /* didn't get it */`
	`  pthread_mutex_unlock(&m2);`
	`}`
	`pthread_mutex_unlock(&m1);`
	`pthread_mutex_unlock(&m2);`

In this example, thread 1 locks mutexes in the prescribed order, but thread 2 takes them out of order. To make certain that there is no deadlock, thread 2 has to take mutex 1 very carefully; if it were to block waiting for the mutex to be released, it is likely to have just entered into a deadlock with thread 1.

To ensure this does not happen, thread 2 calls `pthread_mutex_trylock()`, which takes the mutex if it is available. If it is not, thread 2 returns immediately, reporting failure. At this point, thread 2 must release mutex 2, so that thread 1 can lock it, and then release both mutex 1 and mutex 2.

Nested Locking With a Singly Linked List

Code Example 4-4 and Code Example 4-5 show how to take three locks at once, but prevent deadlock by taking the locks in a prescribed order.)

Code Example 4-4 Singly Linked List Structure

```
typedef struct node1 {
    int value;
    struct node1 *link;
    pthread_mutex_t lock;
} node1_t;

node1_t ListHead;
```

This example uses a singly-linked list structure with each node containing a mutex. To remove a node from the list, first search the list starting at ListHead (which itself is never removed) until the desired node is found.

To protect this search from the effects of concurrent deletions, lock each node before any of its contents are accessed. Because all searches start at ListHead, there is never a deadlock because the locks are always taken in list order.

When the desired node is found, lock both the node and its predecessor since the change involves both nodes. Because the predecessor's lock is always taken first, you are again protected from deadlock. Here is the C code to remove an item from a singly linked list.

Code Example 4-5 Singly-Linked List with Nested Locking

```
node1_t *delete(int value)
{
    node1_t *prev, *current;

    prev = &ListHead;
    pthread_mutex_lock(&prev->lock);
    while ((current = prev->link) != NULL) {
        pthread_mutex_lock(&current->lock);
        if (current->value == value) {
            prev->link = current->link;
            pthread_mutex_unlock(&current->lock);
            pthread_mutex_unlock(&prev->lock);
            current->link = NULL;
            return(current);
        }
        pthread_mutex_unlock(&prev->lock);
        prev = current;
    }
    pthread_mutex_unlock(&prev->lock);
    return(NULL);
}
```

Nested Locking With a Circular Linked List

Code Example 4-6 modifies the previous list structure by converting it into a circular list. There is no longer a distinguished head node; now a thread might be associated with a particular node and might perform operations on that node and its neighbor. Note that lock hierarchies do not work easily here because the obvious hierarchy (following the links) is circular.

Code Example 4-6 Circular Linked List Structure

```
typedef struct node2 {
    int value;
    struct node2 *link;
    pthread_mutex_t lock;
} node2_t;
```

Here is the C code that acquires the locks on two nodes and performs an operation involving both of them.

Code Example 4-7 Circular Linked List With Nested Locking

```
void Hit Neighbor(node2_t *me) {
    while (1) {
        pthread_mutex_lock(&me->lock);
        if (pthread_mutex_lock(&me->link->lock)!= 0) {
            /* failed to get lock */
            pthread_mutex_unlock(&me->lock);
            continue;
        }
        break;
    }
    me->link->value += me->value;
    me->value /=2;
    pthread_mutex_unlock(&me->link->lock);
    pthread_mutex_unlock(&me->lock);
}
```

Condition Variable Attributes

Use condition variables to atomically block threads until a particular condition is true. Always use condition variables together with a mutex lock.

With a condition variable, a thread can atomically block until a condition is satisfied. The condition is tested under the protection of a mutual exclusion lock (mutex).

When the condition is false, a thread usually blocks on a condition variable and atomically releases the mutex waiting for the condition to change. When another thread changes the condition, it can signal the associated condition variable to cause one or more waiting threads to wake up, reacquire the mutex, and reevaluate the condition.

Condition variables can be used to synchronize threads among processes when they are allocated in memory that is writable and shared by the cooperating processes.

The scheduling policy determines how blocking threads are awakened. For the default `SCHED_OTHER`, threads are awakened in priority order.

The attributes for condition variables must be set and initialized before the condition variables can be used. The functions that manipulate condition variable attributes are listed in Table 4-4.

Table 4-4 Condition Variable Attributes

Initialize a Condition Variable Attribute	*pthread_condattr_init(3T)*	*page 88*
Remove a Condition Variable Attribute	*pthread_condattr_destroy(3T)*	*page 89*
Set the Scope of a Condition Variable	*pthread_condattr_setpshared(3T)*	*page 90*
Get the Scope of a Condition Variable	*pthread_condattr_getpshared(3T)*	*page 91*

The differences from the original Solaris threads in defining the scope of a condition variable are shown in Table 4-5.

Table 4-5 Condition Variable Scope Comparison

Solaris	POSIX	Definition
USYNC_PROCESS	PTHREAD_PROCESS_SHARED	Use to synchronize threads in this and other processes
USYNC_THREAD	PTHREAD_PROCESS_PRIVATE	Use to synchronize threads in this process only

Initialize a Condition Variable Attribute

pthread_condattr_init(3T)

Use pthread_condattr_init() to initialize attributes associated with this object to their default values. Storage for each attribute object is allocated by the threads system during execution. The default value of the *pshared* attribute when this function is called is PTHREAD_PROCESS_PRIVATE, which means that the initialized condition variable can be used within a process.

Prototype:

```
int pthread_condattr_init(pthread_condattr_t *cattr);
```

```
#include <pthread.h>
#include <time.h>

pthread_condattr_t cattr;
int ret;

/* initialize an attribute to default value */
ret = pthread_condattr_init(&cattr);
```

cattr is an opaque data type that contains a system-allocated attribute object. The possible values of *cattr*'s scope are PTHREAD_PROCESS_PRIVATE (the default) and PTHREAD_PROCESS_SHARED.

Before a condition variable attribute can be reused, it must first be removed by `pthread_condattr_destroy(3T)`. The `pthread_condattr_init()` call returns a pointer to an opaque object. If the object is not destroyed, a memory leak will result.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When either of the following conditions occurs, the function fails and returns the corresponding value.

`ENOMEM` – There is not enough memory to initialize the thread attributes object.

`EINVAL` – The value specified by *cattr* is invalid.

Remove a Condition Variable Attribute

pthread_condattr_destroy(3T)

Use this routine to remove storage and render the attribute object invalid.

```
Prototype:
int pthread_condattr_destroy(pthread_condattr_t *cattr);
```

```
#include <pthread.h>
#include <time.h>

pthread_condattr_t cattr;
int ret;

/* destroy an attribute */
ret = pthread_condattr_destroy(&cattr);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The value specified by *cattr* is invalid.

Set the Scope of a Condition Variable

pthread_condattr_setpshared(3T)

The scope of a condition variable can be either process private (intraprocess) or system wide (interprocess). If the condition variable is created with the *pshared* attribute set to the PTHREAD_PROCESS_SHARED state, and it exists in shared memory, it can be shared among threads from more than one process. This is equivalent to the USYNC_PROCESS flag in mutex_init() in the original Solaris threads.

If the mutex *pshared* attribute is set to PTHREAD_PROCESS_PRIVATE, only those threads created by the same process can operate on the mutex. Using PTHREAD_PROCESS_PRIVATE results in the same behavior as with the USYNC_THREAD flag in the original Solaris threads cond_init() call, which is that of a local condition variable. PTHREAD_PROCESS_SHARED is equivalent to a global condition variable.

```
Prototype:
int pthread_condattr_setpshared(pthread_condattr_t *cattr,
    int pshared);
```

```
#include <pthread.h>
#include <time.h>

pthread_condattr_t cattr;
int ret;

/* all processes */
ret = pthread_condattr_setpshared(&cattr, PTHREAD_PROCESS_SHARED);

/* within a process */
ret = pthread_condattr_setpshared(&cattr, PTHREAD_PROCESS_PRIVATE);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. If the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value of *cattr* is invalid, or the *pshared* value is invalid.

Get the Scope of a Condition Variable

pthread_condattr_getpshared(3T)

Get the current value of *pshared* for the attribute object *cattr*. The value is either PTHREAD_PROCESS_SHARED or PTHREAD_PROCESS_PRIVATE.

```
Prototype:
int pthread_condattr_getpshared(const pthread_condattr_t *cattr,
    int *pshared);
```

```
#include <pthread.h>
#include <time.h>

pthread_condattr_t cattr;
int pshared;
int ret;

/* get pshared value of condition variable */
ret = pthread_condattr_getpshared(&cattr, &pshared);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

EINVAL – The value of *cattr* is invalid.

Using Condition Variables

This section explains using condition variables. Table 4-6 lists the functions that are available.

Table 4-6 Condition Variables Functions

Initialize a Condition Variable	*pthread_cond_init(3T)*	*page 92*
Block on a Condition Variable	*pthread_cond_wait(3T)*	*page 94*
Unblock a Specific Thread	*pthread_cond_signal(3T)*	*page 96*
Block Until a Specified Event	*pthread_cond_timedwait(3T)*	*page 98*
Unblock All Threads	*pthread_cond_broadcast(3T)*	*page 99*
Destroy Condition Variable State	*pthread_cond_destroy(3T)*	*page 101*

Initialize a Condition Variable

pthread_cond_init(3T)

Use `pthread_cond_init()` to initialize the condition variable pointed at by *cv* to its default value (*cattr* is NULL), or to specify condition variable attributes that are already set with `pthread_condattr_init()`. The effect of *cattr* being NULL is the same as passing the address of a default condition variable attribute object, but without the memory overhead.

```
Prototype:
int pthread_cond_init(pthread_cond_t *cv,
    const pthread_condattr_t *cattr);
```

```
#include <pthread.h>

pthread_cond_t cv;
pthread_condattr_t cattr;
int ret;

/* initialize a condition variable to its default value */
ret = pthread_cond_init(&cv, NULL);

/* initialize a condition variable */
ret = pthread_cond_init(&cv, &cattr);
```

Statically-defined condition variables can be initialized directly to have default attributes with the macro PTHREAD_COND_INITIALIZER. This has the same effect as dynamically allocating pthread_cond_init() with null attributes. No error checking is done.

Multiple threads must not simultaneously initialize or reinitialize the same condition variable. If a condition variable is reinitialized or destroyed, the application must be sure the condition variable is not currently in use.

If a condition variable is dynamically allocated and was initialized with an attribute object, before the condition variable itself is freed, its attribute object should first be freed with pthread_condattr_destroy() .

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EINVAL – The value specified by *cattr* is invalid.

EBUSY – The condition variable is being used.

EAGAIN – The necessary resources are not available.

ENOMEM – There is not enough memory to initialize the condition variable.

Block on a Condition Variable

pthread_cond_wait(3T)

Use this routine to atomically release the mutex pointed to by *mp* and to cause the calling thread to block on the condition variable pointed to by *cv*.

```
Prototype:
int pthread_cond_wait(pthread_cond_t *cv,pthread_mutex_t *mutex);
```

```
#include <pthread.h>

pthread_cond_t cv;
pthread_mutex_t mp;
int ret;

/* wait on condition variable */
ret = pthread_cond_wait(&cv, &mp);
```

The blocked thread can be awakened by a `pthread_cond_signal()`, a `pthread_cond_broadcast()`, or when interrupted by delivery of a signal.

Any change in the value of a condition associated with the condition variable cannot be inferred by the return of `pthread_cond_wait()`, and any such condition must be reevaluated.

The `pthread_cond_wait()` routine always returns with the mutex locked and owned by the calling thread even when returning an error.

This function blocks until the condition is signaled. It atomically releases the associated mutex lock before blocking, and atomically reacquires it before returning.

In typical use, a condition expression is evaluated under the protection of a mutex lock. When the condition expression is false, the thread blocks on the condition variable. The condition variable is then signaled by another thread when it changes the condition value. This causes one or all of the threads waiting on the condition to unblock and to try to reacquire the mutex lock.

Because the condition can change before an awakened thread returns from `pthread_cond_wait()`, the condition that caused the wait must be retested before the mutex lock is acquired. The recommended test method is to write the condition check as a while loop that calls `pthread_cond_wait()`.

```
pthread_mutex_lock();
    while(condition_is_false)
        pthread_cond_wait();
pthread_mutex_unlock();
```

No specific order of acquisition is guaranteed when more than one thread blocks on the condition variable.

Note – `pthread_cond_wait()` is a cancellation point. If a cancel is pending and the calling thread has cancellation enabled, the thread will be terminated and will begin executing its cleanup handlers.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – The value specified by *cv* or *mp* is invalid.

Unblock a Specific Thread

pthread_cond_signal(3T)

Use pthread_cond_signal() to unblock one thread that is blocked on the condition variable pointed to by *cv*.

```
Prototype:
int pthread_cond_signal(pthread_cond_t *cv);
```

```
#include <pthread.h>

pthread_cond_t cv;
int ret;

/* one condition variable is signaled */
ret = pthread_cond_signal(&cv);
```

Call pthread_cond_signal() under the protection of the same mutex used with the condition variable being signaled. Otherwise, the condition variable could be signaled between the test of the associated condition and blocking in pthread_cond_wait(), which can cause an infinite wait.

The scheduling policy determines the order in which blocked threads are awakened. For SCHED_OTHER, threads are awakened in priority order.

When no threads are blocked on the condition variable, then calling pthread_cond_signal() has no effect.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

EINVAL – *cv* points to an illegal address.

Code Example 4-8 Using `pthread_cond_wait()` and `pthread_cond_signal()`

```
pthread_mutex_t count_lock;
pthread_cond_t count_nonzero;
unsigned int count;

decrement_count()
{
    pthread_mutex_lock(&count_lock);
    while (count == 0)
        pthread_cond_wait(&count_nonzero, &count_lock);
    count = count - 1;
    pthread_mutex_unlock(&count_lock);
}
increment_count()
{
    pthread_mutex_lock(&count_lock);
    if (count == 0)
        pthread_cond_signal(&count_nonzero);
    count = count + 1;
    pthread_mutex_unlock(&count_lock);
}
```

Block Until a Specified Event

pthread_cond_timedwait(3T)

```
Prototype:
int pthread_cond_timedwait(pthread_cond_t *cv,
    pthread_mutex_t *mp, const struct timespec *abstime);
```

```
#include <pthread.h>

pthread_cond_t cv;
pthread_mutex_t mp;
timestruct_t abstime;
int ret;

/* wait on condition variable */
ret = pthread_cond_timedwait(&cv, &mp, &abstime);
```

Use `pthread_cond_timedwait()` as you would use `pthread_cond_wait()`, except that `pthread_cond_timedwait()` does not block past the time of day specified by *abstime*. `pthread_cond_timedwait()` always returns with the mutex locked and owned by the calling thread even when it is returning an error.

The `pthread_cond_timedwait()` function blocks until the condition is signaled or until the time of day specified by the last argument has passed.

Note – `pthread_cond_timedwait()` is also a cancellation point.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When either of the following conditions occurs, the function fails and returns the corresponding value.

`EINVAL` – *cv* or *abstime* points to an illegal address.

`ETIMEDOUT` – The time specified by *abstime* has passed.

The time-out is specified as a time of day so that the condition can be retested efficiently without recomputing the value, as shown in Code Example 4-9.

Code Example 4-9 Timed Condition Wait

```
pthread_timestruc_t to;
pthread_mutex_t m;
pthread_cond_t c;
...
pthread_mutex_lock(&m);
to.tv_sec = time(NULL) + TIMEOUT;
to.tv_nsec = 0;
while (cond == FALSE) {
    err = pthread_cond_timedwait(&c, &m, &to);
    if (err == ETIME) {
        /* timeout, do something */
        break;
    }
}
pthread_mutex_unlock(&m);
```

Unblock All Threads

pthread_cond_broadcast(3T)

Prototype:
`int pthread_cond_broadcast(pthread_cond_t *cv);`

```
#include <pthread.h>

pthread_cond_t cv;
int ret;

/* all condition variables are signaled */
ret = pthread_cond_broadcast(&cv);
```

Use `pthread_cond_broadcast()` to unblock all threads that are blocked on the condition variable pointed to by *cv*. When no threads are blocked on the condition variable, `pthread_cond_broadcast()` has no effect.

This function wakes all the threads blocked in `pthread_cond_wait()`.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

EINVAL – *cv* points to an illegal address.

Condition Variable Broadcast Example

Since pthread_cond_broadcast() causes all threads blocked on the condition to contend again for the mutex lock, use it with care. For example, use pthread_cond_broadcast() to allow threads to contend for varying resource amounts when resources are freed, as shown in Code Example 4-10.

Code Example 4-10 Condition Variable Broadcast

```
pthread_mutex_t rsrc_lock;
pthread_cond_t rsrc_add;
unsigned int resources;

get_resources(int amount)
{
    pthread_mutex_lock(&rsrc_lock);
    while (resources < amount) {
        pthread_cond_wait(&rsrc_add, &rsrc_lock);
    }
    resources -= amount;
    pthread_mutex_unlock(&rsrc_lock);
}

add_resources(int amount)
{
    pthread_mutex_lock(&rsrc_lock);
    resources += amount;
    pthread_cond_broadcast(&rsrc_add);
    pthread_mutex_unlock(&rsrc_lock);
}
```

Note that in add_resources() it does not matter whether *resources* is updated first or pthread_cond_broadcast() is called first inside the mutex lock.

Call `pthread_cond_broadcast()` under the protection of the same mutex that is used with the condition variable being signaled. Otherwise, the condition variable could be signaled between the test of the associated condition and blocking in `pthread_cond_wait()`, which can cause an infinite wait.

Destroy Condition Variable State

pthread_cond_destroy(3T)

Use `pthread_cond_destroy()` to destroy any state associated with the condition variable pointed to by *cv*.

```
Prototype:
int pthread_cond_destroy(pthread_cond_t *cv);

#include <pthread.h>

pthread_cond_t cv;
int ret;

/* Condition variable is destroyed */
ret = pthread_cond_destroy(&cv);
```

Note that the space for storing the condition variable is not freed.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EBUSY` – The object has been initialized before, and is not destroyed.

`EINVAL` – The value specified by *cv* is invalid.

The Lost Wake-Up Problem

Calling `pthread_cond_signal()` or `pthread_cond_broadcast()` when the thread does not hold the mutex lock associated with the condition can lead to *lost wake-up* bugs.

A lost wake-up occurs when

- A thread calls `pthread_cond_signal()` or `pthread_cond_broadcast()`
- *And* another thread is between the test of the condition and the call to `pthread_cond_wait()`
- *And* no threads are waiting.

The signal has no effect, and therefore is lost.

The Producer/Consumer Problem

This problem is one of the small collection of standard, well-known problems in concurrent programming: a finite-size buffer and two classes of threads, *producers* and *consumers*, put items into the buffer (producers) and take items out of the buffer (consumers).

A producer must wait until the buffer has space before it can put something in, and a consumer must wait until something is in the buffer before it can take something out.

A condition variable represents a queue of threads waiting for some condition to be signaled.

Code Example 4-11 has two such queues, one (`less`) for producers waiting for a slot in the buffer, and the other (`more`) for consumers waiting for a buffer slot containing information. The example also has a mutex, as the data structure describing the buffer must be accessed by only one thread at a time.

This is the code for the buffer data structure.

Code Example 4-11 The Producer / Consumer Problem and Condition Variables

```
typedef struct {
    char buf[BSIZE];
    int occupied;
    int nextin;
    int nextout;
    mutex_t mutex;
    cond_t more;
    cond_t less;
} buffer_t;

buffer_t buffer;
```

As Code Example 4-12 on page 104 shows, the producer thread takes the mutex protecting the `buffer` data structure and then makes certain that space is available for the item being produced. If not, it calls `pthread_cond_wait()`, which causes it to join the queue of threads waiting for the condition `less`, representing *there is room in the buffer,* to be signaled.

At the same time, as part of the call to `pthread_cond_wait()`, the thread releases its lock on the mutex. The waiting producer threads depend on consumer threads to signal when the condition is true (as shown in Code Example 4-12). When the condition is signaled, the first thread waiting on `less` is awakened. However, before the thread can return from `pthread_cond_wait()`, it must reacquire the lock on the mutex.

This ensures that it again has mutually exclusive access to the buffer data structure. The thread then must check that there really is room available in the buffer; if so, it puts its item into the next available slot.

At the same time, consumer threads might be waiting for items to appear in the buffer. These threads are waiting on the condition variable `more`. A producer thread, having just deposited something in the buffer, calls `pthread_cond_signal()` to wake up the next waiting consumer. (If there are no waiting consumers, this call has no effect.)

Finally, the producer thread unlocks the mutex, allowing other threads to operate on the buffer data structure.

Code Example 4-12 The Producer/Consumer Problem – the Producer

```
void producer(buffer_t *b, char item)
{
    pthread_mutex_lock(&b->mutex);

    while (b->occupied >= BSIZE)
        pthread_cond_wait(&b->less, &b->mutex);

    assert(b->occupied < BSIZE);

    b->buf[b->nextin++] = item;

    b->nextin %= BSIZE;
    b->occupied++;

    /* now: either b->occupied < BSIZE and b->nextin is the index
       of the next empty slot in the buffer, or
       b->occupied == BSIZE and b->nextin is the index of the
       next (occupied) slot that will be emptied by a consumer
       (such as b->nextin == b->nextout) */

    pthread_cond_signal(&b->more);

    pthread_mutex_unlock(&b->mutex);
}
```

Note the use of the `assert()` statement; unless the code is compiled with `NDEBUG` defined, `assert()` does nothing when its argument evaluates to true (that is, nonzero), but causes the program to abort if the argument evaluates to false (zero). Such assertions are especially useful in multithreaded programs—they immediately point out runtime problems if they fail, and they have the additional effect of being useful comments.

The comment a few lines later could better be expressed as an assertion, but it is too complicated as a Boolean-valued expression and so is given in English.

Both the assertion and the comments are examples of *invariants*. These are logical statements that should not be falsified by the execution of the program, except during brief moments when a thread is modifying some of the program variables mentioned in the invariant. (An assertion, of course, should be true whenever any thread executes it.)

Using invariants is an extremely useful technique. Even if they are not stated in the program text, think in terms of invariants when you analyze a program.

The invariant in the producer code that is expressed as a comment is always true whenever a thread is in the part of the code where the comment appears. If you move this comment to just after the `mutex_unlock()`, this does not necessarily remain true. If you move this comment to just after the `assert`, this is still true.

The point is that this invariant expresses a property that is true at all times, except when either a producer or a consumer is changing the state of the buffer. While a thread is operating on the buffer (under the protection of a mutex), it might temporarily falsify the invariant. However, once the thread is finished, the invariant should be true again.

Code Example 4-13 shows the code for the consumer. Its flow is symmetric with that of the producer.

Code Example 4-13 The Producer/Consumer Problem – the Consumer

```
char consumer(buffer_t *b)
{
    char item;
    pthread_mutex_lock(&b->mutex);
    while(b->occupied <= 0)
        pthread_cond_wait(&b->more, &b->mutex);

    assert(b->occupied > 0);

    item = b->buf[b->nextout++];
    b->nextout %= BSIZE;
    b->occupied--;

    /* now: either b->occupied > 0 and b->nextout is the index
       of the next occupied slot in the buffer, or
       b->occupied == 0 and b->nextout is the index of the next
       (empty) slot that will be filled by a producer (such as
       b->nextout == b->nextin) */

    pthread_cond_signal(&b->less);
    pthread_mutex_unlock(&b->mutex);

    return(item);
}
```

Semaphores

Semaphores are a programming construct designed by E. W. Dijkstra in the late 1960s. Dijkstra's model was the operation of railroads: consider a stretch of railroad in which there is a single track over which only one train at a time is allowed.

Guarding this track is a semaphore. A train must wait before entering the single track until the semaphore is in a state that permits travel. When the train enters the track, the semaphore changes state to prevent other trains from entering the track. A train that is leaving this section of track must again change the state of the semaphore to allow another train to enter.

In the computer version, a semaphore appears to be a simple integer. A thread waits for permission to proceed and then signals that it has proceeded by performing a P operation on the semaphore.

The semantics of the operation are such that the thread must wait until the semaphore's value is positive, then change the semaphore's value by subtracting one from it. When it is finished, the thread performs a V operation, which changes the semaphore's value by adding one to it. It is crucial that these operations take place *atomically*—they cannot be subdivided into pieces between which other actions on the semaphore can take place. In the P operation, the semaphore's value must be positive just before it is decremented (resulting in a value that is guaranteed to be nonnegative and one less than what it was before it was decremented).

In both P and V operations, the arithmetic must take place without interference. If two V operations are performed simultaneously on the same semaphore, the net effect should be that the semaphore's new value is two greater than it was.

The mnemonic significance of P and V is lost on most of the world, as Dijkstra is Dutch. However, in the interest of true scholarship: P stands for *prolagen*, a made-up word derived from *proberen te verlagen*, which means *try to decrease*. V stands for *verhogen*, which means *increase*. This is discussed in one of Dijkstra's technical notes, *EWD 74*.

`sem_wait(3T)` and `sem_post(3T)` correspond to Dijkstra's P and V operations. `sem_trywait(3T)` is a conditional form of the P operation: if the calling thread cannot decrement the value of the semaphore without waiting, the call returns immediately with a nonzero value.

There are two basic sorts of semaphores: *binary* semaphores, which never take on values other than zero or one, and *counting* semaphores, which can take on arbitrary nonnegative values. A binary semaphore is logically just like a mutex.

However, although it is not enforced, mutexes should be unlocked only by the thread holding the lock. There is no notion of "the thread holding the semaphore," so any thread can perform a V (or `sem_post(3T)`) operation.

Counting semaphores are about as powerful as conditional variables (used in conjunction with mutexes). In many cases, the code might be simpler when it is implemented with counting semaphores rather than with condition variables (as shown in the next few examples).

However, when a mutex is used with condition variables, there is an implied bracketing—it is clear which part of the program is being protected. This is not necessarily the case for a semaphore, which might be called the *go to* of concurrent programming—it is powerful but too easy to use in an unstructured, unfathomable way.

Counting Semaphores

Conceptually, a semaphore is a nonnegative integer count. Semaphores are typically used to coordinate access to resources, with the semaphore count initialized to the number of free resources. Threads then atomically increment the count when resources are added and atomically decrement the count when resources are removed.

When the semaphore count becomes zero, indicating that no more resources are present, threads trying to decrement the semaphore block wait until the count becomes greater than zero.

Table 4-7 Routines for Semaphores

Initialize a Semaphore	*sem_init(3R)*	*page 108*
Increment a Semaphore	*sem_post(3R)*	*page 110*
Block on a Semaphore Count	*sem_wait(3R)*	*page 111*
Decrement a Semaphore Count	*sem_trywait(3R)*	*page 112*
Destroy the Semaphore State	*sem_destroy(3R)*	*page 113*

Because semaphores need not be acquired and released by the same thread, they can be used for asynchronous event notification (such as in signal handlers). And, because semaphores contain state, they can be used asynchronously without acquiring a mutex lock as is required by condition variables. However, semaphores are not as efficient as mutex locks.

By default, there is no defined order of unblocking if multiple threads are waiting for a semaphore.

Semaphores must be initialized before use, but they do not have attributes.

Initialize a Semaphore

sem_init(3R)

```
Prototype:
int     sem_init(sem_t *sem, int pshared, unsigned int value);
```

```
#include <semaphore.h>

sem_t sem;
int pshared;
int ret;
int value;

/* initialize the semaphore */
ret = sem_init(&sem, pshared, value);
```

Use `sem_init()` to initialize the semaphore variable pointed to by *sem* by *value* amount. If the value of *pshared* is zero, then the semaphore cannot be shared between processes. If the value of *pshared* is nonzero, then the semaphore can be shared between processes.

Multiple threads must not initialize the same semaphore simultaneously.

A semaphore must not be reinitialized while other threads might be using it.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EINVAL – The value argument exceeds SEM_VALUE_MAX.

ENOSPC – A resource required to initialize the semaphore has been exhausted. The limit on semaphores SEM_NSEMS_MAX has been reached.

EPERM – The process lacks the appropriate privileges to initialize the semaphore.

Initializing Semaphores With Intraprocess Scope

When *pshared* is 0, the semaphore can be used by all the threads in this process, only.

```
#include <semaphore.h>

sem_t sem;
int ret;
int count = 4;

/* to be used within this process only */
ret = sem_init(&sem, 0, count);
```

Initializing Semaphores With Interprocess Scope

When *pshared* is nonzero, the semaphore can be shared by other processes.

```
#include <semaphore.h>

sem_t sem;
int ret;
int count = 4;

/* to be used within this process only */
ret = sem_init(&sem, 1, count);
```

Named Semaphores

The functions sem_open(3R), sem_getvalue(3R), sem_close(3R), and sem_unlink(3R) are available to open, retrieve, close, and remove named semaphores. Using sem_open(), you can create a semaphore that has a name defined in the filesystem name space.

Named semaphores are like process shared semaphores, except that they are referenced with a pathname rather than a *pshared* value.

For more information about named semaphores, see sem_open(3R), sem_getvalue(3R), sem_close(3R), and sem_unlink(3R).

Increment a Semaphore

sem_post(3R)

```
Prototype:
int     sem_post(sem_t *sem);
```

```
#include <semaphore.h>

sem_t sem;
int ret;

ret = sem_post(&sem); /* semaphore is posted */
```

Use sem_post() to atomically increment the semaphore pointed to by *sem*. When any threads are blocked on the semaphore, one is unblocked.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

EINVAL – *sem* points to an illegal address.

Block on a Semaphore Count

sem_wait(3R)

```
Prototype:
int     sem_wait(sem_t *sem);
```

```
#include <semaphore.h>

sem_t sem;
int ret;

ret = sem_wait(&sem); /* wait for semaphore */
```

Use `sem_wait()` to block the calling thread until the count in the semaphore pointed to by *sem* becomes greater than zero, then atomically decrement it.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` – *sem* points to an illegal address.

`EINTR` – A signal interrupted this function.

`EDEADLK` – A deadlock condition was detected.

Decrement a Semaphore Count

sem_trywait(3R)

```
Prototype:
int     sem_trywait(sem_t *sem);
```

```
#include <semaphore.h>

sem_t sem;
int ret;

ret = sem_trywait(&sem); /* try to wait for semaphore*/
```

Use `sem_trywait()` to atomically decrement the count in the semaphore pointed to by *sem* when the count is greater than zero. This function is a nonblocking version of `sem_wait()`.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` – *sem* points to an illegal address.

`EINTR` – A signal interrupted this function.

`EDEADLK` – A deadlock condition was detected.

`EAGAIN` – The semaphore was already locked, so it cannot be immediately locked by the `sem_trywait()` operation.

Destroy the Semaphore State

sem_destroy(3R)

```
Prototype:
int     sem_destroy(sem_t *sem);
```

```
#include <semaphore.h>

sem_t sem;
int ret;

ret = sem_destroy(&sem); /* the semaphore is destroyed */
```

Use `sem_destroy()` to destroy any state associated with the semaphore pointed to by *sem*. The space for storing the semaphore is not freed.

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, the function fails and returns the corresponding value.

`EINVAL` – *sem* points to an illegal address.

The Producer/Consumer Problem, Using Semaphores

The data structure in Code Example 4-14 is similar to that used for the solution with condition variables (see page 84). Two semaphores represent the number of full and empty buffers and ensure that producers wait until there are empty buffers and that consumers wait until there are full buffers.

Code Example 4-14 The Producer/Consumer Problem With Semaphores

```
typedef struct {
    char buf[BSIZE];
    sem_t occupied;
    sem_t empty;
    int nextin;
    int nextout;
    sem_t pmut;
    sem_t cmut;
} buffer_t;

buffer_t buffer;

sem_init(&buffer.occupied, 0, 0);
sem_init(&buffer.empty,0, BSIZE);
sem_init(&buffer.pmut, 0, 1);
sem_init(&buffer.cmut, 0, 1);
buffer.nextin = buffer.nextout = 0;
```

Another pair of (binary) semaphores plays the same role as mutexes, controlling access to the buffer when there are multiple producers and multiple empty buffer slots, and when there are multiple consumers and multiple full buffer slots. Mutexes would work better here, but would not provide as good an example of semaphore use.

Code Example 4-15 The Producer / Consumer Problem – the Producer

```
void producer(buffer_t *b, char item) {
    sem_wait(&b->empty);

    sem_wait(&b->pmut);

    b->buf[b->nextin] = item;
    b->nextin++;
    b->nextin %= BSIZE;

    sem_post(&b->pmut);

    sem_post(&b->occupied);
}
```

Code Example 4-16 The Producer / Consumer Problem – the Consumer

```
char consumer(buffer_t *b) {
    char item;

    sem_wait(&b->occupied);

    sem_wait(&b->cmut);

    item = b->buf[b->nextout];
    b->nextout++;
    b->nextout %= BSIZE;

    sem_post(&b->cmut);

    sem_post(&b->empty);

    return(item);
}
```

Synchronization Across Process Boundaries

Each of the synchronization primitives can be set up to be used across process boundaries. This is done quite simply by ensuring that the synchronization variable is located in a shared memory segment and by calling the appropriate `init` routine, after the primitive has been initialized with its shared attribute set as interprocess.

Producer/Consumer Problem Example

Code Example 4-17 shows the producer/consumer problem with the producer and consumer in separate processes. The main routine maps zero-filled memory (that it shares with its child process) into its address space.

A child process is created that runs the consumer. The parent runs the producer.

This example also shows the drivers for the producer and consumer. The `producer_driver()` simply reads characters from `stdin` and calls `producer()`. The `consumer_driver()` gets characters by calling `consumer()` and writes them to `stdout`.

The data structure for Code Example 4-17 is the same as that used for the solution with condition variables (see page 84). Two semaphores represent the number of full and empty buffers and ensure that producers wait until there are empty buffers and that consumers wait until there are full buffers.

Code Example 4-17 Synchronization Across Process Boundaries

```
main() {
    int zfd;
    buffer_t *buffer;
    pthread_mutexattr_t mattr;
    pthread_condattr_t cvattr_less, cvattr_more;

    zfd = open("/dev/zero", O_RDWR);
    buffer = (buffer_t *)mmap(NULL, sizeof(buffer_t),
        PROT_READ|PROT_WRITE, MAP_SHARED, zfd, 0);
    buffer->occupied = buffer->nextin = buffer->nextout = 0;

    mutex_attr_init(&mattr);
    pthread_mutexattr_setpshared(&mattr,
PTHREAD_PROCESS_SHARED);
    mutex_init(&buffer->lock, &mattr);
```

Code Example 4-17 Synchronization Across Process Boundaries

```
    pthread_condattr_init(cvattr_less);
    pthread_condattr_setpshared(&cvattr_less,
        PTHREAD_PROCESS_SHARED);
    pthread_cond_init(&buffer->less, &cvattr_less);

    pthread_condattr_init(cvattr_more);
    pthread_condattr_setpshared(&cvattr_more,
        PTHREAD_PROCESS_SHARED);
    pthread_cond_init(&buffer->more, &cvattr_more);

    if (fork() == 0)
        consumer_driver(buffer);
    else
        producer_driver(buffer);
}

void producer_driver(buffer_t *b) {
    int item;

    while (1) {
        item = getchar();
        if (item == EOF) {
            producer(b, '\0');
            break;
        } else
            producer(b, (char)item);
    }
}

void consumer_driver(buffer_t *b) {
    char item;

    while (1) {
        if ((item = consumer(b)) == '\0')
            break;
        putchar(item);
    }
}
```

```
void consumer_driver(buffer_t *b) {
    char item;

    while (1) {
        if ((item = consumer(b)) == '\0')
            break;
        putchar(item);
    }
}
```

Interprocess Locking Without the Threads Library

Although not generally recommended, it is possible in Solaris threads to do interprocess locking without using the threads library. If this is something you want to do, see the instructions in "Using LWPs Between Processes" on page 220.

Comparing Primitives

The most basic synchronization primitive in threads is the mutual exclusion lock. So, it is the most efficient mechanism in both memory use and execution time. The basic use of a mutual exclusion lock is to serialize access to a resource.

The next most efficient primitive in threads is the condition variable. The basic use of a condition variable is to block on a change of state. Remember that a mutex lock must be acquired before blocking on a condition variable and must be unlocked after returning from `pthread_cond_wait(3T)`. The mutex lock must also be held across the change of state that occurs before the corresponding call to `pthread_cond_signal(3T)`.

The semaphore uses more memory than the condition variable. It is easier to use in some circumstances because a semaphore variable functions on state rather than on control. Unlike a lock, a semaphore does not have an owner. Any thread can increment a semaphore that has blocked.

Programming With the Operating System 5

This chapter describes how multithreading interacts with the Solaris operating system and how the operating system has changed to support multithreading.

Process Creation–Forking Issues

The default handling of the `fork()` function in the Solaris operating system is somewhat different from the way `fork()` is handled in POSIX threads, although the Solaris operating system does support both mechanisms.

Table 5-1 compares the differences and similarities of Solaris and pthreads `fork()` handling. When the comparable interface is not available either in POSIX threads or in Solaris threads, the ‘–’ character appears in the table column.

Table 5-1 Comparing POSIX and Solaris `fork()` Handling

	Solaris Operating System Interface	**POSIX Threads Interface**
Fork-One Model	`fork1(2)`	`fork(2)`
Fork-All Model	`fork(2)`	–
Fork-Safety	–	`pthread_atfork(3T)`

The Fork-One Model

As shown in Table 5-1, the behavior of the pthreads `fork(2)`function is the same as that of the Solaris `fork1(2)` function. Both the pthreads `fork(2)` function and the Solaris `fork1(2)`create a new process, duplicating the complete address space in the child, but duplicating only the calling thread in the child process.

This is useful when the child process immediately calls `exec()`, which is what happens after most calls to `fork()`. In this case, the child process does not need a duplicate of any thread other than the one that called `fork()`.

In the child, do not call any library functions after calling `fork()` and before calling `exec()`—one of the library functions might use a lock that was held in the parent at the time of the `fork()`. The child process may execute only Async-Signal-Safe operations until one of the `exec()` handlers is called.

The Fork-One Safety Problem and Solution

In addition to all of the usual concerns such as locking shared data, a library should be well-behaved with respect to forking a child process when only one thread is running (the one that called `fork()`). The problem is that the sole thread in the child process might try to grab a lock that is held by a thread that wasn't duplicated in the child.

This is not a problem most programs are likely to run into. Most programs call `exec()` in the child right after the return from `fork()`. However, if the program wishes to carry out some actions in the child before the call to `exec()`, or never calls `exec()`, then the child *could* encounter deadlock scenarios.

Each library writer should provide a safe solution, although not providing a `fork`-safe library is not a large concern because this condition is rare.

For example, assume that T1 is in the middle of printing something (and so is holding a lock for `printf()`), when T2 forks a new process. In the child process, if the sole thread (T2) calls `printf()`, it promptly deadlocks.

The POSIX `fork()` or Solaris `fork1()` duplicates only the thread that calls it. (Calling the Solaris `fork()` duplicates all threads, so this issue does not come up.)

To prevent deadlock, ensure that no such locks are being held at the time of forking. The most obvious way to do this is to have the forking thread acquire all the locks that could possibly be used by the child. Because you cannot do this for locks like those in `printf()` (because `printf()` is owned by `libc`), you must ensure that `printf()` is not being used at `fork()` time.

To manage the locks in your library:

- Identify all the locks used by the library.
- Identify the locking order for the locks used by the library. (If a strict locking order is not used, then lock acquisition must be managed carefully.)
- Arrange to acquire those locks at fork time. In Solaris threads this must be done manually, obtaining the locks just before calling `fork1()`, and releasing them right after:

In the following example, the list of locks used by the library is {L1,...Ln}, and the locking order for these locks is also L1...Ln.

```
mutex_lock(L1);
mutex_lock(L2);
fork1(...);
mutex_unlock(L1);
mutex_unlock(L2);
```

In pthreads, you can add a call to `pthread_atfork(f1, f2, f3)` in your library's `.init` section, where `f1, f2, f3` are defined as follows:

```
f1() /* This is executed just before the process forks. */
{
 mutex_lock(L1); |
 mutex_lock(...); | -- ordered in lock order
 mutex_lock(Ln); |
 } V

f2() /* This is executed in the child after the process forks. */
 {
 mutex_unlock(L1);
 mutex_unlock(...);
 mutex_unlock(Ln);
 }

f3() /* This is executed in the parent after the process forks. */
 {
 mutex_unlock(L1);
 mutex_unlock(...);
 mutex_unlock(Ln);
 }
```

Another example of deadlock would be a thread in the parent process—other than the one that called Solaris `fork1(2)`—that has locked a mutex. This mutex is copied into the child process in its locked state, but no thread is copied over to unlock the mutex. So, any thread in the child that tries to lock the mutex waits forever.

Virtual Forks–`vfork(2)`

The standard `vfork(2)` function is unsafe in multithreaded programs. `vfork(2)` is like `fork1(2)` in that only the calling thread is copied in the child process. As in nonthreaded implementations, `vfork()` does not copy the address space for the child process.

Be careful that the thread in the child process does not change memory before it calls `exec(2)`. Remember that `vfork()` gives the parent address space to the child. The parent gets its address space back after the child calls `exec()` or exits. It is important that the child not change the state of the parent.

For example, it is dangerous to create new threads between the call to `vfork()` and the call to `exec()`. This is an issue only if the fork-one model is used, and only if the child does more than just call `exec()`. Most libraries are not fork-safe, so use `pthread_atfork()` to implement fork safety.

The Solution—`pthread_atfork(3T)`

Use `pthread_atfork()`to prevent deadlocks whenever you use the fork-one model.

```
#include <pthread.h>

int pthread_atfork(void (*prepare) (void), void (*parent) (void),
    void (*child) (void) );
```

The `pthread_atfork()` function declares `fork()` handlers that are called before and after `fork()` in the context of the thread that called `fork()`:

- The *prepare* handler is called before `fork()` starts.
- The *parent* handler is called after `fork()` returns in the parent.
- The *child* handler is called after `fork()` returns in the child.

Any one of these can be set to NULL. The order in which successive calls to `pthread_atfork()` are made is significant.

For example, a *prepare* handler could acquire all the mutexes needed, and then the *parent* and *child* handlers could release them. This ensures that all the relevant locks are held by the thread that calls the fork function *before* the process is forked, preventing the deadlock in the child.

Using the fork-all model avoids the deadlock problem described in "The Fork-One Safety Problem and Solution" on page 120.

Return Values

Returns a zero when it completes successfully. Any other returned value indicates that an error occurred. If the following condition is detected, `pthread_atfork(3T)`fails and returns the corresponding value.

`ENOMEM` – Insufficient table space exists to record the fork handler addresses.

The Fork-All Model

The Solaris `fork(2)` function duplicates the address space and all the threads (and LWPs) in the child. This is useful, for example, when the child process never calls `exec(2)` but does use its copy of the parent address space. The fork-all functionality is not available in POSIX threads.

Note that when one thread in a process calls Solaris `fork(2)`, threads that are blocked in an interruptible system call return `EINTR`.

Also, be careful not to create locks that are held by both the parent and child processes. This can happen when locks are allocated in memory that is sharable (that is `mmap`'ed with the `MAP_SHARED` flag). Note that this is not a problem if the fork-one model is used.

Choosing the Right Fork

You determine whether `fork()` has a "fork-all" semantic or a "fork-one" semantic in your application by linking with the appropriate library. Linking with `-lthread` gives you the "fork all" semantic for `fork()`, and linking with `-lpthread` gives the "fork-one" semantic for `fork()` (see "Compilation Flowchart" on page 158 for an explanation of compiling options).

Cautions for Any Fork

Be careful when using global state after a call to any `fork()` function.

For example, when one thread reads a file serially and another thread in the process successfully calls one of the forks, each process then contains a thread that is reading the file. Because the seek pointer for a file descriptor is shared after a `fork()`, the thread in the parent gets some data while the thread in the child gets the other. This introduces gaps in the sequential read accesses.

Process Creation–`exec(2)`and `exit(2)` Issues

Both the `exec(2)`and `exit(2)` system calls work as they do in single-threaded processes except that they destroy all the threads in the address space. Both calls block until all the execution resources (and so all active threads) are destroyed.

When exec() rebuilds the process, it creates a single lightweight process (LWP) . The process startup code builds the initial thread. As usual, if the initial thread returns, it calls exit() and the process is destroyed.

When all the threads in a process exit, the process exits. A call to any exec() function from a process with more than one thread terminates all threads, and loads and executes the new executable image. No destructor functions will be called.

Timers, Alarms, and Profiling

The “End of Life” announcements for per-LWP timers (see timer_create(3R)) and per-thread alarms (see alarm(2) or setitimer(2)) are being made in the Solaris 2.5 release. Both features are now supplemented with the per-process variants described in this section.

Originally, each LWP had a unique Realtime interval timer and alarm that a thread bound to the LWP could use. The timer or alarm delivered one signal to the thread when the timer or alarm expired.

Each LWP also had a virtual time or profile interval timer that a thread bound to the LWP could use. When the interval timer expired, either SIGVTALRM or SIGPROF, as appropriate, was sent to the LWP that owned the interval timer.

Per-LWP POSIX Timers

In the Solaris 2.3 and 2.4 releases, the timer_create(3R) function returned a timer object whose timer ID was meaningful only within the calling LWP and whose expiration signals were delivered to that LWP. Because of this, the only threads that could use the POSIX timer facility were bound threads.

Even with this restricted use, POSIX timers in Solaris 2.3 and 2.4 multithreaded applications were unreliable about masking the resulting signals and delivering the associated value from the sigvent structure.

With the Solaris 2.5 release, an application that is compiled defining the macro _POSIX_PER_PROCESS_TIMERS, or with a value greater that 199506L for the symbol _POSIX_C_SOURCE, can create per-process timers.

Applications compiled with a release before the Solaris 2.5 release, or without the feature test macros, will continue to create per-LWP POSIX timers. In some future release, calls to create per-LWP timers will return per-process timers.

The timer IDs of per-process timers are usable from any LWP, and the expiration signals are generated for the process rather than directed to a specific LWP.

The per-process timers are deleted only by `timer_delete(3R)` or when the process terminates.

Per-Thread Alarms

In the Solaris 2.3 and 2.4 releases, a call to `alarm(2)`or `setitimer(2)` was meaningful only within the calling LWP. Such timers were deleted automatically when the creating LWP terminated. Because of this, the only threads that could use these were bound threads.

Even with this restricted use, `alarm()` and `setitimer()` timers in Solaris 2.3 and 2.4 multithreaded applications were unreliable about masking the signals from the bound thread that issued these calls. When such masking was not required, then these two system calls worked reliably from bound threads.

With the Solaris 2.5 release, an application linking with `-lpthread` (POSIX) threads will get per-process delivery of `SIGALRM` when calling `alarm()`. The `SIGALRM` generated by `alarm()` is generated for the process rather than directed to a specific LWP. Also, the alarm is reset when the process terminates.

Applications compiled with a release before the Solaris 2.5 release, or not linked with `-lpthread`, will continue to see a per-LWP delivery of signals generated by `alarm()` and `setitimer()`.

In some future release, calls to `alarm()` or to `setitimer()` with the `ITIMER_REAL` flag will cause the resulting `SIGALRM` to be sent to the process. For other flag, `setitmer()` will continue to be per-LWP. Flags other than the `ITIMER_REAL` flag to `setitimer()` will continue to result in the generated signal being delivered to the LWP that issued the call, and so are usable only from bound threads.

Profiling

You can profile each LWP with `profil(2)`, giving each LWP its own buffer, or sharing buffers between LWPs. Profiling data is updated at each clock tick in LWP user time. The profile state is inherited from the creating LWP.

Nonlocal Goto—`setjmp(3C)` *and* `longjmp(3C)`

The scope of `setjmp()` and `longjmp()` is limited to one thread, which is fine most of the time. However, this does mean that a thread that handles a signal can `longjmp()` only when `setjmp()` is performed in the same thread.

Resource Limits

Resource limits are set on the entire process and are determined by adding the resource use of all threads in the process. When a soft resource limit is exceeded, the offending thread is sent the appropriate signal. The sum of the resource use in the process is available through `getrusage(3B)`.

LWPs and Scheduling Classes

As mentioned in the "Scheduling" section of the "Covering Multithreading Basics" chapter, the Solaris pthreads implementation supports only the `SCHED_OTHER` scheduling policy. The others are optional under POSIX.

The POSIX `SCHED_FIFO` and `SCHED_RR` policies can be duplicated or emulated using the standard Solaris mechanisms. These scheduling mechanisms are described in this section.

The Solaris kernel has three classes of scheduling. The highest priority scheduling class is Realtime (RT). The middle priority scheduling class is `system`. The `system` class cannot be applied to a user process. The lowest priority scheduling class is timeshare (TS), which is also the default class.

Scheduling class is maintained for each LWP. When a process is created, the initial LWP inherits the scheduling class and priority of the creating LWP in the parent process. As more LWPs are created to run unbound threads, they also inherit this scheduling class and priority.

All unbound threads in a process have the same scheduling class and priority. Each scheduling class maps the priority of the LWP it is scheduling to an overall dispatching priority according to the configurable priority of the scheduling class.

Bound threads have the scheduling class and priority of their underlying LWPs. Each bound thread in a process can have a unique scheduling class and priority that is visible to the kernel. Bound threads are scheduled with respect to all other LWPs in the system.

Thread priorities regulate access to LWP resources. By default LWPs are in the timesharing class. For compute-bound multithreading, thread priorities are not very useful. For multithreaded applications that do a lot of synchronization using the MT libraries, thread priorities become more meaningful.

The scheduling class is set by `priocntl(2)`. How you specify the first two arguments determines whether just the calling LWP or all the LWPs of one or more processes are affected. The third argument of `priocntl()` is the command, which can be one of the following.

- `PC_GETCID`—Get the class ID and class attributes for a specific class.
- `PC_GETCLINFO`—Get the class name and class attributes for a specific class.
- `PC_GETPARMS`—Get the class identifier and the class-specific scheduling parameters of a process, an LWP with a process, or a group of processes.
- `PC_SETPARMS`—Set the class identifier and the class-specific scheduling parameters of a process, an LWP with a process, or a group of processes.

Use `priocntl()` only on bound threads. To affect the priority of unbound threads, use `pthread_setprio(3T)`.

Timeshare Scheduling

Timeshare scheduling distributes the processing resource fairly among the LWPs in this scheduling class. Other parts of the kernel can monopolize the processor for short intervals without degrading response time as seen by the user.

The `priocntl(2)` call sets the `nice(2)` level of one or more processes. The `priocntl()` call also affects the `nice()` level of all the timesharing class LWPs in the process. The `nice()` level ranges from 0 to +20 normally and from -20 to +20 for processes with superuser privilege. The lower the value, the higher the priority.

The dispatch priority of time-shared LWPs is calculated from the instantaneous CPU use rate of the LWP and from its `nice()` level. The `nice()` level indicates the relative priority of the LWPs to the timeshare scheduler.

LWPs with a greater `nice()` value get a smaller, but nonzero, share of the total processing. An LWP that has received a larger amount of processing is given lower priority than one that has received little or no processing.

Realtime Scheduling

The Realtime class (`RT`) can be applied to a whole process or to one or more LWPs in a process. This requires superuser privilege.

Unlike the `nice(2)` level of the timeshare class, LWPs that are classified Realtime can be assigned priorities either individually or jointly. A `priocntl(2)` call affects the attributes of all the Realtime LWPs in the process.

The scheduler always dispatches the highest-priority Realtime LWP. It preempts a lower-priority LWP when a higher-priority LWP becomes runnable. A preempted LWP is placed at the head of its level queue.

A Realtime LWP retains control of a processor until it is preempted, it suspends, or its Realtime priority is changed. LWPs in the `RT` class have absolute priority over processes in the `TS` class.

A new LWP inherits the scheduling class of the parent process or LWP. An `RT` class LWP inherits the parent’s time slice, whether finite or infinite.

An LWP with a finite time slice runs until it terminates, blocks (for example, to wait for an I/O event), is preempted by a higher-priority runnable Realtime process, or the time slice expires.

An LWP with an infinite time slice ceases execution only when it terminates, blocks, or is preempted.

LWP Scheduling and Thread Binding

The threads library automatically adjusts the number of LWPs in the pool used to run unbound threads. Its objectives are:

- To prevent the program from being blocked by a lack of unblocked LWPs.

  For example, if there are more runnable unbound threads than LWPs and all the active threads block in the kernel in indefinite waits (such as while reading a tty), the process cannot progress until a waiting thread returns.

- To make efficient use of LWPs.

  For example, if the library creates one LWP for each thread, many LWPs will usually be idle and the operating system is overloaded by the resource requirements of the unused LWPs.

Keep in mind that LWPs are time-sliced, not threads. This means that when there is only one LWP, there is no time slicing within the process—threads run on the LWP until they block (through interthread synchronization), are preempted, or terminate.

You can assign priorities to threads with `pthread_setprio(3T)`; lower-priority unbound threads are assigned to LWPs only when no higher-priority unbound threads are available. Bound threads, of course, do not compete for LWPs because they have their own. Note that the thread priority that is set with `pthread_setprio()` regulates threads' access to LWPs, not to CPUs.

Bind threads to your LWPs to get precise control over whatever is being scheduled. This control is not possible when many unbound threads compete for an LWP.

In particular, a lower-priority unbound thread could be on a higher priority LWP and running on a CPU, while a higher-priority unbound thread assigned to a lower-priority LWP is not running. In this sense, thread priorities are just a hint about access to CPUs.

Realtime threads are useful for getting a quick response to external stimuli. Consider a thread used for mouse tracking that must respond instantly to mouse clicks. By binding the thread to an LWP, you guarantee that there is an LWP available when it is needed. By assigning the LWP to the Realtime scheduling class, you ensure that the LWP is scheduled quickly in response to mouse clicks.

SIGWAITING—Creating LWPs for Waiting Threads

The library usually ensures that there are enough LWPs in its pool for a program to proceed.

When all the LWPs in the process are blocked in indefinite waits (such as blocked reading from a tty or network), the operating system sends the new signal, `SIGWAITING`, to the process. This signal is handled by the threads library. When the process contains a thread that is waiting to run, a new LWP is created and the appropriate waiting thread is assigned to it for execution.

The `SIGWAITING` mechanism does not ensure that an additional LWP is created when one or more threads are compute bound and another thread becomes runnable. A compute-bound thread can prevent multiple runnable threads from being started because of a shortage of LWPs.

This can be prevented by calling `thr_setconcurrency(3T)`. While using `thr_setconcurrency()` with POSIX threads is not POSIX compliant, its use is recommended to avoid LWP shortages for unbound threads in some computationally-intensive situations. (The only way to be *completely* POSIX compliant *and* avoid LWP shortages is to create only `PTHREAD_SCOPE_SYSTEM` bound threads.)

See “Thread Concurrency (Solaris Threads, Only)” on page 238 for more information about using the `thr_setconcurrency(3T)` function.

In Solaris threads, you can also use `THR_NEW_LWP` in calls to `thr_create(3T)` to create another LWP.

Aging LWPs

When the number of active threads is reduced, some of the LWPs in the pool are no longer needed. When there are more LWPs than active threads, the threads library destroys the unneeded LWPs. The library ages LWPs—they are deleted when they are unused for a “long” time, currently set at five minutes.

5

Extending Traditional Signals

The traditional UNIX signal model is extended to threads in a fairly natural way. The key characteristics are that the signal disposition is process-wide, but the signal mask is per-thread. The process-wide disposition of signals is established using the traditional mechanisms (`signal(2)`, `sigaction(2)`, and so on).

When a signal handler is marked `SIG_DFL` or `SIG_IGN`, the action on receipt of the signal (exit, core dump, stop, continue, or ignore) is performed on the entire receiving process, affecting all threads in the process. For these signals that don't have handlers, the issue of which thread picks the signal is unimportant, because the action on receipt of the signal is carried out on the whole process. See `signal(5)` for basic information about signals.

Each thread has its own signal mask. This lets a thread block some signals while it uses memory or other state that is also used by a signal handler. All threads in a process share the set of signal handlers set up by `sigaction(2)` and its variants, as usual.

A thread in one process cannot send a signal to a specific thread in another process. A signal sent by `kill(2)` or `sigsend(2)` to a process is handled by any one of the receptive threads in the process.

Unbound threads cannot use alternate signal stacks. A bound thread can use an alternate stack because the state is associated with the execution resource. An alternate stack must be enabled for the signal through `sigaction(2)`, and declared and enabled through `sigaltstack(2)`.

An application can have per-thread signal handlers based on the per-process signal handlers. One way is for the process-wide signal handler to use the identifier of the thread handling the signal as an index into a table of per-thread handlers. Note that there is no thread zero.

Signals are divided into two categories: traps and exceptions (synchronously generated signals) and interrupts (asynchronously generated signals).

As in traditional UNIX, if a signal is pending, additional occurrences of that signal have no additional effect—a pending signal is represented by a bit, not by a counter. In other words, signal delivery is idempotent.

As is the case with single-threaded processes, when a thread receives a signal while blocked in a system call, the thread might return early, either with the `EINTR` error code, or, in the case of I/O calls, with fewer bytes transferred than requested.

Of particular importance to multithreaded programs is the effect of signals on `pthread_cond_wait(3T)`. This call usually returns in response to a `pthread_cond_signal(3T)` or a `pthread_cond_broadcast(3T)`, but, if the waiting thread receives a traditional UNIX signal, it returns with the error code `EINTR`. See "Interrupted Waits on Condition Variables (Solaris Threads, Only)" on page 142 for more information.

Synchronous Signals

Traps (such as `SIGILL`, `SIGFPE`, `SIGSEGV`) result from something a thread does to itself, such as dividing by zero or explicitly sending itself a signal. A trap is handled only by the thread that caused it. Several threads in a process can generate and handle the same type of trap simultaneously.

Extending the idea of signals to individual threads is easy for synchronous signals—the signal is dealt with by the thread that caused the problem.

However, if the thread has not chosen to deal with the problem, such as by establishing a signal handler with `sigaction(2)`, the handler is invoked on the thread that receives the synchronous signal.

Because such a synchronous signal usually means that something is seriously wrong with the whole process, and not just with a thread, terminating the process is often a good choice.

Asynchronous Signals

Interrupts (such as `SIGINT` and `SIGIO`) are asynchronous with any thread and result from some action outside the process. They might be signals sent explicitly by other threads, or they might represent external actions such as a user typing Control-c. Dealing with asynchronous signals is more complicated than dealing with synchronous signals.

An interrupt can be handled by any thread whose signal mask allows it. When more than one thread is able to receive the interrupt, only one is chosen.

When multiple occurrences of the same signal are sent to a process, then each occurrence can be handled by a separate thread, as long as threads are available that do not have it masked. When all threads have the signal masked, then the signal is marked *pending* and the first thread to unmask the signal handles it.

Continuation Semantics

Continuation semantics are the traditional way to deal with signals. The idea is that when a signal handler returns, control resumes where it was at the time of the interruption. This is well suited for asynchronous signals in single-threaded processes, as shown in Code Example 5-1.

This is also used as the exception-handling mechanism in some programming languages, such as PL/1.

Code Example 5-1 Continuation Semantics

```
unsigned int nestcount;

unsigned int A(int i, int j) {
    nestcount++;

    if (i==0)
        return(j+1)
    else if (j==0)
        return(A(i-1, 1));
    else
        return(A(i-1, A(i, j-1)));
}

void sig(int i) {
    printf("nestcount = %d\n", nestcount);
}

main() {
    sigset(SIGINT, sig);
    A(4,4);
}
```

Operations on Signals

pthread_sigsetmask(3T)

pthread_sigsetmask(3T) does for a thread what sigprocmask(2) does for a process—it sets the (thread's) signal mask. When a new thread is created, its initial mask is inherited from its creator.

The call to sigprocmask() in a multithreaded process is equivalent to a call to pthread_sigsetmask(). See the sigprocmask(2)page for more information.

pthread_kill(3T)

pthread_kill(3T) is the thread analog of kill(2)—it sends a signal to a specific thread.This, of course, is different from sending a signal to a process. When a signal is sent to a process, the signal can be handled by any thread in the process. A signal sent by pthread_kill() can be handled only by the specified thread.

Note than you can use pthread_kill() to send signals only to threads in the current process. This is because the thread identifier (type thread_t) is local in scope—it is not possible to name a thread in any process but your own.

Note also that the action taken (handler, SIG_DFL, SIG_IGN) on receipt of a signal by the target thread is global, as usual. This means, for example, that if you send SIG*XXX* to a thread, and the SIG*XXX* signal disposition for the process is to kill the process, then the whole process is killed when the target thread receives the signal.

sigwait(2)

For multithreaded programs, sigwait(2) is the preferred interface to use, because it deals so well with aysynchronously-generated signals.

sigwait() causes the calling thread to wait until any signal identified by its *set* argument is delivered to the thread. While the thread is waiting, signals identified by the *set* argument are unmasked, but the original mask is restored when the call returns.

Use sigwait() to separate threads from asynchronous signals. You can create one thread that is listening for asynchronous signals while your other threads are created to block any asynchronous signals that might be set to this process.

New sigwait() *Implementations*

Two versions of sigwait() are available in the Solaris 2.5 release: the new Solaris 2.5 version, and the POSIX.1c version. New applications and libraries should use the POSIX standard interface, as the Solaris version might not be available in future releases.

Note – The new Solaris 2.5 sigwait() does not override the signal's ignore disposition. Applications relying on the older sigwait(2) behavior can break unless you install a dummy signal handler to change the disposition from SIG_IGN to having a handler, so calls to sigwait() for this signal catch it.

The syntax for the two versions of sigwait()is shown below.

```
#include <signal.h>

/* the Solaris 2.5 version*/
int sigwait(sigset_t *set);

/* the POSIX.1c version */
int sigwait(const sigset_t *set, int *sig);
```

When the signal is delivered, the POSIX.1c sigwait() clears the pending signal and places the signal number in *sig*. Many threads can call sigwait() at the same time, but only one thread returns for each signal that is received.

With sigwait() you can treat asynchronous signals synchronously—a thread that deals with such signals simply calls sigwait() and returns as soon as a signal arrives. By ensuring that all threads (including the caller of sigwait()) have such signals masked, you can be sure that signals are handled only by the intended handler and that they are handled safely.

By always masking all signals in all threads, and just calling sigwait() as necessary, your application will be much safer for threads that depend on signals.

Usually, you use `sigwait()` to create one or more threads that wait for signals. Because `sigwait()` can retrieve even masked signals, be sure to block the signals of interest in all other threads so they are not accidentally delivered.

When the signals arrive, a thread returns from `sigwait()`, handles the signal, and waits for more signals. The signal-handling thread is not restricted to using Async-Signal-Safe functions and can synchronize with other threads in the usual way. (The Async-Signal-Safe category is defined in “MT Interface Safety Levels” on page 151.)

Note – `sigwait()` should *never* be used with synchronous signals.

sigtimedwait(2)

`sigtimedwait(2)` is similar to `sigwait(2)` except that it fails and returns an error when a signal is not received in the indicated amount of time.

Thread-Directed Signals

The UNIX signal mechanism is extended with the idea of thread-directed signals. These are just like ordinary asynchronous signals, except that they are sent to a particular thread instead of to a process.

Waiting for asynchronous signals in a separate thread can be safer and easier than installing a signal handler and processing the signals there.

A better way to deal with asynchronous signals is to treat them synchronously. By calling `sigwait(2)`, discussed on page 135, a thread can wait until a signal occurs.

Code Example 5-2 Asynchronous Signals and `sigwait`(2)

```
main() {
    sigset_t set;
    void runA(void);
    int sig;

    sigemptyset(&set);
    sigaddset(&set, SIGINT);
    pthread_sigsetmask(SIG_BLOCK, &set, NULL);
    pthread_create(NULL, 0, runA, NULL, PTHREAD_DETACHED, NULL);

    while (1) {
        sigwait(&set, &sig);
        printf("nestcount = %d\n", nestcount);
        printf("received signal %d\n", sig);
    }
}

void runA() {
    A(4,4);
    exit(0);
}
```

This example modifies the code of Code Example 5-1: the main routine masks the `SIGINT` signal, creates a child thread that calls the function *A* of the previous example, and finally issues `sigwait`s to handle the `SIGINT` signal.

Note that the signal is masked in the compute thread because the compute thread inherits its signal mask from the main thread. The main thread is protected from `SIGINT` while, and only while, it is not blocked inside of `sigwait()`.

Also, note that there is never any danger of having system calls interrupted when you use `sigwait()`.

Completion Semantics

Another way to deal with signals is with completion semantics.

Use completion semantics when a signal indicates that something so catastrophic has happened that there is no reason to continue executing the current code block. The signal handler runs *instead of* the remainder of the block that had the problem. In other words, the signal handler completes the block.

In Code Example 5-3, the block in question is the body of the `then` part of the `if` statement. The call to `setjmp(3C)` saves the current register state of the program in `jbuf` and returns 0—thereby executing the block.

Code Example 5-3 Completion Semantics

```
sigjmp_buf jbuf;
void mult_divide(void) {
    int a, b, c, d;
    void problem();

    sigset(SIGFPE, problem);
    while (1) {
        if (sigsetjmp(&jbuf) == 0) {
            printf("Three numbers, please:\n");
            scanf("%d %d %d", &a, &b, &c);
            d = a*b/c;
            printf("%d*%d/%d = %d\n", a, b, c, d);
        }
    }
}

void problem(int sig) {
    printf("Couldn't deal with them, try again\n");
    siglongjmp(&jbuf, 1);
}
```

If a `SIGFPE` (a floating-point exception) occurs, the signal handler is invoked.

The signal handler calls `siglongjmp(3C)`, which restores the register state saved in `jbuf`, causing the program to return from `sigsetjmp()` again (among the registers saved are the program counter and the stack pointer).

This time, however, `sigsetjmp(3C)` returns the second argument of `siglongjmp()`, which is 1. Notice that the block is skipped over, only to be executed during the next iteration of the `while` loop.

Note that you can use `sigsetjmp(3C)` and `siglongjmp(3C)` in multithreaded programs, but be careful that a thread never does a `siglongjmp()` using the results of another thread's `sigsetjmp()`.

Also, `sigsetjmp()` and `siglongjmp()` save and restore the signal mask, but `setjmp(3C)` and `longjmp(3C)` do not.

It is best to use `sigsetjmp()` and `siglongjmp()` when you work with signal handlers.

Completion semantics are often used to deal with exceptions. In particular, the Ada® programming language uses this model.

Note – Remember, `sigwait(2)` should *never* be used with synchronous signals.

Signal Handlers and Async-Signal Safety

A concept similar to thread safety is Async-Signal safety. Async-Signal-Safe operations are guaranteed not to interfere with operations that are being interrupted.

The problem of Async-Signal safety arises when the actions of a signal handler can interfere with the operation that is being interrupted.

For example, suppose a program is in the middle of a call to `printf(3S)` and a signal occurs whose handler itself calls `printf()`: the output of the two `printf()` statements would be intertwined. To avoid this, the handler should not call `printf()` itself when `printf()` might be interrupted by a signal.

This problem cannot be solved by using synchronization primitives because any attempted synchronization between the signal handler and the operation being synchronized would produce immediate deadlock.

Suppose that `printf()` is to protect itself by using a mutex. Now suppose that a thread that is in a call to `printf()`, and so holds the lock on the mutex, is interrupted by a signal.

If the handler (being called by the thread that is still inside of `printf()`) itself calls `printf()`, the thread that holds the lock on the mutex will attempt to take it again, resulting in an instant deadlock.

To avoid interference between the handler and the operation, either ensure that the situation never arises (perhaps by masking off signals at critical moments) or invoke only Async-Signal-Safe operations from inside signal handlers.

Because setting a thread's mask is an inexpensive user-level operation, you can inexpensively make functions or sections of code fit in the Async-Signal-Safe category.

The only routines that POSIX guarantees to be Async-Signal-Safe are listed in Table 5-2. Any signal handler can safely call into one of these functions.

Table 5-2 Async-Signal-Safe Functions

`_exit()`	`fstat()`	`read()`	`sysconf()`
`access()`	`getegid()`	`rename()`	`tcdrain()`
`alarm()`	`geteuid()`	`rmdir()`	`tcflow()`
`cfgetispeed()`	`getgid()`	`setgid()`	`tcflush()`
`cfgetospeed()`	`getgroups()`	`setpgid()`	`tcgetattr()`
`cfsetispeed()`	`getpgrp()`	`setsid()`	`tcgetpgrp()`
`cfsetospeed()`	`getpid()`	`setuid()`	`tcsendbreak()`
`chdir()`	`getppid()`	`sigaction()`	`tcsetattr()`
`chmod()`	`getuid()`	`sigaddset()`	`tcsetpgrp()`
`chown()`	`kill()`	`sigdelset()`	`time()`
`close()`	`link()`	`sigemptyset()`	`times()`
`creat()`	`lseek()`	`sigfillset()`	`umask()`
`dup2()`	`mkdir()`	`sigismember()`	`uname()`
`dup()`	`mkfifo()`	`sigpending()`	`unlink()`
`execle()`	`open()`	`sigprocmask()`	`utime()`
`execve()`	`pathconf()`	`sigsuspend()`	`wait()`
`fcntl()`	`pause()`	`sleep()`	`waitpid()`
`fork()`	`pipe()`	`stat()`	`write()`

Interrupted Waits on Condition Variables (Solaris Threads, Only)

When a signal is delivered to a thread while the thread is waiting on a condition variable, the old convention (assuming that the process is not terminated) is that interrupted calls return `EINTR`.

The ideal new condition would be that when `cond_wait(3T)` and `cond_timedwait(3T)` return, the lock has been retaken on the mutex.

This is what is done in Solaris threads: when a thread is blocked in `cond_wait()` or `cond_timedwait()` and an unmasked, caught signal is delivered to the thread, the handler is invoked and the call to `cond_wait()` or `cond_timedwait()` returns `EINTR` with the mutex locked.

This implies that the mutex is locked in the signal handler because the handler might have to clean up after the thread. While this is true in the Solaris 2.5 release, it might change in the future, so do not rely upon this behavior.

Note – In POSIX threads, `pthread_cond_wait(3T)` returns from signals, but this is not an error—`pthread_cond_wait()` returns zero as a spurious wakeup.

This is illustrated by Code Example 5-4.

Code Example 5-4 Condition Variables and Interrupted Waits

```
int sig_catcher() {
    sigset_t set;
    void hdlr();

    mutex_lock(&mut);

    sigemptyset(&set);
    sigaddset(&set, SIGINT);
    sigsetmask(SIG_UNBLOCK, &set, 0);

    if (cond_wait(&cond, &mut) == EINTR) {
        /* signal occurred and lock is held */
        cleanup();
        mutex_unlock(&mut);
        return(0);
    }
    normal_processing();
    mutex_unlock(&mut);
    return(1);
}

void hdlr() {
    /* lock is held in the handler */
    ...
}
```

Assume that the `SIGINT` signal is blocked in all threads on entry to `sig_catcher()` and that `hdlr()` has been established (with a call to `sigaction(2)`) as the handler for the `SIGINT` signal. When an unmasked and caught instance of the `SIGINT` signal is delivered to the thread while it is in`cond_wait()`, the thread first reacquires the lock on the mutex, then calls `hdlr()`, and then returns `EINTR` from `cond_wait()`.

Note that whether `SA_RESTART` has been specified as a flag to `sigaction()` has no effect here—`cond_wait(3T)` is not a system call and is not automatically restarted. When a caught signal occurs while a thread is blocked in `cond_wait()`, the call always returns `EINTR`. Again, the application should not rely on an interrupted `cond_wait()` reacquiring the mutex, because this behavior could change in the future.

5

I/O Issues

One of the attractions of multithreaded programming is I/O performance. The traditional UNIX API gave the programmer little assistance in this area—you either used the facilities of the file system or bypassed the file system entirely.

This section shows how to use threads to get more flexibility through I/O concurrency and multibuffering. This section also discusses the differences and similarities between the approaches of synchronous I/O (with threads) and asynchronous I/O (with and without threads).

I/O as a Remote Procedure Call

In the traditional UNIX model, I/O appears to be synchronous, as if you were placing a remote procedure call to the I/O device. Once the call returns, then the I/O has completed (or at least it appears to have completed—a write request, for example, might merely result in the transfer of the data to a buffer in the operating system).

The advantage of this model is that it is easy to understand because programmers are very familiar with the concept of procedure calls.

An alternative approach not found in traditional UNIX systems is the asynchronous model, in which an I/O request merely starts an operation. The program must somehow discover when the operation completes.

This approach is not as simple as the synchronous model, but it has the advantage of allowing concurrent I/O and processing in traditional, single-threaded UNIX processes.

Tamed Asynchrony

You can get most of the benefits of asynchronous I/O by using synchronous I/O in a multithreaded program. Where, with asynchronous I/O, you would issue a request and check later to determine when it completes, you can instead have a separate thread perform the I/O synchronously. The main thread can then check (perhaps by calling `pthread_join(3T)`) for the completion of the operation at some later time.

Asynchronous I/O

In most situations there is no need for asynchronous I/O, since its effects can be achieved with the use of threads, with each thread doing synchronous I/O. However, in a few situations, threads cannot achieve what asynchronous I/O can.

The most straightforward example is writing to a tape drive to make the tape drive stream. Streaming prevents the tape drive from stopping while it is being written to and moves the tape forward at high speed while supplying a constant stream of data that is written to tape.

To do this, the tape driver in the kernel must issue a queued write request when the tape driver responds to an interrupt that indicates that the previous tape-write operation has completed.

Threads cannot guarantee that asynchronous writes will be ordered because the order in which threads execute is indeterminate. Trying to order a write to a tape, for example, is not possible.

Asynchronous I/O Operations

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

int aioread(int fildes, char *bufp, int bufs, off_t offset,
    int whence, aio_result_t *resultp);

int aiowrite(int filedes, const char *bufp, int bufs,
    off_t offset, int whence, aio_result_t *resultp);

aio_result_t *aiowait(const struct timeval *timeout);

int aiocancel(aio_result_t *resultp);
```

`aioread(3)` and `aiowrite(3)` are similar in form to `pread(2)` and `pwrite(2)`, except for the addition of the last argument. Calls to `aioread()` and `aiowrite()` result in the initiation (or queueing) of an I/O operation.

The call returns without blocking, and the status of the call is returned in the structure pointed to by `resultp`. This is an item of type `aio_result_t` that contains the following:

```
int aio_return;
int aio_errno;
```

When a call fails immediately, the failure code can be found in `aio_errno`. Otherwise, this field contains `AIO_INPROGRESS`, meaning that the operation has been successfully queued.

You can wait for an outstanding asynchronous I/O operation to complete by calling `aiowait(3)`. This returns a pointer to the `aio_result_t` structure supplied with the original `aioread(3)` or `aiowrite(3)` call.

This time `aio_result_t` contains whatever `read(2)` or `write(2)` would have returned if one of them had been called instead of the asynchronous version. If the read or write is successful, `aio_return` contains the number of bytes that were read or written; if it was not successful, `aio_return` is -1, and `aio_errno` contains the error code.

`aiowait()` takes a `timeout` argument, which indicates how long the caller is willing to wait. As usual, a NULL pointer here means that the caller is willing to wait indefinitely, and a pointer to a structure containing a zero value means that the caller is unwilling to wait at all.

You might start an asynchronous I/O operation, do some work, then call `aiowait()` to wait for the request to complete. Or you can use `SIGIO` to be notified, asynchronously, when the operation completes.

Finally, a pending asynchronous I/O operation can be cancelled by calling `aiocancel()`. This routine is called with the address of the result area as an argument. This result area identifies which operation is being cancelled.

Shared I/O and New I/O System Calls

When multiple threads are performing I/O operations at the same time with the same file descriptor, you might discover that the traditional UNIX I/O interface is not thread-safe. The problem occurs with nonsequential I/O. This uses the `lseek(2)` system call to set the file offset, which is then used in the next read(2) or write(2) call to indicate where in the file the operation should start. When two or more threads are issuing lseek's to the same file descriptor, a conflict results.

To avoid this conflict, use the pread(2) and pwrite(2) system calls.

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

ssize_t pread(int fildes, void *buf, size_t nbyte, off_t offset);

ssize_t pwrite(int filedes, void *buf, size_t nbyte,
    off_t offset);
```

These behave just like read(2) and write(2) except that they take an additional argument, the file offset. With this argument, you specify the offset without using lseek(2), so multiple threads can use these routines safely for I/O on the same file descriptor.

Alternatives to getc(3S) *and* putc(3S)

An additional problem occurs with standard I/O. Programmers are accustomed to routines such as getc(3S) and putc(3S) being very quick—they are implemented as macros. Because of this, they can be used within the inner loop of a program with no concerns about efficiency.

However, when they are made thread safe they suddenly become more expensive—they now require (at least) two internal subroutine calls, to lock and unlock a mutex.

To get around this problem, alternative versions of these routines are supplied—getc_unlocked(3S) and putc_unlocked(3S).

These do not acquire locks on a mutex and so are as quick as the originals, nonthread-safe versions of getc(3S) and putc(3S).

However, to use them in a thread-safe way, you must explicitly lock and release the mutexes that protect the standard I/O streams, using flockfile(3S) and funlockfile(3S). The calls to these latter routines are placed outside the loop, and the calls to getc_unlocked() or putc_unlocked() are placed inside the loop.

Safe and Unsafe Interfaces 6

This chapter defines MT-safety levels for functions and libraries.

Thread Safety

Thread safety is the avoidance of *data races*—situations in which data are set to either correct or incorrect values depending upon the order in which multiple threads access and modify the data.

When no sharing is intended, give each thread a private copy of the data. When sharing is important, provide explicit synchronization to make certain that the program behaves deterministically.

A procedure is *thread safe* when it is logically correct when executed simultaneously by several threads. At a practical level, it is convenient to recognize three levels of safety.

- Unsafe
- Thread safe—Serializable
- Thread safe—MT-safe

An unsafe procedure can be made thread safe and serializable by surrounding it with statements to lock and unlock a mutex. Code Example 6-1 shows a simplified implementation of `fputs()`, initially thread unsafe.

Next is a serializable version of this routine with a single mutex protecting the procedure from concurrent execution problems. Actually, this is stronger synchronization than is usually necessary. When two threads are sending output to different files using `fputs`(), one need not wait for the other—the threads need synchronization only when they are sharing an output file.

The last version is MT-safe. It uses one lock for each file, allowing two threads to print to different files at the same time. So, a routine is MT-safe when it is thread safe and its execution does not negatively affect performance.

Code Example 6-1 Degrees of Thread Safety

```
/* not thread-safe */
fputs(const char *s, FILE *stream) {
    char *p;
    for (p=s; *p; p++)
        putc((int)*p, stream);
}

/* serializable */
fputs(const char *s, FILE *stream) {
    static mutex_t mut;
    char *p;
    mutex_lock(&m);
    for (p=s; *p; p++)
        putc((int)*p, stream);

    mutex_unlock(&m);
}

/* MT-Safe */
mutex_t m[NFILE];
fputs(const char *s, FILE *stream) {
    static mutex_t mut;
    char *p;
    mutex_lock(&m[fileno(stream)]);
    for (p=s; *p; p++)
        putc((int)*p, stream);
    mutex_unlock(&m[fileno(stream)]0;
}
```

MT Interface Safety Levels

The *man Pages(3): Library Routines* use the following categories to describe how well an interface supports threads (these categories are explained more fully in the `Intro(3)` man page).

Safe	This code can be called from a multithreaded application.
Safe with exceptions	See the NOTES sections of these pages for a description of the exceptions.
Unsafe	This interface is not safe to use with multithreaded applications unless the application arranges for only one thread at a time to execute within the library.
MT-Safe	This interface is fully prepared for multithreaded access in that it is both *safe* and it supports some concurrency.
MT-Safe with exceptions	See the NOTES sections of these pages in the *man Pages(3): Library Routines* for a list of the exceptions.
Async-Signal-Safe	This routine can safely be called from a signal handler. A thread that is executing an Async-Signal-Safe routine does not deadlock with itself when it is interrupted by a signal.
Fork1-Safe	This interface releases locks it has held whenever the Solaris `fork1(2)` or the POSIX `fork(2)` is called.

See the table in Appendix B, “MT Safety Levels: Library Interfaces,” for the safety levels of interfaces from the *man Pages(3): Library Routines*. Check the man page to be sure of the level.

Some functions have purposely not been made safe for the following reasons.

- Making the interface MT-Safe would have negatively affected the performance of single-threaded applications.
- The interface has an Unsafe interface. For example, a function might return a pointer to a buffer in the stack. You can use reentrant counterparts for some of these functions. The reentrant function name is the original function name with “`_r`” appended.

Caution – There is no way to be certain that a function whose name does not end in "_r" is MT-Safe other than by checking its reference manual page. Use of a function identified as not MT-Safe must be protected by a synchronizing device or by restriction to the initial thread.

Reentrant Functions for Unsafe Interfaces

For most functions with Unsafe interfaces, an MT-Safe version of the routine exists. The name of the new MT-Safe routine is always the name of the old Unsafe routine with "_r" appended. The following "_r" routines are supplied in the Solaris system:

Table 6-1 Reentrant Functions

in alphabetical order	gethostbyaddr_r(3n)	getrpcent_r(3n)
asctime_r(3c)	gethostbyname_r(3n)	getservbyname_r(3n)
ctermid_r(3s)	gethostent_r(3n)	getservbyport_r(3n)
ctime_r(3c)	getlogin_r(3c)	getservent_r(3n)
fgetgrent_r(3c)	getnetbyaddr_r(3n)	getspent_r(3c)
fgetpwent_r(3c)	getnetbyname_r(3n)	getspnam_r(3c)
fgetspent_r(3c)	getnetent_r(3n)	gmtime_r(3c)
gamma_r(3m)	getnetgrent_r(3n)	lgamma_r(3m)
getauclassent_r(3)	getprotobyname_r(3n)	localtime_r(3c)
getauclassnam_r(3)	getprotobynumber_r(3n)	nis_sperror_r(3n)
getauevent_r(3)	getprotoent_r(3n)	rand_r(3c)
getauevnam_r(3)	getpwent_r(3c)	readdir_r(3c)
getauevnum_r(3)	getpwnam_r(3c)	strtok_r(3c)
getgrent_r(3c)	getpwuid_r(3c)	tmpnam_r(3s)
getgrgid_r(3c)	getrpcbyname_r(3n)	ttyname_r(3c)
getgrnam_r(3c)	getrpcbynumber_r(3n)	

Async-Signal-Safe Functions

Functions that can safely be called from signal handlers are *Async-Signal-Safe*. The POSIX standard defines and lists Async-Signal-Safe functions (IEEE Std 1003.1-1990, 3.3.1.3 (3)(f), page 55). In addition to the POSIX Async-Signal-Safe functions, these three functions from the Solaris threads library are also Async-Signal-Safe.

- `sema_post(3T)`
- `thr_sigsetmask(3T)`, similar to `pthread_sigmask(3T)`
- `thr_kill(3T)`, similar to `pthread_kill(3T)`

MT Safety Levels for Libraries

All routines that can potentially be called by a thread from a multithreaded program should be MT-Safe.

This means that two or more activations of a routine must be able to *correctly* execute concurrently. So, every library interface that a multithreaded program uses must be MT-Safe.

Not all libraries are now MT-Safe. The commonly used libraries that are MT-Safe are listed in Table 6-2. Additional libraries will eventually be modified to be MT-Safe.

Table 6-2 Some MT-Safe Libraries

Library	**Comments**
`lib/libc`	Interfaces that are not safe have thread-safe interfaces of the form `*_r` (often with different semantics)
`lib/libdl_stubs`	To support static switch compiling
`lib/libintl`	Internationalization library
`lib/libm`	MT-Safe only when compiled for the shared library, but not MT-Safe when linked with the archived library
`lib/libmalloc`	Space-efficient memory allocation library; see `malloc(3X)`
`lib/libmapmalloc`	Alternative `mmap(2)`-based memory allocation library; see `mapmalloc(3X)`

Table 6-2 Some MT-Safe Libraries

Library	**Comments**
`lib/libnsl`	The TLI interface, XDR, RPC clients and servers, `netdir`, `netselect` and `get`*XX*`by`*YY* interfaces are not safe, but have thread-safe interfaces of the form `get`*XX*`by`*YY*`_r`
`lib/libresolv`	Thread-specific `errno` support
`lib/libsocket`	Socket library for making network connections
`lib/libw`	Wide character and wide string functions for supporting multibyte locales
`lib/straddr`	Network name-to-address translation library
`lib/libX11`	X11 Windows library routines
`lib/libC`	C++ runtime shared objects

Unsafe Libraries

Routines in libraries that are not guaranteed to be MT-Safe can safely be called by multithreaded programs only when such calls are single-threaded.

Compiling and Debugging 7

This chapter describes how to compile and debug multithreaded programs.

Compiling a Multithreaded Application

There are many options to consider for header files, define flags, and linking.

Preparing for Compilation

The following items are required to compile and link a multithreaded program. Except for the C compiler, all should come with your Solaris 2.x system.

- A standard C compiler
- Include files:
  - <thread.h> and <pthread.h>
  - `<errno.h>`, `<limits.h>`, `<signal.h>`, `<unistd.h>`
- The regular Solaris linker, `ln(1)`
- The Solaris threads library (`libthread`), the POSIX threads library (`libpthread`), and possibly the POSIX realtime library (`libposix4`) for semaphores
- MT-safe libraries (`libc`, `libm`, `libw`, `libintl`, `libnsl`, `libsocket`, `libmalloc`, `libmapmalloc`, and so on)

Choosing Solaris or POSIX Semantics

Certain functions, including the ones listed below, have different semantics in the POSIX 1003.1c standard than in the Solaris 2.4 release, which was based on an earlier POSIX draft. Function definitions are chosen at compile time. See the *man Pages(3): Library Routines* for a description of the differences in expected parameters and return values.

Table 7-1 Functions with POSIX/Solaris Semantic Differences

`sigwait`(2)	
`ctime_r`(3C)	`asctime_r`(3C)
`ftrylockfile`(3S) – new	`getlogin_r`(3C)
`getgrnam_r`(3C)	`getgrgid_r`(3C)
`getpwnam_r`(3C)	`getpwuid_r`(3C)
`readdir_r`(3C)	`ttyname_r`(3C)

The Solaris `fork(2)` function duplicates all threads (*fork-all* behavior), while the POSIX `fork(2)` function duplicates only the calling thread (*fork-one* behavior), as does the Solaris `fork1()` function.

The handling of an `alarm(2)` is also different: a Solaris alarm goes to the thread's LWP, while a POSIX alarm goes to the whole process (see page 126).

Including `<thread.h>` *or* `<pthread.h>`

The include file `<thread.h>`, used with the `-lthread` library, compiles code that is upward compatible with earlier releases of the Solaris system. This library contains both interfaces—those with Solaris semantics and those with POSIX semantics. To call `thr_setconcurrency(3T)` with POSIX threads, your program needs to include `<thread.h>`.

The include file `<pthread.h>`, used with the `-lpthread` library, compiles code that is conformant with the multithreading interfaces defined by the POSIX 1003.1c standard. For complete POSIX compliance, the define flag `_POSIX_C_SOURCE` should be set to a (long) value ≥ 199506:

`cc` `[`*`flags`*`]` *`file...`* **`-D_POSIX_C_SOURCE=`*`N`*** (*where* ***`N`*** **`199506L`**)

You can mix Solaris threads and POSIX threads in the same application, by including both `<thread.h>` and `<pthread.h>`, and linking with either the `-lthread` or `-lpthread` library.

In mixed use, Solaris semantics prevail when compiling with `-D_REENTRANT` and linking with `-lthread`, whereas POSIX semantics prevail when compiling with `-D_POSIX_C_SOURCE` and linking with `-lpthread`.

Defining `_REENTRANT` *or* `_POSIX_C_SOURCE`

For POSIX behavior, compile applications with the `-D_POSIX_C_SOURCE` flag set ≥ 199506L. For Solaris behavior, compile multithreaded programs with the `-D_REENTRANT` flag. This applies to every module of an application.

For mixed applications (for example, Solaris threads with POSIX semantics), compile with the `-D_REENTRANT` and `-D_POSIX_PTHREAD_SEMANTICS` flags.

To compile a single-threaded application, define neither the `_REENTRANT` nor the `-D_POSIX_C_SOURCE` flag. When these flags are not present, all the old definitions for `errno`, `stdio`, and so on, remain in effect.

To summarize, POSIX applications that define `-D_POSIX_C_SOURCE` get the POSIX 1003.1c semantics for the routines listed in Table 7-1. Applications that define only `-D_REENTRANT` get the Solaris semantics for these routines. Solaris applications that define `-D_POSIX_PTHREAD_SEMANTICS` get the POSIX semantics for these routines, but can still use the Solaris threads interface.

Linking With `libthread` *or* `libpthread`

For POSIX threads behavior, load the `-lpthread` library. For Solaris threads behavior, load the `-lthread` library. Some POSIX programmers might want to link with `-lthread` to preserve the Solaris distinction between `fork()` and `fork1()`. All that `-lpthread` really does is to make `fork()` behave the same way as the Solaris `fork1()` call, and change the behavior of `alarm(2)`.

To use `libthread`, specify `–lthread` before `–lc` on the `ld` command line, or last on the `cc` command line.

To use `libpthread`, specify `–lpthread` before `–lc` on the `ld` command line, or last on the `cc` command line.

Do not link a nonthreaded program with `-lthread` or `-lpthread`. Doing so establishes multithreading mechanisms at link time that are initiated at run time. These slow down a single-threaded application, waste system resources, and produce misleading results when you debug your code.

This diagram summarizes the compile options:

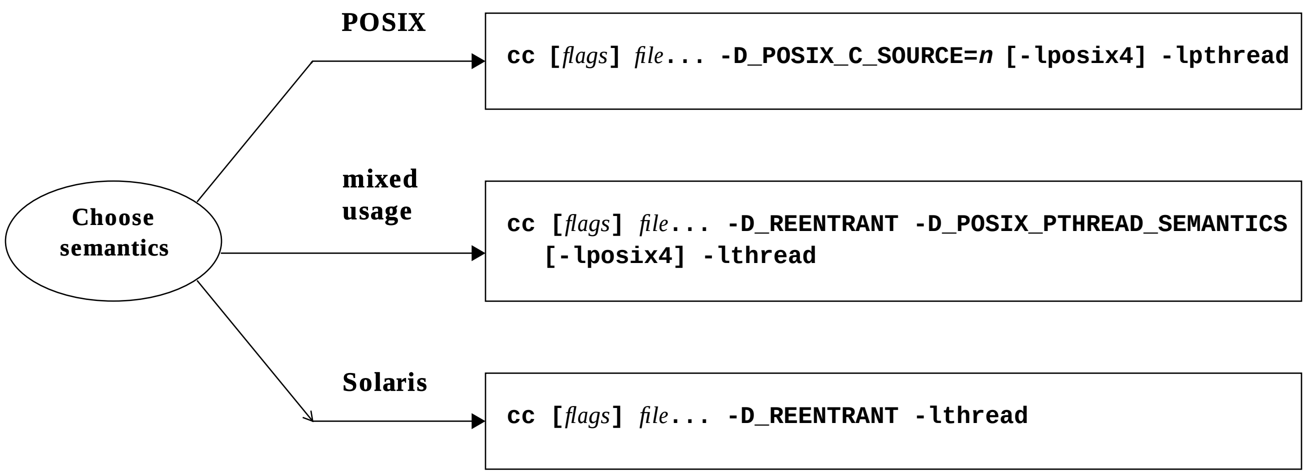


Figure 7-1 Compilation Flowchart

In mixed usage, you need to include both `<thread.h>` and `<pthread.h>`.

All calls to `libthread` and `libpthread` are no-ops if the application does not link `-lthread` or `-lpthread`. The runtime library `libc` has many predefined `libthread` and `libpthread` stubs that are null procedures. True procedures are interposed by `libthread` or `libpthread` when the application links both `libc` and the thread library.

The behavior of the C library is undefined if a program is constructed with an `ld` command line that includes the following *incorrect* fragment:

```
    .o's ... -lc -lthread ... (this is incorrect)
or
    .o's ... -lc -lpthread ... (this is incorrect)
```

Linking with `-lposix4` *for POSIX Semaphores*

The Solaris semaphore routines, `sema_*(3T)`, are contained in the `-lthread` library. By contrast, you link with the `-lposix4` library to get the standard `sem_*(3R)` POSIX 1003.1c semaphore routines described in the section “Semaphores” on page 106.

Link Old With New Carefully

Table 7-2 shows that multithreaded object modules should be linked with old object modules only with great caution.

Table 7-2 Compiling With and Without the _REENTRANT Flag

The File Type	Compiled	Reference	And Return
Old object files (non-threaded) and new object files	*Without* the _REENTRANT or _POSIX_C_SOURCE flag	Static storage	The traditional errno
New object files	*With* the _REENTRANT or _POSIX_C_SOURCE flag	__errno, the new binary entry point	The address of the thread's definition of errno
Programs using TLI in libnsl[1]	*With* the _REENTRANT or _POSIX_C_SOURCE flag (required)	__t_errno, a new entry point	The address of the thread's definition of t_errno.

1. Include tiuser.h to get the TLI global error variable.

Debugging Multithreaded Programs

Common Oversights

The following list points out some of the more frequent oversights that can cause bugs in multithreaded programs.

- Passing a pointer to the caller's stack as an argument to a new thread
- Accessing global memory (shared changeable state) without the protection of a synchronization mechanism
- Creating deadlocks caused by two threads trying to acquire rights to the same pair of global resources in alternate order (so that one thread controls the first resource and the other controls the second resource and neither can proceed until the other gives up)
- Trying to reacquire a lock already held (recursive deadlock)

- Creating a hidden gap in synchronization protection. This is caused when a code segment protected by a synchronization mechanism contains a call to a function that frees and then reacquires the synchronization mechanism before it returns to the caller. The result is that it appears to the caller that the global data has been protected when it actually has not.
- Mixing UNIX signals with threads—it is better to use the `sigwait`(2) model for handling asynchronous signals
- Using `setjmp(3B)` and `longjmp(3B)`, and then long-jumping away without releasing the mutex locks
- Failing to reevaluate the conditions after returning from a call to `*_cond_wait(3T)` or `*_cond_timedwait(3T)`
- Forgetting that default threads are created `PTHREAD_CREATE_JOINABLE` and must be reclaimed with `pthread_join(3T)`; note, `pthread_exit(3T)` does not free up their storage space
- Making deeply nested, recursive calls and using large automatic arrays can cause problems because multithreaded programs have a more limited stack size than single-threaded programs
- Specifying an inadequate stack size, or using non-default stacks

And, note that multithreaded programs (especially buggy ones) often behave differently in two successive runs given identical inputs because of differences in the thread scheduling order.

In general, multithreading bugs are statistical instead of deterministic in character. Tracing is usually more effective in finding problems in the order of execution than is breakpoint-based debugging.

Tracing and Debugging With the TNF Utilities

Use the TNF utilities (included as part of the Solaris system) to trace, debug, and gather performance analysis information from your applications and libraries. The TNF utilities integrate trace information from the kernel and from multiple user processes and threads, and so are especially useful for multithreaded code.

With the TNF utilities, you can easily trace and debug multithreaded programs. See the TNF utilities chapter in the *Programming Utilities Guide* for detailed information on using `prex(1)`, `tnfdump(1)`, and other TNF utilities.

Using truss(1)

See `truss(1)` in the *man Pages(1): User Commands* for information on tracing system calls and signals.

Using adb(1)

When you bind all threads in a multithreaded program, a thread and an LWP are synonymous. Then you can access each thread with the following `adb` commands that support multithreaded programming.

Table 7-3 MT `adb` Commands

pid:A	Attaches to process # *pid*. This stops the process and all its LWPs.
:R	Detaches from process. This resumes the process and all its LWPs.
$L	Lists all active LWPs in the (stopped) process.
n:l	Switches focus to LWP # *n*
$l	Shows the LWP currently focused
num:i	Ignores signal number *num*

These commands to set conditional breakpoints are often useful.

Table 7-4 Setting `adb` Breakpoints

[*label***],[***count***]:b [***expression***]**	Breakpoint is hit when *expression* evaluates to zero
*foo***,ffff:b <g7-0xabcdef**	Stop at *foo* when g7 = the hex value 0xABCDEF

Using dbx

With the `dbx` utility you can debug and execute source programs written in C++, ANSI C, FORTRAN, and Pascal. `dbx` accepts the same commands as the SPARCworks™ Debugger but uses a standard terminal (tty) interface. Both `dbx` and the Debugger now support debugging multithreaded programs. For a full overview of `dbx` and Debugger features see the SunSoft Developer Products (formerly SunPro) `dbx(1)` man page and the *Debugging a Program* user's guide.

All the `dbx` options listed below can support multithreaded applications.

Table 7-5 `dbx` Options for MT Programs

`cont at` *line* [*sig signo id*]	Continues execution at *line* with signal *signo*. The *id*, if present, specifies which thread or LWP to continue. The default value is *all*.
`lwp`	Displays current LWP. Switches to given LWP [lwpid].
`lwps`	Lists all LWPs in the current process.
`next ... tid`	Steps the given thread. When a function call is skipped, all LWPs are implicitly resumed for the duration of that function call. Nonactive threads cannot be stepped.
`next ... lid`	Steps the given LWP. Does not implicitly resume all LWPs when skipping a function. The LWP on which the given thread is active. Does not implicitly resume all LWP when skipping a function.
`step... tid`	Steps the given thread. When a function call is skipped, all LWPs are implicitly resumed for the duration of that function call. Nonactive threads cannot be stepped.
`step... lid`	Steps the given LWP. Does not implicitly resume all LWPs when skipping a function.
`stepi... lid`	The given LWP.
`stepi... tid`	The LWP on which the given thread is active.
`thread`	Displays current thread. Switches to thread *tid*. In all the following variations, an optional *tid* implies the current thread.
`thread -info [ tid ]`	Prints everything known about the given thread.
`thread -locks [ tid ]`	Prints all locks held by the given thread.
`thread -suspend [ tid ]`	Puts the given thread into suspended state.
`thread -continue [ tid ]`	Unsuspends the given thread.
`thread -hide [ tid ]`	*Hide*s the given (or current) thread. It will not appear in the generic `threads` listing.
`thread -unhide [ tid ]`	*Unhide*s the given (or current) thread.
`allthread-unhide`	*Unhide*s all threads.
`threads`	Prints the list of all known threads.
`threads-all`	Prints threads that are not usually printed (zombies).
`all|filterthreads-mode`	Controls whether `threads` prints all threads or filters them by default.
`auto|manualthreads-mode`	Enables automatic updating of the thread listing in the SPARCworks Debugger.
`threads-mode`	Echoes the current modes. Any of the previous forms can be followed by a thread or LWP ID to get the traceback for the specified entity.

Tools for Enhancing MT Programs 8

Sun provides several tools for enhancing the performance of MT programs. This chapter describes three of them.

Thread Analyzer
: Thread Analyzer displays standard profiling information for each thread in your program. Additionally, Thread Analyzer displays metrics specific to a particular thread (such as Mutex Wait Time and Semaphore Wait Time). Thread Analyzer can be used with C, C++, and FORTRAN 77 programs.

LockLint
: LockLint verifies the consistent use of mutex and readers/writer locks in multithreaded ANSI C programs.

  LockLint performs a static analysis of the use of mutex and readers/writer locks, and looks for inconsistent use of these locking techniques. In looking for inconsistent use of locks, LockLint detects the most common causes of data races and deadlocks.

LoopTool
: LoopTool, along with its sister program LoopReport, profiles loops for FORTRAN programs; it provides information about programs parallelized by SPARCompiler FORTRAN MP. LoopTool displays a graph of loop runtimes, shows which loops were parallelized, and provides compiler hints as to why a loop was not parallelized.

  LoopReport creates a summary table of all loop runtimes correlated with compiler hints about why a loop was not parallelized.

This chapter presents scenarios showing how each tool is used:

- Scenario One looks at Mandelbrot, a C program that can be made to run much faster by making it multithreaded. The discussion analyzes the program with Thread Analyzer to see where performance bottlenecks take place, then threads it accordingly.
- Scenario Two (page 171) shows the use of LockLint to check the Mandelbrot program's use of locks.
- Scenario Three (page 176) shows the use of LoopTool to parallelize portions of a library.

Scenario: Threading the Mandelbrot Program

This scenario shows

1. Threading a program to achieve better performance.
2. Examining the program with Thread Analyzer to determine why it hasn't shown optimal speed-up.
3. Re-writing the program to take better advantage of threading.

Mandelbrot is a well-known program that plots vectors on the plane of complex numbers, producing an interesting pattern on the screen.

In the simplest, nonthreaded version of Mandelbrot, the program flow simply repeats this series:

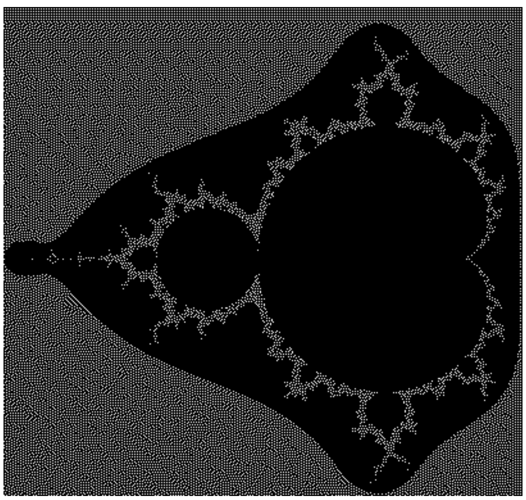
- Calculate each point
- Display each point

Obviously, on a multiprocessor machine this is not the most efficient way to run the program. Since each point can be calculated independently, the program is a good candidate for parallelization.

The program can be threaded to make it more efficient. This time, several threads (one for each processor) are running simultaneously. Each thread calculates and displays a row of points independently.

Thread One	Thread Two
Calculate row	Calculate row
Display row	Display row

However, even though the threaded Mandelbrot is faster than the unthreaded version, it doesn't show the performance speedup that might be expected.



Using Thread Analyzer to Evaluate Mandelbrot

The Thread Analyzer is used to see where the performance bottlenecks are occurring. One thing to check is which procedures were waiting on locks.

After recompiling the program to instrument it for Thread Analyzer, it is loaded.

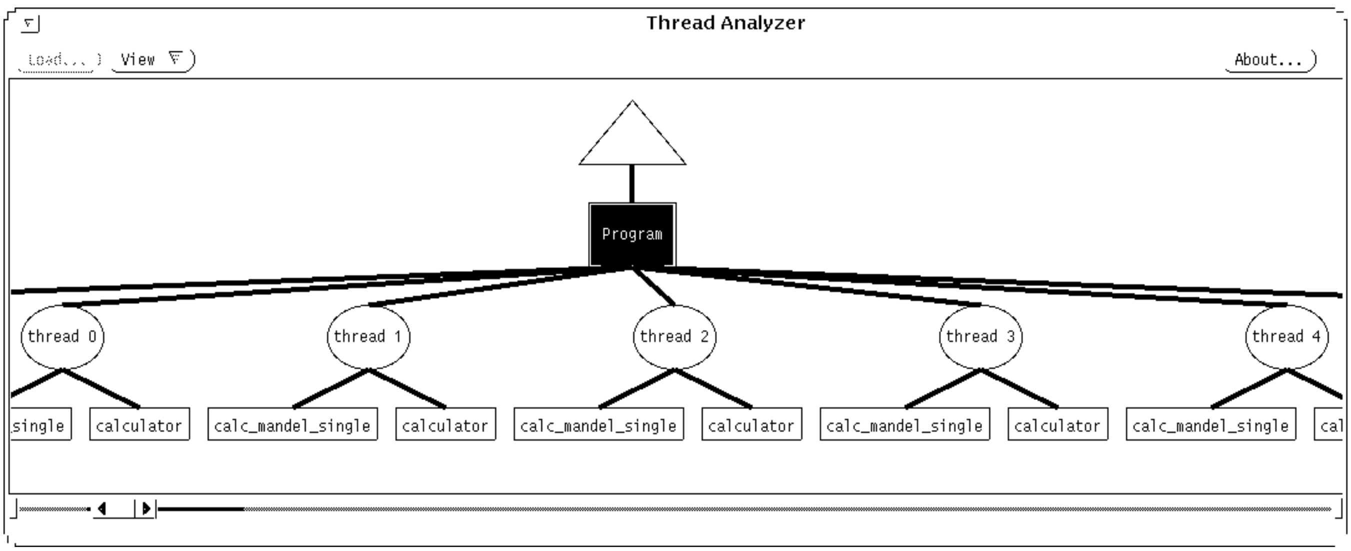


Figure 8-1 Thread Analyzer Main Window (partial)

The main window displays the program's threads and the procedures they call.

Thread Analyzer allows you to view the program in many ways, including the following:

Table 8-1 Thread Analyzer Views

View	**Meaning**
Graph	Plot the value of selected metrics against wallclock time
`gprof`(1) Table	Display call-graph profile data for threads and functions
`prof`(1) Table	Display profile data for program, threads, and functions
Sorted Metric Profile Table	Display a metric for a particular aspect of the program

Table 8-1 Thread Analyzer Views

View	Meaning
Metric Table	Show multiple metrics for a particular thread or function
Filter Threads by CPU	Display the threads whose percent of CPU is equal to or above a designated threshold
Filter Functions by CPU	Display the functions whose percent of CPU is equal to or above a designated threshold

To look at wallclock time and CPU time, choose the Graph view, and select CPU, Wallclock time, and Mutex Wait metrics:

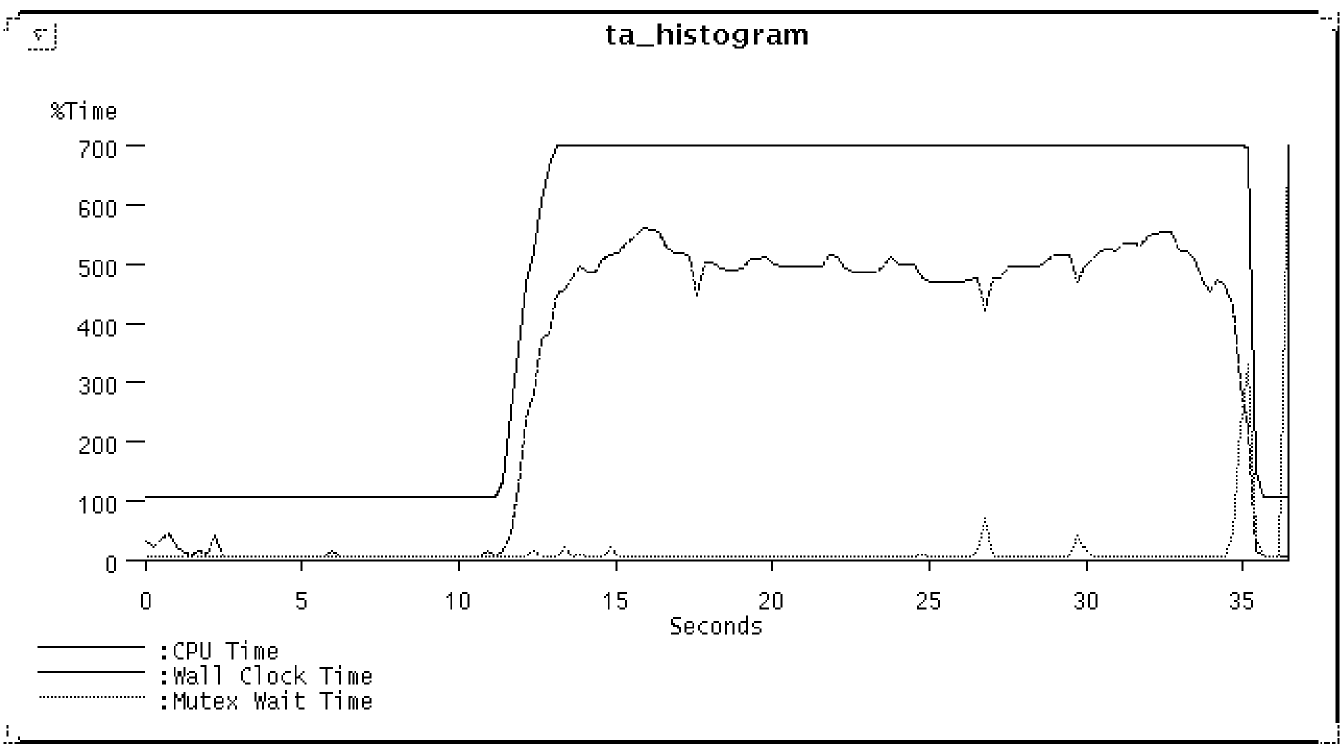
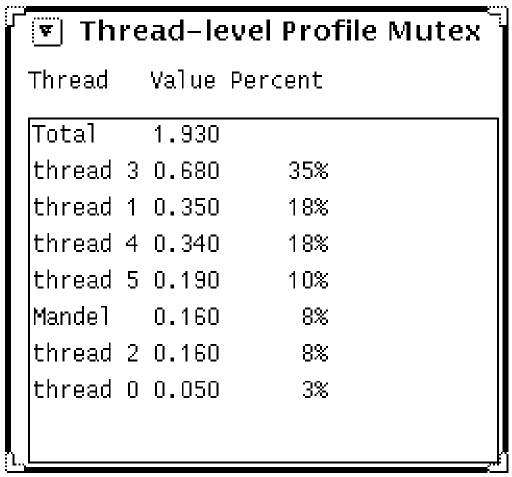


Figure 8-2 Thread Analyzer: Wall-clock and CPU time

According to this graph, CPU time is consistently below wallclock time. This indicates that fewer threads than were allocated are being used, meaning that some threads are blocked (that is, contending for resources).

Look at mutex wait times to see which threads are blocked. To do this, you can select a thread node from the main window, and then Mutex Wait from the Sorted Metrics menu. The table displays the amount of time each thread spent waiting on mutexes:


Thread-level Profile Mutex

Thread	Value	Percent
Total	1.930	
thread 3	0.680	35%
thread 1	0.350	18%
thread 4	0.340	18%
thread 5	0.190	10%
Mandel	0.160	8%
thread 2	0.160	8%
thread 0	0.050	3%

Figure 8-3 Thread Analyzer: Mutex Wait Time

The various threads spend a lot of time waiting for each other to release locks. (The fact that Thread 3 waits so much more than the others is because of randomness.) Because the display is a serial resource — a thread can't display until another thread has finished displaying — the threads are probably waiting for other threads to give up the display lock.

In other words, this is what's happening:

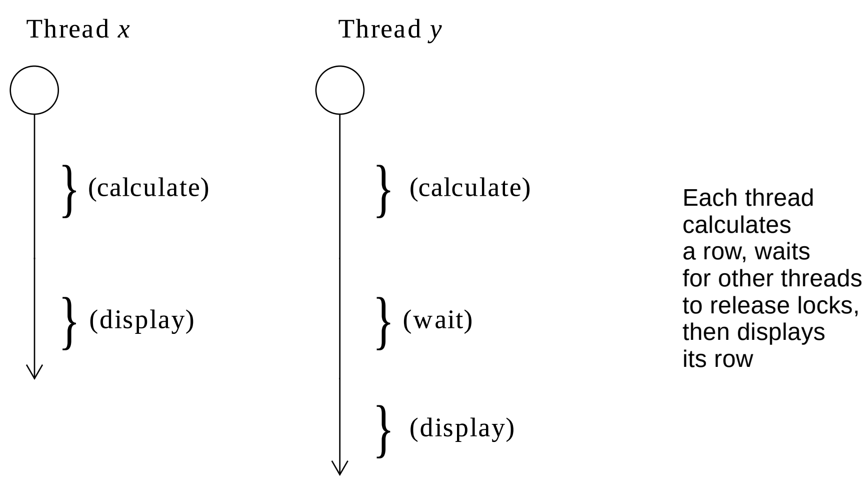


Figure 8-4 Mandelbrot Multithreaded: Each Thread Calculates and Displays

To speed things up further, code can be rewritten so that the calculations and the display are entirely separate. In this version, several threads are simultaneously calculating rows of points and writing into a buffer, while another thread reads from the buffer and displays rows:

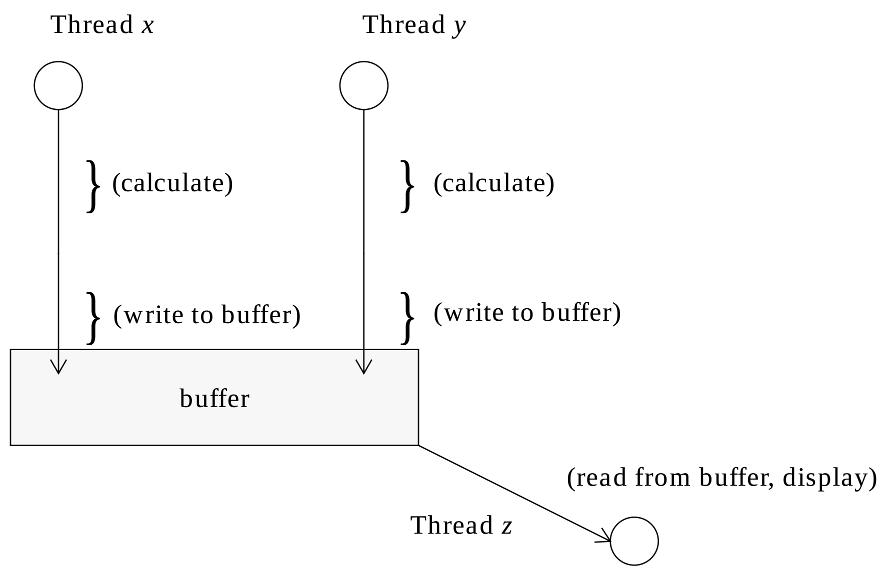


Figure 8-5 Mandelbrot Threaded: Separate Display Thread

Now, instead of the display procedure of each thread waiting on another thread to calculate and display, only the display thread waits (for the current line of the buffer to be filled). While it waits, other threads are calculating and writing, so that there is little time spent waiting for the display lock.

The Thread Analyzer confirms this:

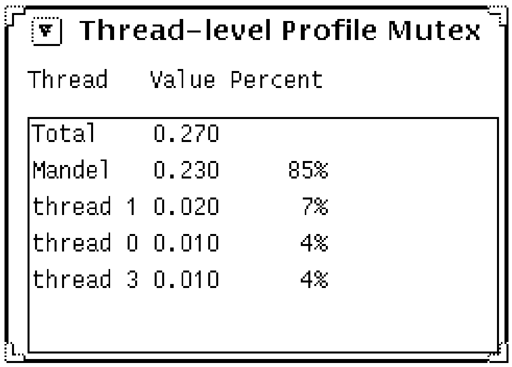


Figure 8-6 Thread Analyzer: Mutex Wait Time (Separate Display Thread)

Now the program spends almost all its time in the main loop (Mandel), and the time spent waiting for locks is reduced significantly. And Mandelbrot runs noticeably faster.

Scenario: Checking a Program With LockLint

A program can run efficiently but still contain potential problems. One such problem is data that two threads might try to access at the same time. This can lead to

- Deadlocks — when two threads are mutually waiting for the other to release a lock.
- Data races — when two or more threads have overlapping read/write access to data, causing unexpected data values. For example, suppose Thread A writes the variable *calc*, goes off and does something else, and then comes back to read *calc*; in the meantime Thread B writes to *calc* and changes its value to something Thread A does not “expect.”

Here's how you can use LockLint to see if data is adequately protected.

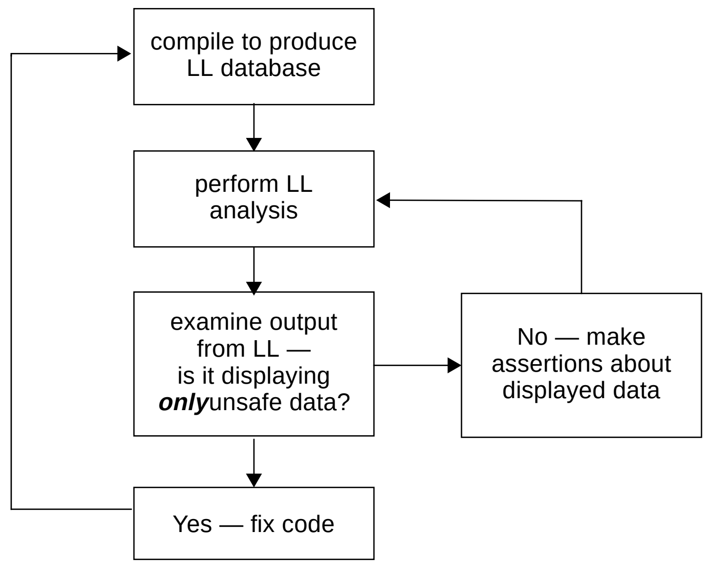


Figure 8-7 The LockLint Usage Pathway

1. **Compile the program with LockLint instrumentation.**
   The compiler has an option to produce a version of the program that LockLint can use for analysis.

2. **Create a LockLint shell and load the instrumented program.**
   You can use this shell as you would any other, including running scripts.

3. **Save the executable's state.**
   LockLint is designed to run iteratively. You run it over and over, making progressively stronger assertions about the data it is analyzing, until you find a problem or are satisfied that the data is safe.

   Analyzing the program with LockLint changes its state; that is, once you've done an analysis, you can't add further assertions. By saving and restoring the state, you can run the analysis over and over, with different assertions about the program's data.

4. **Analyze the program.**
   The `analyze` performs consistency checks on the program's data.

5. **Search for unsafe data.**
   Having run the analysis, you can look for unprotected elements.

   Here variables are displayed that did not have locks consistently held on them while they were accessed (indicated by the empty brackets); further, an asterisk indicates that these variables were written to. An asterisk, therefore, means that LockLint "believes" the data is not safe.

```
$ lock_lint analyze
$ lock_lint vars -h | grep held
:arrow_cursor                    *held={ }
:bottom_row                      *held={ }
:box_height                      *held={ }
:box_width                       *held={ }
:box_x                           *held={ }
:busy_cursor   *held={ }
:c_text *held={ }
:calc_mandel    *held={ }
:calc_type  *held={ }
:canvas *held={ }
:canvas_proc/drag   *held={ }
:canvas_proc/x  *held={ }
[. . . ]
:gap                             *held={ }
:gc                              *held={ }
:next_row                        *held={ }
:now.tv_sec                      held={ }
:now.tv_usec                     held={ }
:p_text                          *held={ }
:panel                           *held={ }
:picture_cols                    *held={ }
:picture_id                      *held={ }
:picture_rows                    *held={ }
:picture_state                   *held={ }
:pw                              *held={ }
:ramp.blue                       *held={ }
:ramp.green                      *held={ }
:ramp.red                        *held={ }
:rectangle_selected*held={ }
:row_inc                         *held={ }
:run_button                      *held={ }
[ . . . ]
```

Figure 8-8 Fragment of Initial LockLint Output

However, this analysis is only of limited usefulness, because many of the variables displayed do not *need* to be protected, such as variables that aren't written to, except when they're initialized. By excluding some data from consideration, and having LockLint repeat its analyses, you can find only the unprotected variables that you are interested in.

6. **Restore the program to its saved state.**
   Tobe able to run the analysis again, pop the state back to what it was before the program was last analyzed.

7. **Refine the analysis by excluding some data.**
   For example, you can ignore variables that aren't written to — since they don't change, they won't cause data races. And you can ignore places where the variables are initialized (if they're not visible to other threads).

   You can ignore the variables that you know are safe by making *assertions* about them. In the example below, the following are done:
   - Initialization functions are ignored (because no data is overwritten at initialization)
   - Some variables are asserted to be read-only

   (For clarity's sake this is done on the command line, the long way; you can use aliases and shell scripts to make the task easier.)

```
$ lock_lint ignore CreateXStuff run_proc canvas_proc main
$ lock_lint assert read only bottom_row
$ lock_lint assert read only calc_mandel
etc.
```

8. Analyze the program again, and search for unsafe data.

Now the list of unsafe data is considerably reduced.

```
$ lock_lint vars -h | grep held
:bottom_row                     held={ }
:calc_mandel                    held={ }
:colors                         held={ }
:corner_i                       held={ }
:corner_r                       held={ }
:display                        held={ }
:drawable                       held={ }
:frame                          held={ }
:gap                            held={ }
:gc                             held={ }
:next_row                       held={
mandel_display.c:next_row_lock }
:picture_cols                   held={ }
:picture_id                     held={ }
:picture_rows                   *held={ }
:picture_state                  *held={ }
:row_inc                        held={ }
```

Figure 8-9 Unsafe Data Reported by LockLint

This time only two variables were written to (`picture_rows` and `picture_state`) and are flagged by LockLint as inconsistently protected.

(The analysis also flags the variable `next_row`, which the calculator threads use to find the next chunk of work to be done. However, as the analysis states, this variable is consistently protected.)

Now you can alter your source code to properly protect these two unsafe variables.

Scenario: Parallelizing Loops with LoopTool

IMSL™ is a popular math library used by many FORTRAN and C programmers.[1] One of its routines is a good candidate for parallelizing with LoopTool.

This example is a FORTRAN program called `l2trg.f`. (It computes LU factorization of a single-precision general matrix.) The program is compiled without any parallelization; then checked to see how long it takes to run with the `time`(1) command:

```
$ f77 l2trg.f -cg92 -O3 -lmsl
$ /bin/time a.out
real        44.8
user        43.5
sys         1.0
```

Figure 8-10 Original Times for `l2trg.f` (Not Parallelized)

To look at the program with LoopTool, recompile with the LoopTool instrumentation, using the `-Zlp` option:

```
$ f77 l2trg.f -cg92 -O3 -Zlp -lmsl
```

1. IMSL is a registered trademark of IMSL, Inc. This example is used with permission.

This is what LoopTool shows:

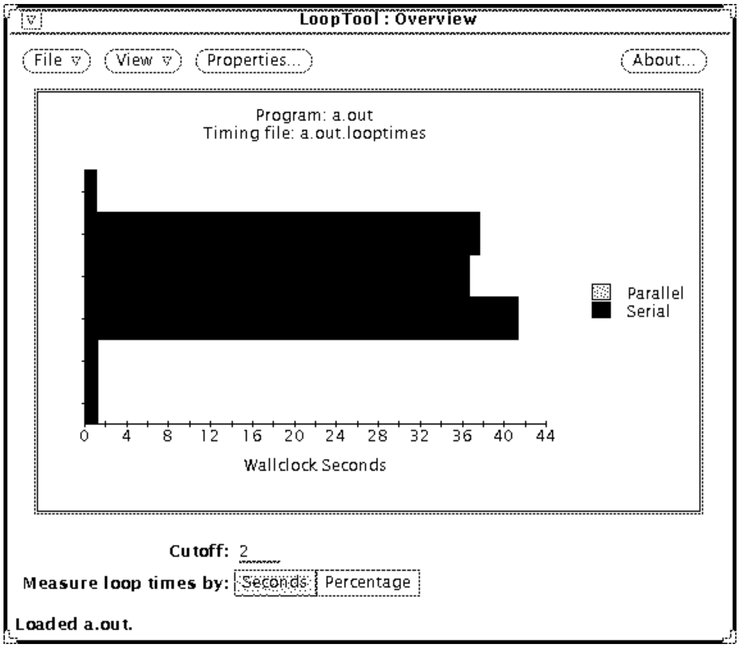


Figure 8-11 LoopTool View Before Parallelization

Putting the cursor over a loop gives its line number; clicking on it brings up a window that displays the loop in the source code. (Contrast the display in this example with the display on page 181.)

Most of the program's time is spent in three loops; looking at the source shows that they are nested. The middle loop gives a hint about parallelization:

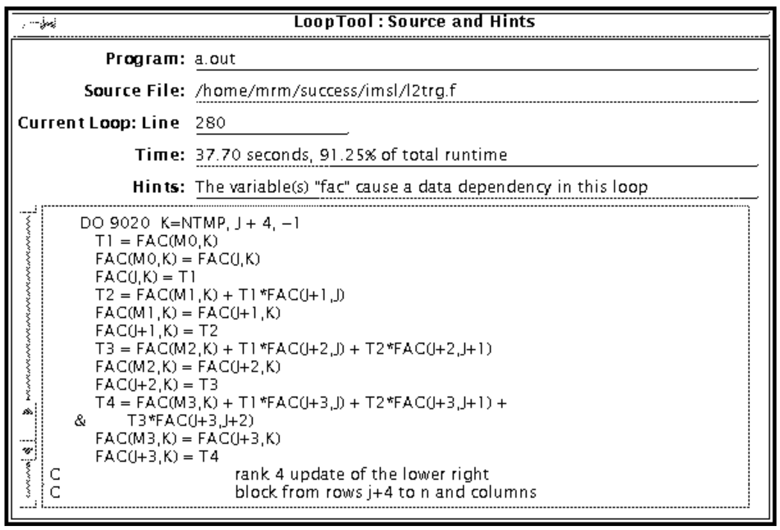


Figure 8-12 LoopTool Hint About Parallelization

In this case, LoopTool gives the message

```
The variable “fac” causes a data dependency in this loop
```

And, indeed, looking at the source, you can see that `fac` is calculated in the nested, innermost loop (9030):

```
C                            update the remaining rectangular
C                            block of U, rows j to j+3 and
C                            columns j+4 to n

      DO 9020  K=NTMP, J + 4, -1
         T1 = FAC(M0,K)
         FAC(M0,K) = FAC(J,K)
         FAC(J,K) = T1
         T2 = FAC(M1,K) + T1*FAC(J+1,J)
         FAC(M1,K) = FAC(J+1,K)
         FAC(J+1,K) = T2
         T3 = FAC(M2,K) + T1*FAC(J+2,J) + T2*FAC(J+2,J+1)
         FAC(M2,K) = FAC(J+2,K)
         FAC(J+2,K) = T3
         T4 = FAC(M3,K) + T1*FAC(J+3,J) + T2*FAC(J+3,J+1) +
     &        T3*FAC(J+3,J+2)
         FAC(M3,K) = FAC(J+3,K)
         FAC(J+3,K) = T4
C                            rank 4 update of the lower right
C                            block from rows j+4 to n and columns
C                            j+4 to n
         DO 9030  I=KBEG, NTMP
            FAC(I,K) = FAC(I,K) + T1*FAC(I,J) + T2*FAC(I,J+1) +
     &                 T3*FAC(I,J+2) + T4*FAC(I,J+3)
 9030    CONTINUE
 9020 CONTINUE
```

The loop index, `I`, of the innermost loop is used to access rows of the array `fac`. So the innermost loop updates the `I`th row of `fac`. Since updating these rows doesn't depend on updates of any other rows of `fac`, it's safe to parallelize this loop.

Therefore, if the calculation of `fac` can be speeded by parallelizing loop 9030, there should be a significant performance improvement. Force explicit parallelization by inserting a `DOALL` directive in front of loop 9030:

```
C$PAR DOALL                                (Add DOALL directive here)
        DO 9030  I=KBEG, NTMP
            FAC(I,K) = FAC(I,K) + T1*FAC(I,J) + T2*FAC(I,J+1) +
     &                 T3*FAC(I,J+2) + T4*FAC(I,J+3)
 9030    CONTINUE
```

Now recompile, forcing explicit parallelization of that loop with the `-explicitpar` option. First, though, make sure to use all the processors on the machine; do that by setting the `PARALLEL` environment variable. Finally, run the program and compare its time with that of the original times (shown in Figure 8-10 on page 176).

```
$ setenv PARALLEL 2                           (2 is the # of processors on
the machine)
$ f77 l2trg.f -cg92 -03 -explicitpar -imsl
$ /bin/time a.out
real        28.4
user        53.8
sys         1.1
```

Figure 8-13 Post-Parallelization Times for `l2trg.f`

The program now runs over a third faster. (The higher number for `user` reflects the fact that there are now two processes running.) Looking at the program again in LoopTool, you see that, in fact, the innermost loop is now parallel.

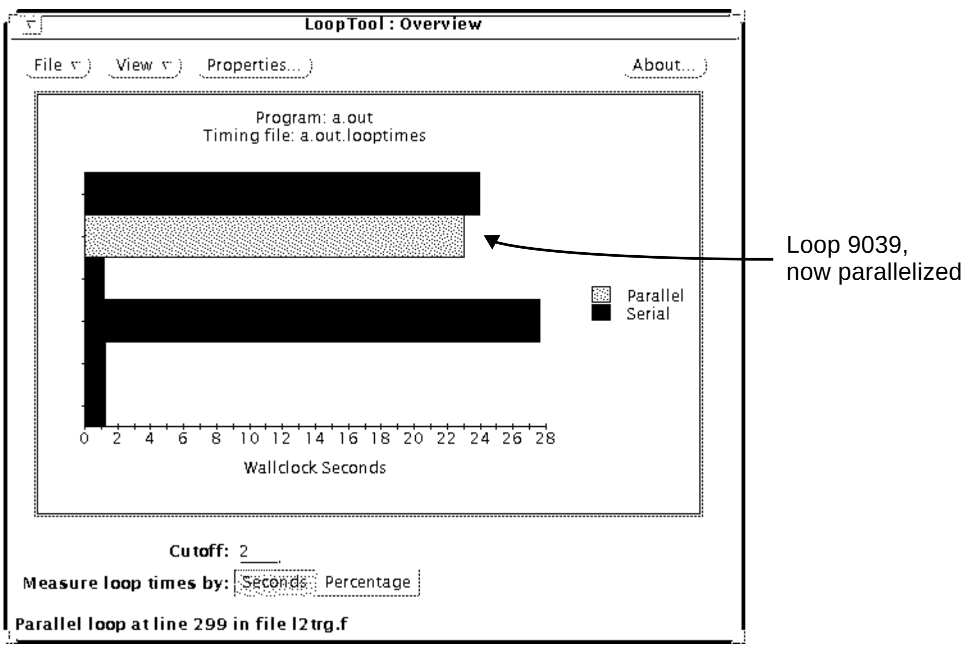


Figure 8-14 LoopTool View After Parallelization

For More Information

You might be able to find out more about Solaris threads and related issues on the World Wide Web (WWW) at the following URL:

`http://www.sun.com/sunsoft/Products/Developer-products/sig/threads`

Also, the following manuals might be of interest:

Thread Analyzer User's Guide p/n 801-6691-10

LockLint User's Guide p/n 801-6692-10

LoopTool User's Guide p/n 801-6693-10

Programming with Solaris Threads 9

This chapter compares the APIs for Solaris threads and POSIX threads, and explains the Solaris features that are not found in POSIX threads.

Comparing APIs for Solaris Threads and POSIX Threads

The Solaris threads API and the pthreads API are two solutions to the same problem: building parallelism into application software. Although each API is complete in itself, you can safely mix Solaris threads functions and pthread functions in the same program.

The two APIs do not match exactly, however. Solaris threads supports functions that are not found in pthreads, and pthreads includes functions that are not supported in the Solaris interface. For those functions that *do* match, the associated arguments might not, although the information content is effectively the same.

By combining the two APIs, you can use features not found in one to enhance the other. Similarly, you can run applications using Solaris threads, exclusively, with applications using pthreads, exclusively, on the same system.

Major API Differences

Solaris threads and pthreads are very similar in both API action and syntax. The major differences are listed in Table 9-1.

Table 9-1 Unique Solaris Threads and pthreads Features

Solaris Threads, Only	POSIX Threads, Only
`thr_` prefix for threads function names; `sema_` prefix for semaphore function names	`pthread_` prefix for pthreads function names; `sem_` prefix for semaphore function names
Readers/Writer locks	Attribute objects (these replace many Solaris arguments or flags with pointers to pthreads attribute objects)
Ability to create "daemon" threads	Cancellation semantics
Suspending and continuing a thread	Scheduling policies
Setting concurrency (requesting a new LWP): determining concurrency level	

Function Comparison Table

The following table compares Solaris threads functions with pthreads functions. Note that even when Solaris threads and pthreads functions appear to be essentially the same, the arguments to the functions can differ.

When a comparable interface is not available either in pthreads or Solaris threads, the character '-' appears in the column. Entries in the pthreads column that are followed by "POSIX 1003.4" or "POSIX.4" are part of the POSIX Realtime standard specification and are not part of pthreads.

Table 9-2 Solaris Threads and POSIX pthreads Comparison

Solaris Threads	**pthreads**
thr_create()	pthread_create()
thr_exit()	pthread_exit()
thr_join()	pthread_join()
thr_yield()	sched_yield() POSIX.4
thr_self()	pthread_self()
thr_kill()	pthread_kill()
thr_sigsetmask()	pthread_sigmask()
thr_setprio()	pthread_setschedparam()
thr_getprio()	pthread_getschedparam()
thr_setconcurrency()	-
thr_getconcurrency()	-
thr_suspend()	-
thr_continue()	-
thr_keycreate()	pthread_key_create()
-	pthread_key_delete()
thr_setspecific()	pthread_setspecific()
thr_getspecific()	pthread_getspecific()
-	pthread_once()
-	pthread_equal()
-	pthread_cancel()
-	pthread_testcancel()
-	pthread_cleanup_push()
-	pthread_cleanup_pop()
-	pthread_setcanceltype()
-	pthread_setcancelstate()
mutex_lock()	pthread_mutex_lock()
mutex_unlock()	pthread_mutex_unlock()
mutex_trylock()	pthread_mutex_trylock()
mutex_init()	pthread_mutex_init()
mutex_destroy()	pthread_mutex_destroy()
cond_wait()	pthread_cond_wait()
cond_timedwait()	pthread_cond_timedwait()
cond_signal()	pthread_cond_signal()
cond_broadcast()	pthread_cond_broadcast()

Table 9-2 Solaris Threads and POSIX pthreads Comparison

Solaris Threads	pthreads
cond_init()	pthread_cond_init()
cond_destroy()	pthread_cond_destroy()
rwlock_init()	-
rwlock_destroy()	-
rw_rdlock()	-
rw_wrlock()	-
rw_unlock()	-
rw_tryrdlock()	-
rw_trywrlock()	-
sema_init()	sem_init() POSIX 1003.4
sema_destroy()	sem_destroy() POSIX 1003.4
sema_wait()	sem_wait() POSIX 1003.4
sema_post()	sem_post() POSIX 1003.4
sema_trywait()	sem_trywait() POSIX 1003.4
fork1()	fork()
-	pthread_atfork()
fork() (multiple thread copy)	-
-	pthread_mutexattr_init()
-	pthread_mutexattr_destroy()
type argument in cond_init()	pthread_mutexattr_setpshared()
-	pthread_mutxattr_getpshared()
-	pthread_condattr_init()
-	pthread_condattr_destroy()
type argument in cond_init()	pthread_condattr_setpshared()
-	pthread_condattr_getpshared()
-	pthread_attr_init()
-	pthread_attr_destroy()
THR_BOUND flag in thr_create()	pthread_attr_setscope()
-	pthread_attr_getscope()
stack_size argument in thr_create()	pthread_attr_setstacksize()
-	pthread_attr_getstacksize()
stack_addr argument in thr_create()	pthread_attr_setstackaddr()
-	pthread_attr_getstackaddr()
THR_DETACH flag in thr_create()	pthread_attr_setdetachstate()

Table 9-2 Solaris Threads and POSIX pthreads Comparison

Solaris Threads	pthreads
-	pthread_attr_getdetachstate()
-	pthread_attr_setschedparam()
-	pthread_attr_getschedparam()
-	pthread_attr_setinheritsched()
-	pthread_attr_getinheritsched()
-	pthread_attr_setsschedpolicy()
-	pthread_attr_getschedpolicy()

To use the Solaris threads functions described in this chapter, you must link with the Solaris threads library (`-lthread`).

Where functionality is virtually the same for both Solaris threads and for pthreads, (even though the function names or arguments might differ), only a brief example consisting of the correct include file and the function prototype is presented. Where return values are not given for the Solaris threads functions, see the appropriate pages in *man Pages(3): Library Routines* for the function return values.

For more information on Solaris related functions, see the related pthreads documentation for the similarly named function.

Where Solaris threads functions offer capabilities that are not available in pthreads, a full description of the functions is provided.

9

Unique Solaris Threads Functions

Suspend Thread Execution

thr_suspend(3T)

thr_suspend() immediately suspends the execution of the thread specified by *target_thread*. On successful return from thr_suspend(), the suspended thread is no longer executing.

Once a thread is suspended, subsequent calls to thr_suspend() have no effect. Signals can not awaken the suspended thread; they remain pending until the thread resumes execution.

```
#include <thread.h>

int thr_suspend(thread_t tid);
```

In the following synopsis, pthread_t *tid* as defined in pthreads is the same as thread_t *tid* in Solaris threads. *tid* values can be used interchangeably either by assignment or through the use of casts.

```
thread_t tid; /* tid from thr_create() */

/* pthreads equivalent of Solaris tid from thread created */
/* with pthread_create() */
pthread_t ptid;

int ret;

ret = thr_suspend(tid);

/* using pthreads ID variable with a cast */
ret = thr_suspend((thread_t) ptid);
```

Return Values

Returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, `thr_suspend()` fails and returns the corresponding value.

`ESRCH` - *tid* cannot be found in the current process.

Continue a Suspended Thread

`thr_continue(3T)`

`thr_continue()` resumes the execution of a suspended thread. Once a suspended thread is continued, subsequent calls to `thr_continue()` have no effect.

```
#include <thread.h>

int thr_continue(thread_t tid);
```

A suspended thread will not be awakened by a signal. The signal stays pending until the execution of the thread is resumed by `thr_continue()`.

`pthread_t` *tid* as defined in pthreads is the same as `thread_t` *tid* in Solaris threads. *tid* values can be used interchangeably either by assignment or through the use of casts.

```
thread_t tid; /* tid from thr_create()*/

/* pthreads equivalent of Solaris tid from thread created */
/* with pthread_create()*/
pthread_t ptid;

int ret;

ret = thr_continue(tid);

/* using pthreads ID variable with a cast */
ret = thr_continue((thread_t) ptid)
```

Return Values

`thr_continue()` returns zero after completing successfully. Any other returned value indicates that an error occurred. When the following condition occurs, `thr_continue()` fails and returns the corresponding value.

`ESRCH` - *tid* cannot be found in the current process.

Set Thread Concurrency Level

By default, Solaris threads attempts to adjust the system execution resources (LWPs) used to run unbound threads to match the real number of active threads. While the Solaris threads package cannot make perfect decisions, it at least ensures that the process continues to make progress.

When you have some idea of the number of unbound threads that should be simultaneously active (executing code or system calls), tell the library through `thr_setconcurrency()`. To get the number of threads being used, use `thr_getconcurrency()`.

thr_setconcurrency(3T)

`thr_setconcurrency()` provides a hint to the system about the required level of concurrency in the application. The system ensures that a sufficient number of threads are active so that the process continues to make progress.

```
#include <thread.h>

int new_level;
int ret;

ret = thr_setconcurrency(new_level);
```

Unbound threads in a process might or might not be required to be simultaneously active. To conserve system resources, the threads system ensures by default that enough threads are active for the process to make progress, and that the process will not deadlock through a lack of concurrency.

Because this might not produce the most effective level of concurrency, `thr_setconcurrency ()` permits the application to give the threads system a hint, specified by *new_level*, for the desired level of concurrency.

The actual number of simultaneously active threads can be larger or smaller than *new_level*.

Note that an application with multiple compute-bound threads can fail to schedule all the runnable threads if `thr_setconcurrency`() has not been called to adjust the level of execution resources.

You can also affect the value for the desired concurrency level by setting the `THR_NEW_LWP` flag in `thr_create`(). This effectively increments the current level by one.

Return Values

Returns a zero when it completes successfully. Any other returned value indicates that an error occurred. When any of the following conditions are detected, `thr_setconcurrency`() fails and returns the corresponding value.

`EAGAIN` - The specified concurrency level would cause a system resource to be exceeded.

`EINVAL` - The value for *new_level* is negative.

Get Thread Concurrency

thr_getconcurrency(3T)

Use `thr_getconcurrency`() to get the current value of the concurrency level previously set by `thr_setconcurrency`(). Note that the actual number of simultaneously active threads can be larger or smaller than this number.

```
#include <thread.h>

int thr_getconcurrency(void)
```

Return Value

`thr_getconcurrency`() always returns the current value for the desired concurrency level.

Unique Solaris Synchronization Functions–Readers/Writer Locks

Readers / Writer locks allow simultaneous read access by many threads while restricting write access to only one thread at a time.

Initialize a Readers/Writer Lock	*rwlock_init(3T)*	*page 193*
Acquire a Read Lock	*rw_rdlock(3T)*	*page 195*
Try to Acquire a Read Lock	*rw_tryrdlock(3T)*	*page 195*
Acquire a Write Lock	*rw_wrlock(3T)*	*page 196*
Try to Acquire a Write Lock	*rw_trywrlock(3T)*	*page 197*
Unlock a Readers/Writer Lock	*rw_unlock(3T)*	*page 197*
Destroy Readers/Writer Lock State	*rwlock_destroy(3T)*	*page 198*

When any thread holds the lock for reading, other threads can also acquire the lock for reading but must wait to acquire the lock for writing. If one thread holds the lock for writing, or is waiting to acquire the lock for writing, other threads must wait to acquire the lock for either reading or writing.

Readers / Writer locks are slower than mutexes, but can improve performance when they protect data that are not frequently written but that are read by many concurrent threads.

Use readers / writer locks to synchronize threads in this process and other processes by allocating them in memory that is writable and shared among the cooperating processes (see `mmap`(2)) and by initializing them for this behavior.

By default, the acquisition order is not defined when multiple threads are waiting for a readers / writer lock. However, to avoid writer starvation, the Solaris threads package tends to favor writers over readers.

Readers / Writer locks must be initialized before use.

Initialize a Readers/Writer Lock

rwlock_init(3T)

```
#include <synch.h>   (or #include <thread.h>)

int rwlock_init(rwlock_t *rwlp, int type, void * arg);
```

Use `rwlock_init`() to initialize the readers/writer lock pointed to by *rwlp* and to set the lock state to unlocked. *type* can be one of the following (note that *arg* is currently ignored).

- `USYNC_PROCESS` The readers/writer lock can be used to synchronize threads in this process and other processes. *arg* is ignored.
- `USYNC_THREAD` The readers/writer lock can be used to synchronize threads in this process, only. *arg* is ignored.

Multiple threads must not initialize the same readers/writer lock simultaneously. Readers/Writer locks can also be initialized by allocation in zeroed memory, in which case a type of `USYNC_THREAD` is assumed. A readers/writer lock must not be reinitialized while other threads might be using it.

Initializing Readers/Writer Locks With Intraprocess Scope

```
#include <thread.h>

rwlock_t rwlp;
int ret;

/* to be used within this process only */
ret = rwlock_init(&rwlp, USYNC_THREAD, 0);
```

Initializing Readers/Writer Locks With Interprocess Scope

```
#include <thread.h>

rwlock_t rwlp;
int ret;

/* to be used among all processes */
ret = rwlock_init(&rwlp, USYNC_PROCESS, 0);
```

Return Values

`rwlock_init()` returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` - Invalid argument.

`EFAULT` - *rwlp* or *arg* points to an illegal address.

Acquire a Read Lock

rw_rdlock(3T)

```
#include <synch.h> (or #include <thread.h>)

int rw_rdlock(rwlock_t *rwlp);
```

Use rw_rdlock() to acquire a read lock on the readers/writer lock pointed to by *rwlp*. When the readers/writer lock is already locked for writing, the calling thread blocks until the write lock is released. Otherwise, the read lock is acquired.

Return Values

rw_rdlock() returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EINVAL - Invalid argument.

EFAULT - *rwlp* points to an illegal address.

Try to Acquire a Read Lock

rw_tryrdlock(3T)

```
#include <synch.h>  (or #include <thread.h>)

int rw_tryrdlock(rwlock_t *rwlp);
```

Use rw_tryrdlock() to attempt to acquire a read lock on the readers/writer lock pointed to by *rwlp*. When the readers/writer lock is already locked for writing, it returns an error. Otherwise, the read lock is acquired.

Return Values

`rw_tryrdlock()` returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` - Invalid argument.

`EFAULT` - *rwlp* points to an illegal address.

`EBUSY` - The readers/writer lock pointed to by *rwlp* was already locked.

Acquire a Write Lock

rw_wrlock(3T)

```
#include <synch.h>  (or #include <thread.h>)

int rw_wrlock(rwlock_t *rwlp);
```

Use `rw_wrlock()` to acquire a write lock on the readers/writer lock pointed to by *rwlp*. When the readers/writer lock is already locked for reading or writing, the calling thread blocks until all the read locks and write locks are released. Only one thread at a time can hold a write lock on a readers/writer lock.

Return Values

`rw_wrlock()` returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` - Invalid argument.

`EFAULT` - *rwlp* points to an illegal address.

Try to Acquire a Write Lock

rw_trywrlock(3T)

```
#include <synch.h>   (or #include <thread.h>)

int rw_trywrlock(rwlock_t *rwlp);
```

Use `rw_trywrlock()` to attempt to acquire a write lock on the readers/writer lock pointed to by *rwlp*. When the readers/writer lock is already locked for reading or writing, it returns an error.

Return Values

`rw_trywrlock()` returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

`EINVAL` - Invalid argument.

`EFAULT` - *rwlp* points to an illegal address.

`EBUSY` - The readers/writer lock pointed to by *rwlp* was already locked.

Unlock a Readers/Writer Lock

rw_unlock(3T)

```
#include <synch.h>   (or #include <thread.h>)

int rw_unlock(rwlock_t *rwlp);
```

Use `rw_unlock()` to unlock a readers/writer lock pointed to by *rwlp*. The readers/writer lock must be locked and the calling thread must hold the lock either for reading or writing. When any other threads are waiting for the readers/writer lock to become available, one of them is unblocked.

Return Values

rw_unlock() returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EINVAL - Invalid argument.

EFAULT - *rwlp* points to an illegal address.

Destroy Readers/Writer Lock State

rwlock_destroy(3T)

```
#include <synch.h>   (or #include <thread.h>)

int rwlock_destroy(rwlock_t *rwlp);
```

Use rwlock_destroy() to destroy any state associated with the readers/writer lock pointed to by *rlwp*. The space for storing the readers/writer lock is not freed.

Return Values

rwlock_destroy() returns zero after completing successfully. Any other returned value indicates that an error occurred. When any of the following conditions occur, the function fails and returns the corresponding value.

EINVAL - Invalid argument.

EFAULT - *rwlp* points to an illegal address.

Readers/Writer Lock Example

Code Example 9-1 uses a bank account to demonstrate readers/writer locks. While the program could allow multiple threads to have concurrent read-only access to the account balance, only a single writer is allowed. Note that the get_balance() function needs the lock to ensure that the addition of the checking and saving balances occurs atomically.

Code Example 9-1 Read / Write Bank Account

```
rwlock_t account_lock;
float checking_balance = 100.0;
float saving_balance = 100.0;
...
rwlock_init(&account_lock, 0, NULL);
...
float
get_balance() {
    float bal;

    rw_rdlock(&account_lock);
    bal = checking_balance + saving_balance;
    rw_unlock(&account_lock);
    return(bal);
}

void
transfer_checking_to_savings(float amount) {
    rw_wrlock(&account_lock);
    checking_balance = checking_balance - amount;
    saving_balance = saving_balance + amount;
    rw_unlock(&account_lock);
}
```

9

Similar Solaris Threads Functions

Create a Thread

The `thr_create`(3T) routine is one of the most elaborate of all the Solaris threads library routines.

thr_create(3T)

Use `thr_create`() to add a new thread of control to the current process.

Note that the new thread does not inherit pending signals, but it does inherit priority and signal masks.

```
#include <thread.h>

int thr_create(void *stack_base, size_t stack_size,
    void *(*start_routine) (void *), void *arg, long flags,
    thread_t *new_thread);

size_t thr_min_stack(void);
```

stack_base—Contains the address for the stack that the new thread uses. If *stack_base* is NULL then thr_create() allocates a stack for the new thread with at least *stack_size* bytes.

stack_size—Contains the size, in number of bytes, for the stack that the new thread uses. If *stack_size* is zero, a default size is used. In most cases, a zero value works best. If *stack_size* is not zero, it must be greater than the value returned by thr_min_stack().

There is no general need to allocate stack space for threads. The threads library allocates one megabyte of virtual memory for each thread's stack with no swap space reserved. (The library uses the MAP_NORESERVE option of mmap() to make the allocations.)

start_routine—Contains the function with which the new thread begins execution. When *start_routine* returns, the thread exits with the exit status set to the value returned by *start_routine* (see "thr_exit(3T)").

arg—Can be anything that is described by void, which is typically any 4-byte value. Anything larger must be passed indirectly by having the argument point to it.

Note that you can supply only one argument. To get your procedure to take multiple arguments, encode them as one (such as by putting them in a structure).

flags–Specifies attributes for the created thread. In most cases a zero value works best.

The value in *flags* is constructed from the bitwise inclusive OR of the following:

- THR_SUSPENDED—Suspends the new thread and does not execute *start_routine* until the thread is started by thr_continue(). Use this to operate on the thread (such as changing its priority) before you run it. The termination of a detached thread is ignored.
- THR_DETACHED—Detaches the new thread so that its thread ID and other resources can be reused as soon as the thread terminates. Set this when you do not want to wait for the thread to terminate.

Note – When there is no explicit synchronization to prevent it, an unsuspended, detached thread can die and have its thread ID reassigned to another new thread before its creator returns from thr_create().

- THR_BOUND—Permanently binds the new thread to an LWP (the new thread is a *bound thread*).
- THR_NEW_LWP—Increases the concurrency level for unbound threads by one. The effect is similar to incrementing concurrency by one with thr_setconcurrency(3T), although THR_NEW_LWP does not affect the level set through the thr_setconcurrency() function. Typically, THR_NEW_LWP adds a new LWP to the pool of LWPs running unbound threads.
- When you specify both THR_BOUND and THR_NEW_LWP, two LWPs are typically created—one for the bound thread and another for the pool of LWPs running unbound threads.
- THR_DAEMON—Marks the new thread as a daemon. The process exits when all nondaemon threads exit. Daemon threads do not affect the process exit status and are ignored when counting the number of thread exits.

  A process can exit either by calling exit() or by having every thread in the process that was not created with the THR_DAEMON flag call thr_exit(3T). An application, or a library it calls, can create one or more threads that should be ignored (not counted) in the decision of whether to exit. The THR_DAEMON flag identifies threads that are not counted in the process exit criterion.

new_thread—Points to a location (when *new_thread* is not NULL) where the ID of the new thread is stored when thr_create() is successful. The caller is responsible for supplying the storage this argument points to. The ID is valid only within the calling process.

If you are not interested in this identifier, supply a zero value to *new_thread*.

Return Values

Returns a zero and exits when it completes successfully. Any other returned value indicates that an error occurred. When any of the following conditions are detected, thr_create() fails and returns the corresponding value.

EAGAIN - A system limit is exceeded, such as when too many LWPs have been created.

ENOMEM - Not enough memory was available to create the new thread.

`EINVAL` - *stack_base* is not NULL and *stack_size* is less than the value returned by `thr_min_stack()`.

Stack Behavior

Stack behavior in Solaris threads is generally the same as that in pthreads. For more information about stack setup and operation, see *"About Stacks" on page 61*.

You can get the absolute minimum on stack size by calling `thr_min_stack`(), which returns the amount of stack space required for a thread that executes a null procedure. Useful threads need more than this, so be very careful when reducing the stack size.

You can specify a custom stack in two ways. The first is to supply a `NULL` for the stack location, thereby asking the runtime library to allocate the space for the stack, but to supply the desired size in the stacksize parameter to `thr_create`().

The other approach is to take overall aspects of stack management and supply a pointer to the stack to `thr_create`(). This means that you are responsible not only for stack allocation but also for stack deallocation—when the thread terminates, you must arrange for the disposal of its stack.

When you allocate your own stack, be sure to append a red zone to its end by calling `mprotect`(2).

Get the Minimal Stack Size

`thr_min_stack(3T)`

Use `thr_min_stack`(3T) to get the minimum stack size for a thread.

```
#include <thread.h>

size_t thr_min_stack(void);
```

`thr_min_stack`() returns the amount of space needed to execute a null thread (a null thread is a thread that is created to execute a null procedure).

A thread that does more than execute a null procedure should allocate a stack size greater than the size of thr_min_stack().

When a thread is created with a user-supplied stack, the user must reserve enough space to run the thread. In a dynamically linked execution environment, it is difficult to know what the thread minimal stack requirements are.

Most users should not create threads with user-supplied stacks. User-supplied stacks exist only to support applications that require complete control over their execution environments.

Instead, users should let the threads library manage stack allocation. The threads library provides default stacks that should meet the requirements of any created thread.

Get the Thread Identifier

thr_self(3T)

Use thr_self(3T) to get the ID of the calling thread.

```
#include <thread.h>

thread_t thr_self(void);
```

Yield Thread Execution

thr_yield(3T)

thr_yield() causes the current thread to yield its execution in favor of another thread with the same or greater priority; otherwise it has no effect. There is no guarantee that a thread calling thr_yield() will do so.

```
#include <thread.h>

void thr_yield(void);
```

Send a Signal to a Thread

thr_kill(3T)

thr_kill() sends a signal to a thread.

```
#include <thread.h>
#include <signal.h>

int thr_kill(thread_t target_thread, int sig);
```

Access the Signal Mask of the Calling Thread

thr_sigsetmask(3T)

Use thr_sigsetmask() to change or examine the signal mask of the calling thread.

```
#include <thread.h>
#include <signal.h>

int thr_sigsetmask(int how, const sigset_t *set, sigset_t *oset);
```

Terminate a Thread

thr_exit(3T)

Use thr_exit() to terminate a thread.

```
#include <thread.h>

void thr_exit(void *status);
```

Wait for Thread Termination

thr_join(3T)

Use the `thr_join()` function to wait for a thread to terminate.

```
#include <thread.h>

int thr_join(thread_t tid, thread_t *departedid, void **status);
```

Join specific

```
#include <thread.h>

thread_t tid;
thread_t departedid;
int ret;
int status;

/* waiting to join thread "tid" with status */
ret = thr_join(tid, &departedid, (void**)&status);

/* waiting to join thread "tid" without status */
ret = thr_join(tid, &departedid, NULL);

/* waiting to join thread "tid" without return id and status */
ret = thr_join(tid, NULL, NULL);
```

When the *tid* is `(thread_t)0`, then `thread_join()` waits for any undetached thread in the process to terminate. In other words, when no thread identifier is specified, any undetached thread that exits causes `thread_join()` to return.

Join any

```
#include <thread.h>

thread_t tid;
thread_t departedid;
int ret;
int status;

/* waiting to join thread "tid" with status */
ret = thr_join(NULL, &departedid, (void **)&status);
```

By indicating NULL as thread id in the Solaris `thr_join`(), a join will take place when any non detached thread in the process exits. The *departedid* will indicate the thread ID of exiting thread.

Create a Thread-Specific Data Key

Except for the function names and arguments, thread specific data is the same for Solaris as it is for POSIX. The synopses for the Solaris functions are given in this section. The functions are explained in "Create a Thread-Specific Data Key" on page 207.

thr_keycreate(3T)

`thr_keycreate()` allocates a key that is used to identify thread-specific data in a process.

```
#include <thread.h>

int thr_keycreate(thread_key_t *keyp,
    void (*destructor) (void *value));
```

Set the Thread-Specific Data Key

thr_setspecific(3T)

`thr_setspecific()` binds *value* to the thread-specific data key, *key*, for the calling thread.

```
#include <thread.h>

int thr_setspecific(thread_key_t key, void *value);
```

Get the Thread-Specific Data Key

thr_getspecific(3T)

`thr_getspecific()` stores the current value bound to *key* for the calling thread into the location pointed to by *valuep*.

```
#include <thread.h>

int thr_getspecific(thread_key_t key, void **valuep);
```

Set the Thread Priority

In Solaris threads, if a thread is to be created with a priority other than that of its parent's, it is created in SUSPEND mode. While suspended, the threads priority is modified using the `thr_setprio(3T)` function call; then it is continued.

An unbound thread is usually scheduled only with respect to other threads in the process using simple priority levels with no adjustments and no kernel involvement. Its system priority is usually uniform and is inherited from the creating process.

thr_setprio(3T)

The function `thr_setprio()` changes the priority of the thread, specified by *tid*, within the current process to the priority specified by *newprio*.

```
#include <thread.h>

int thr_setprio(thread_t tid, int newprio)
```

By default, threads are scheduled based on fixed priorities that range from zero, the least significant, to the largest integer. The *tid* will preempt lower priority threads, and will yield to higher priority threads.

```
thread_t tid;
int ret;
int newprio = 20;

/* suspended thread creation */
ret = thr_create(NULL, NULL, func, arg, THR_SUSPEND, &tid);

/* set the new priority of suspended child thread */
ret = thr_setprio(tid, newprio);

/* suspended child thread starts executing with new priority */
ret = thr_continue(tid);
```

Get the Thread Priority

thr_getprio(3T)

Use `thr_getprio()` to get the current priority for the thread. Each thread inherits a priority from its creator. `thr_getprio()` stores the current priority, *tid*, in the location pointed to by *newprio*.

```
#include <thread.h>

int thr_getprio(thread_t tid, int *newprio)
```

Similar Synchronization Functions–Mutual Exclusion Locks

Initialize a Mutex	*mutex_init(3T)*	*page 210*
Destroy a Mutex	*mutex_destroy(3T)*	*page 211*
Acquire a Mutex	*mutex_lock(3T)*	*page 212*
Release a Mutex	*mutex_unlock(3T)*	*page 212*
Try to Acquire a Mutex	*mutex_trylock(3T)*	*page 212*

Initialize a Mutex

mutex_init(3T)

```
#include <synch.h>  (or #include <thread.h>)

int mutex_init(mutex_t *mp, int type, void *arg));
```

Use `mutex_init()` to initialize the mutex pointed to by *mp*. The *type* can be one of the following (note that *arg* is currently ignored).

- `USYNC_PROCESS` The mutex can be used to synchronize threads in this and other processes.
- `USYNC_THREAD` The mutex can be used to synchronize threads in this process, only.

Mutexes can also be initialized by allocation in zeroed memory, in which case a *type* of `USYNC_THREAD` is assumed.

Multiple threads must not initialize the same mutex simultaneously. A mutex lock must not be reinitialized while other threads might be using it.

Mutexes With Intraprocess Scope

```
#include <thread.h>

mutex_t mp;
int ret;

/* to be used within this process only */
ret = mutex_init(&mp, USYNC_THREAD, 0);
```

Mutexes With Interprocess Scope

```
#include <thread.h>

mutex_t mp;
int ret;

/* to be used among all processes */
ret = mutex_init(&mp, USYNC_PROCESS, 0);
```

Destroy a Mutex

mutex_destroy(3T)

```
#include <thread.h>

int mutex_destroy (mutex_t *mp);
```

Use `mutex_destroy()` to destroy any state associated with the mutex pointed to by *mp*. Note that the space for storing the mutex is not freed.

Acquire a Mutex

mutex_lock(3T)

```
#include <thread.h>

int mutex_lock(mutex_t *mp);
```

Use `mutex_lock()` to lock the mutex pointed to by *mp*. When the mutex is already locked, the calling thread blocks until the mutex becomes available (blocked threads wait on a prioritized queue).

Release a Mutex

mutex_unlock(3T)

```
#include <thread.h>

int mutex_unlock(mutex_t *mp);
```

Use `mutex_unlock()` to unlock the mutex pointed to by *mp*. The mutex must be locked and the calling thread must be the one that last locked the mutex (the owner).

Try to Acquire a Mutex

mutex_trylock(3T)

```
#include <thread.h>

int mutex_trylock(mutex_t *mp);
```

Use `mutex_trylock()` to attempt to lock the mutex pointed to by *mp*. This function is a nonblocking version of `mutex_lock()`.

Similar Synchronization Functions–Condition Variables

Initialize a Condition Variable	*cond_init(3T)*	*page 213*
Destroy a Condition Variable	*cond_destroy(3T)*	*page 214*
Wait for a Condition	*cond_wait(3T)*	*page 215*
Wait For an Absolute Time	*cond_timedwait(3T)*	*page 215*
Signal One Condition Variable	*cond_signal(3T)*	*page 216*
Signal All Condition Variables	*cond_broadcast(3T)*	*page 216*

Initialize a Condition Variable

cond_init(3T)

```
#include <thread.h>

int cond_init(cond_t *cv, int type, int arg);
```

Use `cond_init()` to initialize the condition variable pointed to by *cv*. The *type* can be one of the following (note that *arg* is currently ignored).

- `USYNC_PROCESS` The condition variable can be used to synchronize threads in this and other processes. *arg* is ignored.
- `USYNC_THREAD` The condition variable can be used to synchronize threads in this process, only. *arg* is ignored.

Condition variables can also be initialized by allocation in zeroed memory, in which case a type of `USYNC_THREAD` is assumed.

Multiple threads must not initialize the same condition variable simultaneously. A condition variable must not be reinitialized while other threads might be using it.

Condition Variables With Intraprocess Scope

```
#include <thread.h>

cond_t cv;
int ret;

/* to be used within this process only */
ret = cond_init(cv, USYNC_THREAD, 0);
```

Condition Variables With Interprocess Scope

```
#include <thread.h>

cond_t cv;
int ret;

/* to be used among all processes */
ret = cond_init(&cv, USYNC_PROCESS, 0);
```

Destroy a Condition Variable

cond_destroy(3T)

```
#include <thread.h>

int cond_destroy(cond_t *cv);
```

Use `cond_destroy()` to destroy state associated with the condition variable pointed to by *cv*. The space for storing the condition variable is not freed.

Wait for a Condition

cond_wait(3T)

```
#include <thread.h>

int cond_wait(cond_t *cv, mutex_t *mp);
```

Use cond_wait() to atomically release the mutex pointed to by *mp* and to cause the calling thread to block on the condition variable pointed to by *cv*. The blocked thread can be awakened by cond_signal(), cond_broadcast(), or when interrupted by delivery of a signal or a fork().

Wait For an Absolute Time

cond_timedwait(3T)

```
#include <thread.h>

int cond_timedwait(cond_t *cv, mutex_t *mp, timestruct_t abstime)
```

Use cond_timedwait() as you would use cond_wait(), except that cond_timedwait() does not block past the time of day specified by *abstime*.

cond_timedwait() always returns with the mutex locked and owned by the calling thread even when returning an error.

The cond_timedwait() function blocks until the condition is signaled or until the time of day specified by the last argument has passed. The time-out is specified as a time of day so the condition can be retested efficiently without recomputing the time-out value.

Signal One Condition Variable

cond_signal(3T)

```
#include <thread.h>

int cond_signal(cond_t *cv);
```

Use `cond_signal`() to unblock one thread that is blocked on the condition variable pointed to by *cv*. Call this function under protection of the same mutex used with the condition variable being signaled. Otherwise, the condition could be signaled between its test and `cond_wait`(), causing an infinite wait.

Signal All Condition Variables

cond_broadcast(3T)

```
#include <thread.h>

int cond_broadcast(cond_t *cv);
```

Use `cond_broadcast`() to unblock all threads that are blocked on the condition variable pointed to by *cv*. When no threads are blocked on the condition variable then `cond_broadcast`() has no effect.

Similar Synchronization Functions–Semaphores

Semaphore operations are the same in both Solaris and POSIX. The function name changed from `sema_` in Solaris to `sem_` in pthreads.

Initialize a Semaphore	*sema_init(3T)*	*page 217*
Increment a Semaphore	*sema_post(3T)*	*page 218*
Block on a Semaphore Count	*sema_wait(3T)*	*page 218*
Decrement a Semaphore Count	*sema_trywait(3T)*	*page 219*
Destroy the Semaphore State	*sema_destroy(3T)*	*page 219*

Initialize a Semaphore

sema_init(3T)

```
#include <thread.h>

int sema_init(sema_t *sp, unsigned int count, int type,
    void *arg);
```

Use `sema_init()` to initialize the semaphore variable pointed to by *sp* by *count* amount. *type* can be one of the following (note that *arg* is currently ignored).

`USYNC_PROCESS` The semaphore can be used to synchronize threads in this process and other processes. Only one process should initialize the semaphore. *arg* is ignored.

`USYNC_THREAD` The semaphore can be used to synchronize threads in this process, only. *arg* is ignored.

Multiple threads must not initialize the same semaphore simultaneously. A semaphore must not be reinitialized while other threads may be using it.

Semaphores With Intraprocess Scope

```
#include <thread.h>

sema_t sp;
int ret;
int count;
count = 4;

/* to be used within this process only */
ret = sema_init(&sp, count, USYNC_THREAD, 0);
```

Semaphores With Interprocess Scope

```
#include <thread.h>

sema_t sp;
int ret;
int count;
count = 4;

/* to be used among all the processes */
ret = sema_init (&sp, count, USYNC_PROCESS, 0);
```

Increment a Semaphore

sema_post(3T)

```
#include <thread.h>

int sema_post(sema_t *sp);
```

Use `sema_post()` to atomically increment the semaphore pointed to by *sp*. When any threads are blocked on the semaphore, one is unblocked.

Block on a Semaphore Count

sema_wait(3T)

```
#include <thread.h>

int sema_wait(sema_t *sp);
```

Use `sema_wait()` to block the calling thread until the count in the semaphore pointed to by *sp* becomes greater than zero, then atomically decrement it.

Decrement a Semaphore Count

sema_trywait(3T)

```
#include <thread.h>

int sema_trywait(sema_t *sp);
```

Use sema_trywait() to atomically decrement the count in the semaphore pointed to by *sp* when the count is greater than zero. This function is a nonblocking version of sema_wait().

Destroy the Semaphore State

sema_destroy(3T)

```
#include <thread.h>

int sema_destroy(sema_t *sp);
```

Use sema_destroy() to destroy any state associated with the semaphore pointed to by *sp*. The space for storing the semaphore is not freed.

Synchronization Across Process Boundaries

Each of the synchronization primitives can be set up to be used across process boundaries. This is done quite simply by ensuring that the synchronization variable is located in a shared memory segment and by calling the appropriate `init` routine with *type* set to `USYNC_PROCESS`.

If this has been done, then the operations on the synchronization variables work just as they do when *type* is `USYNC_THREAD`.

```
mutex_init(&m, USYNC_PROCESS, 0);

rwlock_init(&rw, USYNC_PROCESS, 0);

cond_init(&cv, USYNC_PROCESS, 0);

sema_init(&s, count, USYNC_PROCESS, 0);
```

Using LWPs Between Processes

Using locks and condition variables between processes does not require using the threads library. The recommended approach is to use the threads library interfaces, but when this is not desirable, then the `_lwp_mutex_*` and `_lwp_cond_*` interfaces can be used as follows:

1. Allocate the locks and condition variables as usual in shared memory (either with `shmop(2)` or `mmap(2)`).

2. Then initialize the newly allocated objects appropriately with the `USYNC_PROCESS` type. Because no interface is available to perform the initialization (`_lwp_mutex_init(2)` and `_lwp_cond_init(2)` do not exist), the objects can be initialized using statically allocated and initialized dummy objects.

For example, to initialize lockp:

```
lwp_mutex_t *lwp_lockp;
lwp_mutex_t dummy_shared_mutex = SHAREDMUTEX;
    /* SHAREDMUTEX is defined in /usr/include/synch.h */
...
...
lwp_lockp = alloc_shared_lock();
*lwp_lockp = dummy_shared_mutex;
```

Similarly, for condition variables:

```
lwp_cond_t *lwp_condp;
lwp_cond_t dummy_shared_cv = SHAREDCV;
    /* SHAREDCV is defined in /usr/include/synch.h */
...
...
lwp_condp = alloc_shared_cv();
*lwp_condp = dummy_shared_cv;
```

Producer/Consumer Problem Example

Code Example 9-2 shows the producer/consumer problem with the producer and consumer in separate processes. The main routine maps zero-filled memory (that it shares with its child process) into its address space. Note that `mutex_init()` and `cond_init()` must be called because the type of the synchronization variables is `USYNC_PROCESS`.

A child process is created that runs the consumer. The parent runs the producer.

This example also shows the drivers for the producer and consumer. The `producer_driver()` simply reads characters from `stdin` and calls `producer()`. The `consumer_driver()` gets characters by calling `consumer()` and writes them to `stdout`.

The data structure for Code Example 9-2 is the same as that used for the solution with condition variables (see page 84).

Code Example 9-2 The Producer/Consumer Problem, Using USYNC_PROCESS

```
main() {
    int zfd;
    buffer_t *buffer;

    zfd = open(“/dev/zero”, O_RDWR);
    buffer = (buffer_t *)mmap(NULL, sizeof(buffer_t),
        PROT_READ|PROT_WRITE, MAP_SHARED, zfd, 0);
    buffer->occupied = buffer->nextin = buffer->nextout = 0;

    mutex_init(&buffer->lock, USYNC_PROCESS, 0);
    cond_init(&buffer->less, USYNC_PROCESS, 0);
    cond_init(&buffer->more, USYNC_PROCESS, 0);
    if (fork() == 0)
        consumer_driver(buffer);
    else
        producer_driver(buffer);
}

void producer_driver(buffer_t *b) {
    int item;

    while (1) {
        item = getchar();
        if (item == EOF) {
            producer(b, ‘\0’);
            break;
        } else
            producer(b, (char)item);
    }
}

void consumer_driver(buffer_t *b) {
    char item;

    while (1) {
        if ((item = consumer(b)) == ’\0’)
            break;
        putchar(item);
    }
}
```

A child process is created to run the consumer; the parent runs the producer.

Special Issues for `fork()` and Solaris Threads

Solaris threads and POSIX threads define the behavior of `fork()` differently. See “Process Creation–exec(2)and exit(2) Issues” on page 124 for a thorough discussion of `fork()` issues.

Solaris `libthread` supports both `fork`() and `fork1`(). The `fork`() call has “fork-all” semantics—it duplicates everything in the process, including threads and LWPs, creating a true clone of the parent. The `fork1`() call creates a clone that has only one thread; the process state and address space are duplicated, but only the calling thread is cloned.

POSIX `libpthread` supports only `fork`(), which has the same semantics as `fork1`() in Solaris threads.

Whether `fork`() has “fork-all” semantics or “fork-one” semantics is dependent upon which library is used. Linking with `-lthread` assigns “fork-all” semantics to `fork`(), while linking with `-lpthread` assigns “fork-one” semantics to `fork`().

See “Linking With libthread or libpthread” on page 157 for more details.

Programming Guidelines 10

This chapter gives some pointers on programming with threads. Most pointers apply to both Solaris and POSIX threads, but where functionality differs, it is noted. Changing from single-threaded thinking to multithreaded thinking is emphasized in this chapter.

Rethinking Global Variables

Historically, most code has been designed for single-threaded programs. This is especially true for most of the library routines called from C programs. The following implicit assumptions were made for single-threaded code:

- When you write into a global variable and then, a moment later, read from it, what you read is exactly what you just wrote.
- This is also true for nonglobal, static storage.

- You do not need synchronization because there is nothing to synchronize with.

The next few examples discuss some of the problems that arise in multithreaded programs because of these assumptions, and how you can deal with them.

Traditional, single-threaded C and UNIX have a convention for handling errors detected in system calls. System calls can return anything as a functional value (for example, `write()` returns the number of bytes that were transferred). However, the value -1 is reserved to indicate that something went wrong. So, when a system call returns -1, you know that it failed.

Code Example 10-1 Global Variables and `errno`

```
extern int errno;
...
if (write(file_desc, buffer, size) == -1) {
    /* the system call failed */
    fprintf(stderr, “something went wrong, “
        “error code = %d\n”, errno);
    exit(1);
}
...
```

Rather than return the actual error code (which could be confused with normal return values), the error code is placed into the global variable `errno`. When the system call fails, you can look in `errno` to find out what went wrong.

Now consider what happens in a multithreaded environment when two threads fail at about the same time, but with different errors. Both expect to find their error codes in `errno`, but one copy of `errno` cannot hold both values. This global variable approach simply does not work for multithreaded programs.

Threads solves this problem through a conceptually new storage class—thread-specific data. This storage is similar to global storage in that it can be accessed from any procedure in which a thread might be running. However, it is private to the thread—when two threads refer to the thread-specific data location of the same name, they are referring to two different areas of storage.

So, when using threads, each reference to `errno` is thread-specific because each thread has a private copy of `errno`. This is achieved in this implementation by making `errno` a macro that expands to a function call.

Providing for Static Local Variables

Code Example 10-2 shows a problem similar to the `errno` problem, but involving static storage instead of global storage. The function `gethostbyname(3N)` is called with the computer name as its argument. The return value is a pointer to a structure containing the required information for contacting the computer through network communications.

Code Example 10-2 The `gethostbyname()` Problem

```
struct hostent *gethostbyname(char *name) {
    static struct hostent result;
        /* Lookup name in hosts database */
        /* Put answer in result */
    return(&result);
}
```

Returning a pointer to a local variable is generally not a good idea, although it works in this case because the variable is static. However, when two threads call this variable at once with different computer names, the use of static storage conflicts.

Thread-specific data could be used as a replacement for static storage, as in the `errno` problem, but this involves dynamic allocation of storage and adds to the expense of the call.

A better way to handle this kind of problem is to make the caller of `gethostbyname()` supply the storage for the result of the call. This is done by having the caller supply an additional argument, an output argument, to the routine. This requires a new interface to `gethostbyname()`.

This technique is used in threads to fix many of these problems. In most cases, the name of the new interface is the old name with "`_r`" appended, as in `gethostbyname_r(3N)`.

Synchronizing Threads

The threads in an application must cooperate and synchronize when sharing the data and the resources of the process.

A problem arises when multiple threads call something that manipulates an object. In a single-threaded world, synchronizing access to such objects is not a problem, but as Code Example 10-3 illustrates, this is a concern with multithreaded code. (Note that the `printf(3S)`function is safe to call for a multithreaded program; this example illustrates what could happen if `printf`() were not safe.)

Code Example 10-3 The `printf`() Problem

```
/* thread 1: */
    printf("go to statement reached");


/* thread 2: */
    printf("hello world");



printed on display:
    go to hello
```

Single-Threaded Strategy

One strategy is to have a single, application-wide mutex lock that is acquired whenever any thread in the application is running and is released before it must block. Since only one thread can be accessing shared data at any one time, each thread has a consistent view of memory.

Because this is effectively a single-threaded program, very little is gained by this strategy.

Reentrance

A better approach is to take advantage of the principles of modularity and data encapsulation. A reentrant function is one that behaves correctly if it is called simultaneously by several threads. Writing a reentrant function is a matter of understanding just what *behaves correctly* means for this particular function.

Functions that are callable by several threads must be made reentrant. This might require changes to the function interface or to the implementation.

Functions that access global state, like memory or files, have reentrance problems. These functions need to protect their use of global state with the appropriate synchronization mechanisms provided by threads.

The two basic strategies for making functions in modules reentrant are code locking and data locking.

Code Locking

Code locking is done at the function call level and guarantees that a function executes entirely under the protection of a lock. The assumption is that all access to data is done through functions. Functions that share data should execute under the same lock.

Some parallel programming languages provide a construct called a monitor that implicitly does code locking for functions that are defined within the scope of the monitor. A monitor can also be implemented by a mutex lock.

Functions under the protection of the same mutex lock or within the same monitor are guaranteed to execute atomically with respect to each other.

Data Locking

Data locking guarantees that access to a collection of data is maintained consistently. For data locking, the concept of locking code is still there, but code locking is around references to shared (global) data, only. For a mutual exclusion locking protocol, only one thread can be in the critical section for each collection of data.

Alternatively, in a multiple readers, single writer protocol, several readers can be allowed for each collection of data or one writer. Multiple threads can execute in a single module when they operate on different data collections and do not conflict on a single collection for the multiple readers, single writer protocol. So, data locking typically allows more concurrency than does code locking. (Note that Solaris threads has “Readers / Writer Lock” functionality built in.)

What strategy should you use when using locks (whether implemented with mutexes, condition variables, or semaphores) in a program? Should you try to achieve maximum parallelism by locking only when necessary and unlocking as soon as possible (*fine-grained locking*)? Or should you hold locks for long periods to minimize the overhead of taking and releasing them (*coarse-grained locking*)?

The granularity of the lock depends on the amount of data it protects. A very coarse-grained lock might be a single lock to protect all data. Dividing how the data is protected by the appropriate number of locks is very important. Too fine a grain of locking can degrade performance. The small cost associated with acquiring and releasing locks can add up when there are too many locks.

The common wisdom is to start with a coarse-grained approach, identify bottlenecks, and add finer-grained locking where necessary to alleviate the bottlenecks. This is reasonably sound advice, but use your own judgment about taking it to the extreme.

Invariants

For both code locking and data locking, *invariants* are important to control locking complexity. An invariant is a condition or relation that is always true.

The definition is modified somewhat for concurrent execution: an invariant is a condition or relation that is true when the associated lock is being set. Once the lock is set, the invariant can be false. However, the code holding the lock must reestablish the invariant before releasing the lock.

An invariant can also be a condition or relation that is true when a lock is being set. Condition variables can be thought of as having an invariant that is the condition.

Code Example 10-4 Testing the Invariant With `assert`(3X)

```
    mutex_lock(&lock);
    while((condition)==FALSE)
        cond_wait(&cv,&lock);
    assert((condition)==TRUE);
      .
      .
      .
    mutex_unlock(&lock);
```

The `assert()` statement is testing the invariant. The `cond_wait()` function does not preserve the invariant, which is why the invariant must be re-evaluated when the thread returns.

Another example is a module that manages a doubly linked list of elements. For each item on the list a good invariant is the forward pointer of the previous item on the list that should also point to the same thing as the backward pointer of the forward item.

Assume this module uses code-based locking and therefore is protected by a single global mutex lock. When an item is deleted or added the mutex lock is acquired, the correct manipulation of the pointers is made, and the mutex lock is released. Obviously, at some point in the manipulation of the pointers the invariant is false, but the invariant is reestablished before the mutex lock is released.

Avoiding Deadlock

Deadlock is a permanent blocking of a set of threads that are competing for a set of resources. Just because some thread can make progress does not mean that there is not a deadlock somewhere else.

The most common error causing deadlock is *self deadlock* or *recursive deadlock*: a thread tries to acquire a lock it is already holding. Recursive deadlock is very easy to program by mistake.

For example, if a code monitor has every module function grabbing the mutex lock for the duration of the call, then any call between the functions within the module protected by the mutex lock immediately deadlocks. If a function calls some code outside the module which, through some circuitous path, calls back into any method protected by the same mutex lock, then it will deadlock too.

The solution for this kind of deadlock is to avoid calling functions outside the module when you don't know whether they will call back into the module without reestablishing invariants and dropping all module locks before making the call. Of course, after the call completes and the locks are reacquired, the state must be verified to be sure the intended operation is still valid.

An example of another kind of deadlock is when two threads, thread 1 and thread 2, each acquires a mutex lock, A and B, respectively. Suppose that thread 1 tries to acquire mutex lock B and thread 2 tries to acquire mutex lock A. Thread 1 cannot proceed and it is blocked waiting for mutex lock B. Thread 2 cannot proceed and it is blocked waiting for mutex lock A. Nothing can change, so this is a permanent blocking of the threads, and a deadlock.

This kind of deadlock is avoided by establishing an order in which locks are acquired (a *lock hierarchy*). When all threads always acquire locks in the specified order, this deadlock is avoided.

Adhering to a strict order of lock acquisition is not always optimal. When thread 2 has many assumptions about the state of the module while holding mutex lock B, giving up mutex lock B to acquire mutex lock A and then reacquiring mutex lock B in order would cause it to discard its assumptions and reevaluate the state of the module.

The blocking synchronization primitives usually have variants that attempt to get a lock and fail if they cannot, such as `mutex_trylock()`. This allows threads to violate the lock hierarchy when there is no contention. When there is contention, the held locks must usually be discarded and the locks reacquired in order.

Deadlocks Related to Scheduling

Because there is no guaranteed order in which locks are acquired, a problem in threaded programs is that a particular thread never acquires a lock, even though it seems that it should.

This usually happens when the thread that holds the lock releases it, lets a small amount of time pass, and then reacquires it. Because the lock was released, it might seem that the other thread should acquire the lock. But, because nothing blocks the thread holding the lock, it continues to run from the time it releases the lock until it reacquires the lock, and so no other thread is run.

You can usually solve this type of problem by calling `thr_yield(3T)` just before the call to reacquire the lock. This allows other threads to run and to acquire the lock.

Because the time-slice requirements of applications are so variable, the threads library does not impose any. Use calls to `thr_yield()` to make threads share time as you require.

Locking Guidelines

Here are some simple guidelines for locking.

- Try not to hold locks across long operations like I/O where performance can be adversely affected.
- Don't hold locks when calling a function that is outside the module and that might reenter the module.
- In general, start with a coarse-grained approach, identify bottlenecks, and add finer-grained locking where necessary to alleviate the bottlenecks. Most locks are held for short amounts of time and contention is rare, so fix only those locks that have measured contention.
- When using multiple locks, avoid deadlocks by making sure that all threads acquire the locks in the same order.

Following Some Basic Guidelines

- Know what you are importing and whether it is safe.

  A threaded program cannot arbitrarily enter nonthreaded code.
- Threaded code can safely refer to unsafe code only from the initial thread.

  This ensures that the static storage associated with the initial thread is used only by that thread.
- Sun-supplied libraries are defined to be *safe* unless explicitly documented as unsafe.

  If a reference manual entry does not say whether a function is MT-Safe, it is safe. All MT-unsafe functions are identified explicitly in the manual page.

- Use compilation flags to manage binary incompatible source changes. (See Chapter 7, “Compiling and Debugging” for complete instructions.)
  - `-D_REENTRANT` enables multithreading with the Solaris threads `-lthread` library
  - `-D_POSIX_C_SOURCE` with `-lpthread` gives POSIX threads behavior
  - `-D_POSIX_PTHREADS_SEMANTICS` with `-lthread` gives both Solaris threads and pthreads interfaces with a preference given to the POSIX interfaces when the two interfaces conflict.
- When making a library safe for multithreaded use, do not thread global process operations.

  Do not change global operations (or actions with global side effects) to behave in a threaded manner. For example, if file I/O is changed to per-thread operation, threads cannot cooperate in accessing files.

  For thread-specific behavior, or *thread cognizant* behavior, use thread facilities. For example, when the termination of `main()` should terminate only the thread that is exiting `main()`, the end of `main()` should be:

```
thr_exit();
/*NOTREACHED*/
```

Creating and Using Threads

The threads packages will cache the threads data structure, stacks, and LWPs so that the repetitive creation of unbound threads can be inexpensive.

Unbound thread creation is very inexpensive when compared to process creation or even to bound thread creation. In fact, the cost is similar to unbound thread synchronization when you include the context switches to stop one thread and start another.

So, creating and destroying threads as they are required is usually better than attempting to manage a pool of threads that wait for independent work.

A good example of this is an RPC server that creates a thread for each request and destroys it when the reply is delivered, instead of trying to maintain a pool of threads to service requests.

While thread creation is relatively inexpensive when compared to process creation, it is not inexpensive when compared to the cost of a few instructions. Create threads for processing that lasts at least a couple of thousand machine instructions.

Lightweight Processes

Figure 10-1 Multithreading Levels and Relationships.

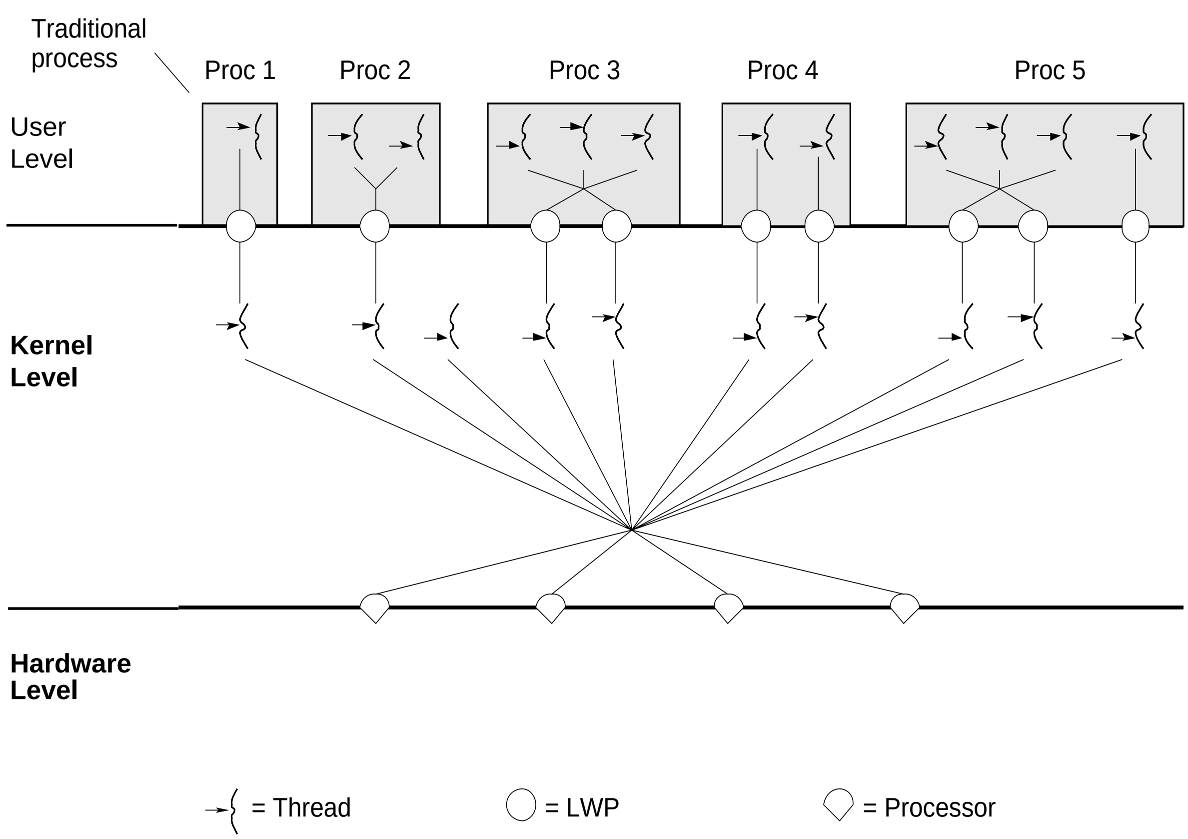


Figure 10-1 illustrates the relationship between LWPs and the user and kernel levels.

The user-level threads library, with help from the programmer and the operating system, ensures that the number of LWPs available is adequate for the currently active user-level threads. However, there is no one-to-one mapping between user threads and LWPs, and user-level threads can freely migrate from one LWP to another.

With Solaris threads, a programmer can tell the threads library how many threads should be “running” at the same time.

For example, if the programmer says that up to three threads should run at the same time, then at least three LWPs should be available. If there are three available processors, the threads run in parallel. If there is only one processor, then the operating system multiplexes the three LWPs on that one processor. If all the LWPs block, the threads library adds another LWP to the pool.

When a user thread blocks due to synchronization, its LWP transfers to another runnable thread. This transfer is done with a coroutine linkage and not with a system call.

The operating system decides which LWP should run on which processor and when. It has no knowledge about what user threads are or how many are active in each process.

The kernel schedules LWPs onto CPU resources according to their scheduling classes and priorities. The threads library schedules threads on the process pool of LWPs in much the same way.

Each LWP is independently dispatched by the kernel, performs independent system calls, incurs independent page faults, and runs in parallel on a multiprocessor system.

An LWP has some capabilities that are not exported directly to threads, such as a special scheduling class.

Unbound Threads

The library invokes LWPs as needed and assigns them to execute runnable threads. The LWP assumes the state of the thread and executes its instructions. If the thread becomes blocked on a synchronization mechanism, or if another thread should be run, the thread state is saved in process memory and the threads library assigns another thread to the LWP to run.

Bound Threads

Sometimes having more threads than LWPs, as can happen with unbound threads, is a disadvantage.

For example, a parallel array computation divides the rows of its arrays among different threads. If there is one LWP for each processor, but multiple threads for each LWP, each processor spends time switching between threads. In this case, it is better to have one thread for each LWP, divide the rows among a smaller number of threads, and reduce the number of thread switches.

A mixture of threads that are permanently bound to LWPs and unbound threads is also appropriate for some applications.

An example of this is a realtime application that has some threads with system-wide priority and realtime scheduling, and other threads that attend to background computations. Another example is a window system with unbound threads for most operations and a mouse serviced by a high-priority, bound, realtime thread.

When a user-level thread issues a system call, the LWP running the thread calls into the kernel and remains attached to the thread at least until the system call completes.

Bound threads are more expensive than unbound threads. Because bound threads can change the attributes of the underlying LWP, the LWPs are not cached when the bound threads exit. Instead, the operating system provides a new LWP when a bound thread is created and destroys it when the bound thread exits.

Use bound threads only when a thread needs resources that are available only through the underlying LWP, such as a virtual time interval timer or an alternate stack, or when the thread must be visible to the kernel to be scheduled with respect to all other active threads in the system, as in realtime scheduling.

Use unbound threads even when you expect all threads to be active simultaneously. This allows Solaris threads to efficiently cache LWP and thread resources so that thread creation and destruction are fast. Use `thr_setconcurrency(3T)` to tell Solaris threads how many threads you expect to be simultaneously active.

Thread Concurrency (Solaris Threads, Only)

By default, Solaris threads attempts to adjust the system execution resources (LWPs) used to run unbound threads to match the real number of active threads. While the Solaris threads package cannot make perfect decisions, it at least ensures that the process continues to make progress.

When you have some idea of the number of unbound threads that should be simultaneously active (executing code or system calls), tell the library through `thr_setconcurrency`(3T).

For example:

- A database server that has a thread for each user should tell Solaris threads the expected number of simultaneously active users.
- A window server that has one thread for each client should tell Solaris threads the expected number of simultaneously active clients.
- A file copy program that has one reader thread and one writer thread should tell Solaris threads that the desired concurrency level is two.

Alternatively, the concurrency level can be incremented by one through the `THR_NEW_LWP` flag as each thread is created.

Include unbound threads blocked on interprocess (`USYNC_PROCESS`) synchronization variables as active when you compute thread concurrency. Exclude bound threads—they do not require concurrency support from Solaris threads because they are equivalent to LWPs.

Efficiency

A new thread is created with `thr_create`(3T) in less time than an existing thread can be restarted. This means that it is more efficient to create a new thread when one is needed and have it call `thr_exit`(3T) when it has completed its task than it would be to stockpile an idle thread and restart it.

Thread Creation Guidelines

Here are some simple guidelines for using threads.

- Use threads for independent activities that must do a meaningful amount of work.
- Use Solaris threads to take advantage of CPU concurrency.
- Use bound threads only when absolutely necessary, that is, when some facility of the underlying LWP is required.

Working With Multiprocessors

Multithreading lets you take advantage of multiprocessors, primarily through parallelism and scalability. Programmers should be aware of the differences between the memory models of a multiprocessor and a uniprocessor.

Memory consistency is always from the viewpoint of the processor interrogating memory. For uniprocessors, memory is obviously consistent because there is only one processor viewing memory.

To improve multiprocessor performance, memory consistency is relaxed.You cannot always assume that changes made to memory by one processor are immediately reflected in the other processors' views of that memory.

You can avoid this complexity by using synchronization variables when you use shared or global variables.

Barrier synchronization is sometimes an efficient way to control parallelism on multiprocessors. An example of barriers can be found in Appendix A, "Solaris Threads Example: barrier.c."

Another multiprocessor issue is efficient synchronization when threads must wait until all have reached a common point in their execution.

Note – The issues discussed here are not important when the threads synchronization primitives are *always* used to access shared memory locations.

The Underlying Architecture

When threads synchronize access to shared storage locations using the threads synchronization routines, the effect of running a program on a shared-memory multiprocessor is identical to the effect of running the program on a uniprocessor.

However, in many situations a programmer might be tempted to take advantage of the multiprocessor and use “tricks” to avoid the synchronization routines. As Code Example 10-5 and Code Example 10-6 show, such tricks can be dangerous.

Understanding the memory models supported by common multiprocessor architectures helps to understand the dangers.

The major multiprocessor components are:

- The *processors* themselves
- *Store buffers*, which connect the processors to their caches
- *Caches*, which hold the contents of recently accessed or modified storage locations
- *memory*, which is the primary storage (and is shared by all processors).

In the simple traditional model, the multiprocessor behaves as if the processors are connected directly to memory: when one processor stores into a location and another immediately loads from the same location, the second processor loads what was stored by the first.

Caches can be used to speed the average memory access, and the desired semantics can be achieved when the caches are kept consistent with one another.

A problem with this simple approach is that the processor must often be delayed to make certain that the desired semantics are achieved. Many modern multiprocessors use various techniques to prevent such delays, which, unfortunately, change the semantics of the memory model.

Two of these techniques and their effects are explained in the next two examples.

"Shared-Memory" Multiprocessors

Consider the purported solution to the producer/consumer problem shown in Code Example 10-5.

Although this program works on current SPARC-based multiprocessors, it assumes that all multiprocessors have strongly ordered memory. This program is therefore not portable.

Code Example 10-5 The Producer/Consumer Problem—Shared Memory Multiprocessors

```
                    char buffer[BSIZE];
                    unsigned int in = 0;
                    unsigned int out = 0;

void                                char
producer(char item) {                 consumer(void) {
                                       char item;
    do
        ;/* nothing */                   do
    while                                    ;/* nothing */
        (in - out == BSIZE);              while
                                           (in - out == 0);
    buffer[in%BSIZE] = item;              item = buffer[out%BSIZE];
    in++;                                out++;
}                                   }
```

When this program has exactly one producer and exactly one consumer and is run on a shared-memory multiprocessor, it appears to be correct. The difference between `in` and `out` is the number of items in the buffer.

The producer waits (by repeatedly computing this difference) until there is room for a new item, and the consumer waits until there is an item in the buffer.

For memory that is *strongly ordered* (for instance, a modification to memory on one processor is immediately available to the other processors), this solution is correct (it is correct even taking into account that `in` and `out` will eventually overflow, as long as `BSIZE` is less than the largest integer that can be represented in a word).

Shared-memory multiprocessors do not necessarily have strongly ordered memory. A change to memory by one processor is not necessarily available immediately to the other processors. When two changes to different memory locations are made by one processor, the other processors do not necessarily see the changes in the order in which they were made because changes to memory don't happen immediately.

First the changes are stored in *store buffers* that are not visible to the cache.

The processor looks at these store buffers to ensure that a program has a consistent view, but because store buffers are not visible to other processors, a write by one processor doesn't become visible until it is written to cache.

The synchronization primitives (see Chapter 4, "Programming With Synchronization Objects") use special instructions that flush the store buffers to cache. So, using locks around your shared data ensures memory consistency.

When memory ordering is very relaxed, Code Example 10-5 has a problem because the consumer might see that `in` has been incremented by the producer before it sees the change to the corresponding buffer slot.

This is called *weak ordering* because stores made by one processor can appear to happen out of order by another processor (memory, however, is always consistent from the same processor). To fix this, the code should use mutexes to flush the cache.

The trend is toward relaxing memory order. Because of this, programmers are becoming increasingly careful to use locks around all global or shared data.

As demonstrated by Code Example 10-5 and Code Example 10-6, locking is essential.

Peterson's Algorithm

The code in Code Example 10-6 is an implementation of Peterson's Algorithm, which handles mutual exclusion between two threads. This code tries to guarantee that there is never more than one thread in the critical section and that, when a thread calls `mut_excl`(), it enters the critical section sometime "soon."

An assumption here is that a thread exits fairly quickly after entering the critical section.

Code Example 10-6 Mutual Exclusion for Two Threads?

```
void mut_excl(int me /* 0 or 1 */) {
    static int loser;
    static int interested[2] = {0, 0};
    int other; /* local variable */

    other = 1 - me;
    interested[me] = 1;
    loser = me;
    while (loser == me && interested[other])
        ;

    /* critical section */
    interested[me] = 0;
}
```

This algorithm works some of the time when it is assumed that the multiprocessor has strongly ordered memory.

Some multiprocessors, including some SPARC-based multiprocessors, have store buffers. When a thread issues a store instruction, the data is put into a store buffer. The buffer contents are eventually sent to the cache, but not necessarily right away. (Note that the caches on each of the processors maintain a consistent view of memory, but modified data does not reach the cache right away.)

When multiple memory locations are stored into, the changes reach the cache (and memory) in the correct order, but possibly after a delay. SPARC-based multiprocessors with this property are said to have *total store order* (TSO).

When one processor stores into location *A* and then loads from location *B*, and another processor stores into location *B* and loads from location *A*, the expectation is that either the first processor fetches the newly modified value in location *B* or the second processor fetches the newly modified value in location *A*, or both, but that the case in which both processors load the old values simply cannot happen.

However, with the delays caused by load and store buffers, the “impossible case” can happen.

What could happen with Peterson's algorithm is that two threads running on separate processors each stores into its own slot of the interested array and then loads from the other slot. They both see the old values (0), assume that the other party is not present, and both enter the critical section. (Note that this is the sort of problem that might not show up when you test a program, but only much later.)

This problem is avoided when you use the threads synchronization primitives, whose implementations issue special instructions to force the writing of the store buffers to the cache.

Parallelizing a Loop on a Shared-Memory Parallel Computer

In many applications, and especially numerical applications, while part of the algorithm can be parallelized, other parts are inherently sequential (as shown in Code Example 10-7).

Code Example 10-7 Multithreaded Cooperation (Barrier Synchronization)

Thread$_1$	**Thread$_2$ through Thread$_n$**

`while(many_iterations) {`
 	
`    sequential_computation`
`    --- Barrier ---`
`    parallel_computation`
`}`
	`while(many_iterations) {`
	
	`    --- Barrier ---`
	`    parallel_computation`
	`}`

For example, you might produce a set of matrices with a strictly linear computation, then perform operations on the matrices using a parallel algorithm, then use the results of these operations to produce another set of matrices, then operate on them in parallel, and so on.

The nature of the parallel algorithms for such a computation is that little synchronization is required during the computation, but synchronization of all the threads employed is required to ensure that the sequential computation is finished before the parallel computation begins.

The barrier forces all the threads that are doing the parallel computation to wait until all threads involved have reached the barrier. When they've reached the barrier, they are released and begin computing together.

Summary

This guide has covered a wide variety of important threads programming issues. Look in Appendix A, "Sample Application – Multithreaded grep" for a pthreads program example that uses many of the features and styles that have been discussed. Look in Appendix A, "Solaris Threads Example: barrier.c" for a program example that uses Solaris threads.

Further Reading

For more in-depth information about multithreading, see the following book:

- *Programming with Threads* by Steve Kleiman, Devang Shah, and Bart Smaalders (Prentice-Hall, to be published in 1995)

Sample Application – Multithreaded `grep` — A

Description of `tgrep`

The `tgrep` sample program is a multithreaded version of `find`(1) combined with `grep`(1). `tgrep` supports all but the `-w` (word search) options of the normal `grep`, and a few exclusively available options.

By default, the `tgrep` searches are like the following command:

`find . -exec grep [` *options* `]` *pattern* `{} \;`

For large directory hierarchies, `tgrep` gets results more quickly than the `find` command, depending on the number of processors available. On uniprocessor machines it is about twice as fast, and on four processor machines it is about four times as fast.

The `-e` option changes the way `tgrep` interprets the pattern string. Ordinarily (without the `-e` option) `tgrep` uses a literal string match. With the `-e` option, `tgrep` uses an MT-Safe public domain version of a regular expression handler. The regular expression method is slower.

The `-B` option tells `tgrep` to use the value of the environment variable called TGLIMIT to limit the number of threads it will use during a search. This option has no affect if TGLIMIT is not set. Because `tgrep` can use a lot of system resources, this is a way to run it politely on a timesharing system.

A

Getting Online Source Code

Source for tgrep is included on the Catalyst Developer’s CD. Contact your sales representative to find out how you can get a copy.

A copy might also be available on the World Wide Web (WWW) at the following URL:

http://www.sun.com/sunsoft/Products/Developer-products/sig/threads/

Only the multithreaded main.c module appears here. Other modules, including those for regular expression handling, plus documentation and Makefiles, might be available from the sources listed above.

Code Example A-1 Source Code for tgrep Program

```
/* Copyright (c) 1993, 1994  Ron Winacott                           */
/* This program may be used, copied, modified, and redistributed freely */
/* for ANY purpose, so long as this notice remains intact.           */

#define _REENTRANT

#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <assert.h>
#include <errno.h>
#include <ctype.h>
#include <sys/types.h>
#include <time.h>
#include <sys/stat.h>
#include <dirent.h>

#include "version.h"

#include <fcntl.h>
#include <sys/uio.h>
#include <pthread.h>
#include <sched.h>

#ifdef MARK
#include <prof.h> /* to turn on MARK(), use -DMARK to compile (see man prof5)*/
#endif

#include "pmatch.h"
```

Code Example A-1 Source Code for `tgrep` Program

```
#define PATH_MAX                1024 /* max # of characters in a path name */
#define HOLD_FDS                6  /* stdin,out,err and a buffer */
#define UNLIMITED               99999 /* The default tglimit */
#define MAXREGEXP               10  /* max number of -e options */

#define FB_BLOCK                0x00001
#define FC_COUNT                0x00002
#define FH_HOLDNAME             0x00004
#define FI_IGNCASE              0x00008
#define FL_NAMEONLY             0x00010
#define FN_NUMBER               0x00020
#define FS_NOERROR              0x00040
#define FV_REVERSE              0x00080
#define FW_WORD                 0x00100
#define FR_RECUR                0x00200
#define FU_UNSORT               0x00400
#define FX_STDIN                0x00800
#define TG_BATCH                0x01000
#define TG_FILEPAT              0x02000
#define FE_REGEXP               0x04000
#define FS_STATS                0x08000
#define FC_LINE                 0x10000
#define TG_PROGRESS             0x20000

#define FILET                   1
#define DIRT                    2

typedef struct work_st {
    char                *path;
    int                 tp;
    struct work_st      *next;
} work_t;

typedef struct out_st {
    char                *line;
    int                 line_count;
    long                byte_count;
    struct out_st       *next;
} out_t;

#define ALPHASIZ        128
typedef struct bm_pattern {     /* Boyer - Moore pattern                */
        short            p_m;           /* length of pattern string     */
```

Code Example A-1 Source Code for `tgrep` Program

```
        short            p_r[ALPHASIZ]; /* "r" vector                   */
        short           *p_R;           /* "R" vector                   */
        char            *p_pat;         /* pattern string               */
} BM_PATTERN;

/* bmpmatch.c */
extern BM_PATTERN *bm_makepat(char *p);
extern char *bm_pmatch(BM_PATTERN *pat, register char *s);
extern void bm_freepat(BM_PATTERN *pattern);
BM_PATTERN      *bm_pat;  /* the global target read only after main */

/* pmatch.c */
extern char *pmatch(register PATTERN *pattern, register char *string, int *len);
extern PATTERN *makepat(char *string, char *metas);
extern void freepat(register PATTERN *pat);
extern void printpat(PATTERN *pat);
PATTERN         *pm_pat[MAXREGEXP];  /* global targets read only for pmatch */

#include "proto.h"  /* function prototypes of main.c */

/* local functions to POSIX only */
void pthread_setconcurrency_np(int con);
int pthread_getconcurrency_np(void);
void pthread_yield_np(void);

pthread_attr_t  detached_attr;
pthread_mutex_t output_print_lk;
pthread_mutex_t global_count_lk;

int             global_count = 0;

work_t          *work_q = NULL;
pthread_cond_t  work_q_cv;
pthread_mutex_t work_q_lk;
pthread_mutex_t debug_lock;

#include "debug.h"  /* must be included AFTER the
                        mutex_t debug_lock line */

work_t          *search_q = NULL;
pthread_mutex_t search_q_lk;
pthread_cond_t  search_q_cv;
int             search_pool_cnt = 0;    /* the count in the pool now */
int             search_thr_limit = 0;   /* the max in the pool */
```

Code Example A-1 Source Code for `tgrep` Program

```
work_t          *cascade_q = NULL;
pthread_mutex_t cascade_q_lk;
pthread_cond_t  cascade_q_cv;
int             cascade_pool_cnt = 0;
int             cascade_thr_limit = 0;

int             running = 0;
pthread_mutex_t running_lk;

pthread_mutex_t stat_lk;
time_t          st_start = 0;
int             st_dir_search = 0;
int             st_file_search = 0;
int             st_line_search = 0;
int             st_cascade = 0;
int             st_cascade_pool = 0;
int             st_cascade_destroy = 0;
int             st_search = 0;
int             st_pool = 0;
int             st_maxrun = 0;
int             st_worknull = 0;
int             st_workfds = 0;
int             st_worklimit = 0;
int             st_destroy = 0;

int             all_done = 0;
int             work_cnt = 0;
int             current_open_files = 0;
int             tglimit = UNLIMITED;    /* if -B limit the number of
                                   threads */
int             progress_offset = 1;
int             progress = 0;  /* protected by the print_lock ! */
unsigned int    flags = 0;
int             regexp_cnt = 0;
char            *string[MAXREGEXP];
int             debug = 0;
int             use_pmatch = 0;
char            file_pat[255];  /* file patten match */
PATTERN         *pm_file_pat; /* compiled file target string (pmatch()) */

/*
 * Main: This is where the fun starts
 */
```

Code Example A-1 Source Code for `tgrep` Program

```
int
main(int argc, char **argv)
{
    int         c,out_thr_flags;
    long        max_open_files = 0l, ncpus = 0l;
    extern int  optind;
    extern char *optarg;
    int         prio = 0;
    struct stat sbuf;
    pthread_t tid,dtid;
    void        *status;
    char        *e = NULL, *d = NULL; /* for debug flags */
    int         debug_file = 0;
    struct sigaction sigact;
    sigset_t    set,oset;
    int         err = 0, i = 0, pm_file_len = 0;
    work_t      *work;
    int         restart_cnt = 10;

    /* NO OTHER THREADS ARE RUNNING */
    flags = FR_RECUR;  /* the default */

    while ((c = getopt(argc, argv, "d:e:bchilnsvwruf:p:BCSZzHP:")) != EOF) {
        switch (c) {
#ifdef DEBUG
        case 'd':
            debug = atoi(optarg);
            if (debug == 0)
                debug_usage();

            d = optarg;
            fprintf(stderr,"tgrep: Debug on at level(s) ");
            while (*d) {
                for (i=0; i<9; i++)
                    if (debug_set[i].level == *d) {
                        debug_levels |= debug_set[i].flag;
                        fprintf(stderr,"%c ",debug_set[i].level);
                        break;
                    }
                d++;
            }
            fprintf(stderr,"\n");
            break;
        case 'f': debug_file = atoi(optarg); break;
```

Code Example A-1 Source Code for `tgrep` Program

```
#endif      /* DEBUG */

        case 'B':
            flags |= TG_BATCH;
#ifndef __lock_lint
        /* locklint complains here, but there are no other threads */
            if ((e = getenv("TGLIMIT"))) {
                tglimit = atoi(e);
            }
            else {
                if (!(flags & FS_NOERROR))  /* order dependent! */
                    fprintf(stderr,"env TGLIMIT not set, overriding -B\n");
                flags &= ~TG_BATCH;
            }
#endif
            break;
        case 'p':
            flags |= TG_FILEPAT;
            strcpy(file_pat,optarg);
            pm_file_pat = makepat(file_pat,NULL);
            break;
        case 'P':
            flags |= TG_PROGRESS;
            progress_offset = atoi(optarg);
            break;
        case 'S': flags |= FS_STATS;    break;
        case 'b': flags |= FB_BLOCK;    break;
        case 'c': flags |= FC_COUNT;    break;
        case 'h': flags |= FH_HOLDNAME; break;
        case 'i': flags |= FI_IGNCASE;  break;
        case 'l': flags |= FL_NAMEONLY; break;
        case 'n': flags |= FN_NUMBER;   break;
        case 's': flags |= FS_NOERROR;  break;
        case 'v': flags |= FV_REVERSE;  break;
        case 'w': flags |= FW_WORD;     break;
        case 'r': flags &= ~FR_RECUR;   break;
        case 'C': flags |= FC_LINE;     break;
        case 'e':
            if (regexp_cnt == MAXREGEXP) {
                fprintf(stderr,"Max number of regexp's (%d) exceeded!\n",
                        MAXREGEXP);
                exit(1);
            }
            flags |= FE_REGEXP;
```

Code Example A-1 Source Code for `tgrep` Program

```
            if ((string[regexp_cnt] =(char *)malloc(strlen(optarg)+1))==NULL){
                fprintf(stderr,"tgrep: No space for search string(s)\n");
                exit(1);
            }
            memset(string[regexp_cnt],0,strlen(optarg)+1);
            strcpy(string[regexp_cnt],optarg);
            regexp_cnt++;
            break;
        case 'z':
        case 'Z': regexp_usage();
            break;
        case 'H':
        case '?':
        default : usage();
        }
    }
    if (flags & FS_STATS)
        st_start = time(NULL);

    if (!(flags & FE_REGEXP)) {
       if (argc - optind < 1) {
            fprintf(stderr,"tgrep: Must supply a search string(s) "
                    "and file list or directory\n");
            usage();
        }
        if ((string[0]=(char *)malloc(strlen(argv[optind])+1))==NULL){
            fprintf(stderr,"tgrep: No space for search string(s)\n");
            exit(1);
        }
        memset(string[0],0,strlen(argv[optind])+1);
        strcpy(string[0],argv[optind]);
        regexp_cnt=1;
        optind++;
    }

    if (flags & FI_IGNCASE)
        for (i=0; i<regexp_cnt; i++)
            uncase(string[i]);

    if (flags & FE_REGEXP) {
        for (i=0; i<regexp_cnt; i++)
            pm_pat[i] = makepat(string[i],NULL);
        use_pmatch = 1;
    }
```

Code Example A-1 Source Code for `tgrep` Program

```
    else {
        bm_pat = bm_makepat(string[0]); /* only one allowed */
    }

    flags |= FX_STDIN;


    max_open_files = sysconf(_SC_OPEN_MAX);
    ncpus = sysconf(_SC_NPROCESSORS_ONLN);
    if ((max_open_files - HOLD_FDS - debug_file) < 1) {
        fprintf(stderr,"tgrep: You MUST have at least ONE fd "
                "that can be used, check limit (>10)\n");
        exit(1);
    }
    search_thr_limit = max_open_files - HOLD_FDS - debug_file;
    cascade_thr_limit = search_thr_limit / 2;
    /* the number of files that can be open */
    current_open_files = search_thr_limit;

    pthread_attr_init(&detached_attr);
    pthread_attr_setdetachstate(&detached_attr,
        PTHREAD_CREATE_DETACHED);

    pthread_mutex_init(&global_count_lk,NULL);
    pthread_mutex_init(&output_print_lk,NULL);
    pthread_mutex_init(&work_q_lk,NULL);
    pthread_mutex_init(&running_lk,NULL);
    pthread_cond_init(&work_q_cv,NULL);
    pthread_mutex_init(&search_q_lk,NULL);
    pthread_cond_init(&search_q_cv,NULL);
    pthread_mutex_init(&cascade_q_lk,NULL);
    pthread_cond_init(&cascade_q_cv,NULL);

    if ((argc == optind) && ((flags & TG_FILEPAT) || (flags & FR_RECUR))) {
        add_work(".",DIRT);
        flags = (flags & ~FX_STDIN);
    }
    for ( ; optind < argc; optind++) {
        restart_cnt = 10;
        flags = (flags & ~FX_STDIN);
      STAT_AGAIN:
        if (stat(argv[optind], &sbuf)) {
            if (errno == EINTR) { /* try again !, restart */
                if (--restart_cnt)
```

Code Example A-1 Source Code for `tgrep` Program

```
                    goto STAT_AGAIN;
            }
            if (!(flags & FS_NOERROR))
                fprintf(stderr,"tgrep: Can't stat file/dir %s, %s\n",
                        argv[optind], strerror(errno));
            continue;
        }
        switch (sbuf.st_mode & S_IFMT) {
        case S_IFREG :
            if (flags & TG_FILEPAT) {
                if (pmatch(pm_file_pat, argv[optind], &pm_file_len))
                    DP(DLEVEL1,("File pat match %s\n",argv[optind]));
                    add_work(argv[optind],FILET);
            }
            else {
                add_work(argv[optind],FILET);
            }
            break;
        case S_IFDIR :
            if (flags & FR_RECUR) {
                add_work(argv[optind],DIRT);
            }
            else {
                if (!(flags & FS_NOERROR))
                    fprintf(stderr,"tgrep: Can't search directory %s, "
                            "-r option is on. Directory ignored.\n",
                            argv[optind]);
            }
            break;
        }
    }

    pthread_setconcurrency_np(3);

    if (flags & FX_STDIN) {
        fprintf(stderr,"tgrep: stdin option is not coded at this time\n");
        exit(0);                        /* XXX Need to fix this SOON */
        search_thr(NULL);
        if (flags & FC_COUNT) {
            pthread_mutex_lock(&global_count_lk);
            printf("%d\n",global_count);
            pthread_mutex_unlock(&global_count_lk);
        }
        if (flags & FS_STATS)
```

Code Example A-1 Source Code for tgrep Program

```
            prnt_stats();
        exit(0);
    }

    pthread_mutex_lock(&work_q_lk);
    if (!work_q) {
        if (!(flags & FS_NOERROR))
            fprintf(stderr,"tgrep: No files to search.\n");
        exit(0);
    }
    pthread_mutex_unlock(&work_q_lk);

    DP(DLEVEL1,("Starting to loop through the work_q for work\n"));

    /* OTHER THREADS ARE RUNNING */
    while (1) {
        pthread_mutex_lock(&work_q_lk);
        while ((work_q == NULL || current_open_files == 0 || tglimit <= 0) &&
               all_done == 0) {
            if (flags & FS_STATS) {
                pthread_mutex_lock(&stat_lk);
                if (work_q == NULL)
                    st_worknull++;
                if (current_open_files == 0)
                    st_workfds++;
                if (tglimit <= 0)
                    st_worklimit++;
                pthread_mutex_unlock(&stat_lk);
            }
            pthread_cond_wait(&work_q_cv,&work_q_lk);
        }
        if (all_done != 0) {
            pthread_mutex_unlock(&work_q_lk);
            DP(DLEVEL1,("All_done was set to TRUE\n"));
            goto OUT;
        }
        work = work_q;
        work_q = work->next;  /* maybe NULL */
        work->next = NULL;
        current_open_files--;
        pthread_mutex_unlock(&work_q_lk);

        tid = 0;
        switch (work->tp) {
```

Code Example A-1 Source Code for `tgrep` Program

```
        case DIRT:
            pthread_mutex_lock(&cascade_q_lk);
            if (cascade_pool_cnt) {
                if (flags & FS_STATS) {
                    pthread_mutex_lock(&stat_lk);
                    st_cascade_pool++;
                    pthread_mutex_unlock(&stat_lk);
                }
                work->next = cascade_q;
                cascade_q = work;
                pthread_cond_signal(&cascade_q_cv);
                pthread_mutex_unlock(&cascade_q_lk);
                DP(DLEVEL2,("Sent work to cascade pool thread\n"));
            }
            else {
                pthread_mutex_unlock(&cascade_q_lk);
                err = pthread_create(&tid,&detached_attr,cascade,(void *)work);
                DP(DLEVEL2,("Sent work to new cascade thread\n"));
                if (flags & FS_STATS) {
                    pthread_mutex_lock(&stat_lk);
                    st_cascade++;
                    pthread_mutex_unlock(&stat_lk);
                }
            }
            break;
        case FILET:
            pthread_mutex_lock(&search_q_lk);
            if (search_pool_cnt) {
                if (flags & FS_STATS) {
                    pthread_mutex_lock(&stat_lk);
                    st_pool++;
                    pthread_mutex_unlock(&stat_lk);
                }
                work->next = search_q;  /* could be null */
                search_q = work;
                pthread_cond_signal(&search_q_cv);
                pthread_mutex_unlock(&search_q_lk);
                DP(DLEVEL2,("Sent work to search pool thread\n"));
            }
            else {
                pthread_mutex_unlock(&search_q_lk);
                err = pthread_create(&tid,&detached_attr,
                                     search_thr,(void *)work);
                pthread_setconcurrency_np(pthread_getconcurrency_np()+1);
```

Code Example A-1 Source Code for `tgrep` Program

```
                 DP(DLEVEL2,("Sent work to new search thread\n"));
                 if (flags & FS_STATS) {
                     pthread_mutex_lock(&stat_lk);
                     st_search++;
                     pthread_mutex_unlock(&stat_lk);
                 }
             }
             break;
         default:
             fprintf(stderr,"tgrep: Internal error, work_t->tp not valid\n");
             exit(1);
         }
         if (err) {  /* NEED TO FIX THIS CODE. Exiting is just wrong */
             fprintf(stderr,"Could not create new thread!\n");
             exit(1);
         }
     }

 OUT:
     if (flags & TG_PROGRESS) {
         if (progress)
             fprintf(stderr,".\n");
         else
             fprintf(stderr,"\n");
     }
     /* we are done, print the stuff. All other threads are parked */
     if (flags & FC_COUNT) {
         pthread_mutex_lock(&global_count_lk);
         printf("%d\n",global_count);
         pthread_mutex_unlock(&global_count_lk);
     }
     if (flags & FS_STATS)
         prnt_stats();
     return(0); /* should have a return from main */
}

/*
 * Add_Work: Called from the main thread, and cascade threads to add file
 * and directory names to the work Q.
 */
int
add_work(char *path,int tp)
{
    work_t      *wt,*ww,*wp;
```

Code Example A-1 Source Code for `tgrep` Program

```
    if ((wt = (work_t *)malloc(sizeof(work_t))) == NULL)
        goto ERROR;
    if ((wt->path = (char *)malloc(strlen(path)+1)) == NULL)
        goto ERROR;

    strcpy(wt->path,path);
    wt->tp = tp;
    wt->next = NULL;
    if (flags & FS_STATS) {
        pthread_mutex_lock(&stat_lk);
        if (wt->tp == DIRT)
            st_dir_search++;
        else
            st_file_search++;
        pthread_mutex_unlock(&stat_lk);
    }
    pthread_mutex_lock(&work_q_lk);
    work_cnt++;
    wt->next = work_q;
    work_q = wt;
    pthread_cond_signal(&work_q_cv);
    pthread_mutex_unlock(&work_q_lk);
    return(0);
 ERROR:
    if (!(flags & FS_NOERROR))
        fprintf(stderr,"tgrep: Could not add %s to work queue. Ignored\n",
                path);
    return(-1);
}

/*
 * Search thread: Started by the main thread when a file name is found
 * on the work Q to be serached. If all the needed resources are ready
 * a new search thread will be created.
 */
void *
search_thr(void *arg) /* work_t *arg */
{
    FILE        *fin;
    char        fin_buf[(BUFSIZ*4)];  /* 4 Kbytes */
    work_t      *wt,std;
    int         line_count;
    char        rline[128];
```

Code Example A-1 Source Code for `tgrep` Program

```
    char        cline[128];
    char        *line;
    register char *p,*pp;
    int            pm_len;
    int         len = 0;
    long        byte_count;
    long        next_line;
    int         show_line;  /* for the -v option */
    register int slen,plen,i;
    out_t       *out = NULL;    /* this threads output list */

    pthread_yield_np();
    wt = (work_t *)arg; /* first pass, wt is passed to use. */

    /* len = strlen(string);*/  /* only set on first pass */

    while (1) {  /* reuse the search threads */
        /* init all back to zero */
        line_count = 0;
        byte_count = 0l;
        next_line = 0l;
        show_line = 0;

        pthread_mutex_lock(&running_lk);
        running++;
        pthread_mutex_unlock(&running_lk);
        pthread_mutex_lock(&work_q_lk);
        tglimit--;
        pthread_mutex_unlock(&work_q_lk);
        DP(DLEVEL5,("searching file (STDIO) %s\n",wt->path));

        if ((fin = fopen(wt->path,"r")) == NULL) {
            if (!(flags & FS_NOERROR)) {
                fprintf(stderr,"tgrep: %s. File \"%s\" not searched.\n",
                        strerror(errno),wt->path);
            }
            goto ERROR;
        }
        setvbuf(fin,fin_buf,_IOFBF,(BUFSIZ*4));  /* XXX */
        DP(DLEVEL5,("Search thread has opened file %s\n",wt->path));
        while ((fgets(rline,127,fin)) != NULL) {
            if (flags & FS_STATS) {
                pthread_mutex_lock(&stat_lk);
                st_line_search++;
```

Code Example A-1 Source Code for `tgrep` Program

```
            pthread_mutex_unlock(&stat_lk);
        }
        slen = strlen(rline);
        next_line += slen;
        line_count++;
        if (rline[slen-1] == '\n')
            rline[slen-1] = '\0';
        /*
        ** If the uncase flag is set, copy the read in line (rline)
        ** To the uncase line (cline) Set the line pointer to point at
        ** cline.
        ** If the case flag is NOT set, then point line at rline.
        ** line is what is compared, rline is what is printed on a
        ** match.
        */
        if (flags & FI_IGNCASE) {
            strcpy(cline,rline);
            uncase(cline);
            line = cline;
        }
        else {
            line = rline;
        }
        show_line = 1;  /* assume no match, if -v set */
        /* The old code removed */
        if (use_pmatch) {
            for (i=0; i<regexp_cnt; i++) {
                if (pmatch(pm_pat[i], line, &pm_len)) {
                    if (!(flags & FV_REVERSE)) {
                        add_output_local(&out,wt,line_count,
                                         byte_count,rline);
                        continue_line(rline,fin,out,wt,
                                      &line_count,&byte_count);
                    }
                    else {
                        show_line = 0;
                    } /* end of if -v flag if / else block */
                    /*
                    ** if we get here on ANY of the regexp targets
                    ** jump out of the loop, we found a single
                    ** match so do not keep looking!
                    ** If name only, do not keep searcthing the same
                    ** file, we found a single match, so close the file,
                    ** print the file name and move on to the next file.
```

Code Example A-1 Source Code for `tgrep` Program

```
                         */
                         if (flags & FL_NAMEONLY)
                             goto OUT_OF_LOOP;
                         else
                             goto OUT_AND_DONE;
                     } /* end found a match if block */
                 } /* end of the for pat[s] loop */
             }
             else {
                 if (bm_pmatch( bm_pat, line)) {
                     if (!(flags & FV_REVERSE)) {
                         add_output_local(&out,wt,line_count,byte_count,rline);
                         continue_line(rline,fin,out,wt,
                                       &line_count,&byte_count);
                     }
                     else {
                         show_line = 0;
                     }
                     if (flags & FL_NAMEONLY)
                         goto OUT_OF_LOOP;
                 }
             }
           OUT_AND_DONE:
             if ((flags & FV_REVERSE) && show_line) {
                 add_output_local(&out,wt,line_count,byte_count,rline);
                 show_line = 0;
             }
             byte_count = next_line;
         }
       OUT_OF_LOOP:
         fclose(fin);
         /*
         ** The search part is done, but before we give back the FD,
         ** and park this thread in the search thread pool, print the
         ** local output we have gathered.
         */
         print_local_output(out,wt);  /* this also frees out nodes */
         out = NULL; /* for the next time around, if there is one */
     ERROR:
         DP(DLEVEL5,("Search done for %s\n",wt->path));
         free(wt->path);
         free(wt);

         notrun();
```

Code Example A-1 Source Code for `tgrep` Program

```
        pthread_mutex_lock(&search_q_lk);
        if (search_pool_cnt > search_thr_limit) {
            pthread_mutex_unlock(&search_q_lk);
            DP(DLEVEL5,("Search thread exiting\n"));
            if (flags & FS_STATS) {
                pthread_mutex_lock(&stat_lk);
                st_destroy++;
                pthread_mutex_unlock(&stat_lk);
            }
            return(0);
        }
        else {
            search_pool_cnt++;
            while (!search_q)
                pthread_cond_wait(&search_q_cv,&search_q_lk);
            search_pool_cnt--;
            wt = search_q;  /* we have work to do! */
            if (search_q->next)
                search_q = search_q->next;
            else
                search_q = NULL;
            pthread_mutex_unlock(&search_q_lk);
        }
    }
    /*NOTREACHED*/
}

/*
 * Continue line: Special case search with the -C flag set. If you are
 * searching files like Makefiles, some lines might have escape char's to
 * contine the line on the next line. So the target string can be found, but
 * no data is displayed. This function continues to print the escaped line
 * until there are no more "\" chars found.
 */
int
continue_line(char *rline, FILE *fin, out_t *out, work_t *wt,
              int *lc, long *bc)
{
    int len;
    int cnt = 0;
    char *line;
    char nline[128];

    if (!(flags & FC_LINE))
```

Code Example A-1 Source Code for `tgrep` Program

```
        return(0);

    line = rline;
  AGAIN:
    len = strlen(line);
    if (line[len-1] == '\\') {
        if ((fgets(nline,127,fin)) == NULL) {
            return(cnt);
        }
        line = nline;
        len = strlen(line);
        if (line[len-1] == '\n')
            line[len-1] = '\0';
        *bc = *bc + len;
        *lc++;
        add_output_local(&out,wt,*lc,*bc,line);
        cnt++;
        goto AGAIN;
    }
    return(cnt);
}

/*
 * cascade: This thread is started by the main thread when directory names
 * are found on the work Q. The thread reads all the new file, and directory
 * names from the directory it was started when and adds the names to the
 * work Q. (it finds more work!)
 */

void *
cascade(void *arg)  /* work_t *arg */
{
    char        fullpath[1025];
    int         restart_cnt = 10;
    DIR         *dp;

    char        dir_buf[sizeof(struct dirent) + PATH_MAX];
    struct dirent *dent = (struct dirent *)dir_buf;
    struct stat   sbuf;
    char        *fpath;
    work_t      *wt;
    int         fl = 0, dl = 0;
    int         pm_file_len = 0;
```

Code Example A-1 Source Code for `tgrep` Program

```
    pthread_yield_np();  /* try toi give control back to main thread */
    wt = (work_t *)arg;

    while(1) {
        fl = 0;
        dl = 0;
        restart_cnt = 10;
        pm_file_len = 0;

        pthread_mutex_lock(&running_lk);
        running++;
        pthread_mutex_unlock(&running_lk);
        pthread_mutex_lock(&work_q_lk);
        tglimit--;
        pthread_mutex_unlock(&work_q_lk);

        if (!wt) {
            if (!(flags & FS_NOERROR))
                fprintf(stderr,"tgrep: Bad work node passed to cascade\n");
            goto DONE;
        }
        fpath = (char *)wt->path;
        if (!fpath) {
            if (!(flags & FS_NOERROR))
                fprintf(stderr,"tgrep: Bad path name passed to cascade\n");
            goto DONE;
        }
        DP(DLEVEL3,("Cascading on %s\n",fpath));
        if (( dp = opendir(fpath)) == NULL) {
            if (!(flags & FS_NOERROR))
                fprintf(stderr,"tgrep: Can't open dir %s, %s. Ignored.\n",
                        fpath,strerror(errno));
            goto DONE;
        }
        while ((readdir_r(dp,dent)) != NULL) {
            restart_cnt = 10;  /* only try to restart the interupted 10 X */

            if (dent->d_name[0] == '.') {
                if (dent->d_name[1] == '.' && dent->d_name[2] == '\0')
                    continue;
                if (dent->d_name[1] == '\0')
                    continue;
            }
```

Code Example A-1 Source Code for `tgrep` Program

```
            fl = strlen(fpath);
            dl = strlen(dent->d_name);
            if ((fl + 1 + dl) > 1024) {
                fprintf(stderr,"tgrep: Path %s/%s is too long. "
                        "MaxPath = 1024\n",
                        fpath, dent->d_name);
                continue;  /* try the next name in this directory */
            }
            strcpy(fullpath,fpath);
            strcat(fullpath,"/");
            strcat(fullpath,dent->d_name);

          RESTART_STAT:
            if (stat(fullpath,&sbuf)) {
                if (errno == EINTR) {
                    if (--restart_cnt)
                        goto RESTART_STAT;
                }
                if (!(flags & FS_NOERROR))
                    fprintf(stderr,"tgrep: Can't stat file/dir %s, %s. "
                            "Ignored.\n",
                            fullpath,strerror(errno));
                goto ERROR;
            }

            switch (sbuf.st_mode & S_IFMT) {
            case S_IFREG :
                if (flags & TG_FILEPAT) {
                    if (pmatch(pm_file_pat, dent->d_name, &pm_file_len)) {
                        DP(DLEVEL3,("file pat match (cascade) %s\n",
                                    dent->d_name));
                        add_work(fullpath,FILET);
                    }
                }
                else {
                    add_work(fullpath,FILET);
                    DP(DLEVEL3,("cascade added file (MATCH) %s to Work Q\n",
                                fullpath));
                }
                break;

            case S_IFDIR :
                DP(DLEVEL3,("cascade added dir %s to Work Q\n",fullpath));
                add_work(fullpath,DIRT);
```

Code Example A-1 Source Code for `tgrep` Program

```
                break;
            }
        }

      ERROR:
        closedir(dp);

      DONE:
        free(wt->path);
        free(wt);
        notrun();
        pthread_mutex_lock(&cascade_q_lk);
        if (cascade_pool_cnt > cascade_thr_limit) {
            pthread_mutex_unlock(&cascade_q_lk);
            DP(DLEVEL5,("Cascade thread exiting\n"));
            if (flags & FS_STATS) {
                pthread_mutex_lock(&stat_lk);
                st_cascade_destroy++;
                pthread_mutex_unlock(&stat_lk);
            }
            return(0); /* pthread_exit */
        }
        else {
            DP(DLEVEL5,("Cascade thread waiting in pool\n"));
            cascade_pool_cnt++;
            while (!cascade_q)
                pthread_cond_wait(&cascade_q_cv,&cascade_q_lk);
            cascade_pool_cnt--;
            wt = cascade_q;  /* we have work to do! */
            if (cascade_q->next)
                cascade_q = cascade_q->next;
            else
                cascade_q = NULL;
            pthread_mutex_unlock(&cascade_q_lk);
        }
    }
    /*NOTREACHED*/
}

/*
 * Print Local Output: Called by the search thread after it is done searching
 * a single file. If any oputput was saved (matching lines), the lines are
 * displayed as a group on stdout.
 */
```

Code Example A-1 Source Code for `tgrep` Program

```
int
print_local_output(out_t *out, work_t *wt)
{
    out_t       *pp, *op;
    int         out_count = 0;
    int         printed = 0;

    pp = out;
    pthread_mutex_lock(&output_print_lk);
    if (pp && (flags & TG_PROGRESS)) {
        progress++;
        if (progress >= progress_offset) {
            progress = 0;
            fprintf(stderr,".");
        }
    }
    while (pp) {
        out_count++;
        if (!(flags & FC_COUNT)) {
            if (flags & FL_NAMEONLY) {  /* Pint name ONLY ! */
                if (!printed) {
                    printed = 1;
                    printf("%s\n",wt->path);
                }
            }
            else {  /* We are printing more then just the name */
                if (!(flags & FH_HOLDNAME))
                    printf("%s :",wt->path);
                if (flags & FB_BLOCK)
                    printf("%ld:",pp->byte_count/512+1);
                if (flags & FN_NUMBER)
                    printf("%d:",pp->line_count);
                printf("%s\n",pp->line);
            }
        }
        op = pp;
        pp = pp->next;
        /* free the nodes as we go down the list */
        free(op->line);
        free(op);
    }

    pthread_mutex_unlock(&output_print_lk);
    pthread_mutex_lock(&global_count_lk);
```

Code Example A-1 Source Code for `tgrep` Program

```
    global_count += out_count;
    pthread_mutex_unlock(&global_count_lk);
    return(0);
}

/*
 * add output local: is called by a search thread as it finds matching lines.
 * the matching line, its byte offset, line count, etc. are stored until the
 * search thread is done searching the file, then the lines are printed as
 * a group. This way the lines from more then a single file are not mixed
 * together.
 */

int
add_output_local(out_t **out, work_t *wt,int lc, long bc, char *line)
{
    out_t       *ot,*oo, *op;

    if (( ot = (out_t *)malloc(sizeof(out_t))) == NULL)
        goto ERROR;
    if (( ot->line = (char *)malloc(strlen(line)+1)) == NULL)
        goto ERROR;

    strcpy(ot->line,line);
    ot->line_count = lc;
    ot->byte_count = bc;

    if (!*out) {
        *out = ot;
        ot->next = NULL;
        return(0);
    }
    /* append to the END of the list; keep things sorted! */
    op = oo = *out;
    while(oo) {
        op = oo;
        oo = oo->next;
    }
    op->next = ot;
    ot->next = NULL;
    return(0);

 ERROR:
    if (!(flags & FS_NOERROR))
```

Code Example A-1 Source Code for tgrep Program

```
        fprintf(stderr,"tgrep: Output lost. No space. "
                "[%s: line %d byte %d match : %s\n",
                wt->path,lc,bc,line);
    return(1);
}

/*
 * print stats: If the -S flag is set, after ALL files have been searched,
 * main thread calls this function to print the stats it keeps on how the
 * search went.
 */

void
prnt_stats(void)
{
    float a,b,c;
    float t = 0.0;
    time_t  st_end = 0;
    char    tl[80];

    st_end = time(NULL); /* stop the clock */
    printf("\n----------------- Tgrep Stats. --------------------\n");
    printf("Number of directories searched:           %d\n",st_dir_search);
    printf("Number of files searched:                 %d\n",st_file_search);
    c = (float)(st_dir_search + st_file_search) / (float)(st_end - st_start);
    printf("Dir/files per second:                     %3.2f\n",c);
    printf("Number of lines searched:                 %d\n",st_line_search);
    printf("Number of matching lines to target:       %d\n",global_count);

    printf("Number of cascade threads created:        %d\n",st_cascade);
    printf("Number of cascade threads from pool:      %d\n",st_cascade_pool);
    a = st_cascade_pool; b = st_dir_search;
    printf("Cascade thread pool hit rate:             %3.2f%%\n",((a/b)*100));
    printf("Cascade pool overall size:                %d\n",cascade_pool_cnt);
    printf("Cascade pool size limit:                 %d\n",cascade_thr_limit);
   printf("Number of cascade threads destroyed:      %d\n",st_cascade_destroy);

    printf("Number of search threads created:         %d\n",st_search);
    printf("Number of search threads from pool:       %d\n",st_pool);
    a = st_pool; b = st_file_search;
    printf("Search thread pool hit rate:              %3.2f%%\n",((a/b)*100));
    printf("Search pool overall size:                 %d\n",search_pool_cnt);
    printf("Search pool size limit:                   %d\n",search_thr_limit);
    printf("Number of search threads destroyed:       %d\n",st_destroy);
```

Code Example A-1 Source Code for `tgrep` Program

```
    printf("Max # of threads running concurrenly:     %d\n",st_maxrun);
    printf("Total run time, in seconds.               %d\n",
           (st_end - st_start));

    /* Why did we wait ? */
    a = st_workfds; b = st_dir_search+st_file_search;
    c = (a/b)*100; t += c;
    printf("Work stopped due to no FD's:  (%.3d)       %d Times, %3.2f%%\n",
           search_thr_limit,st_workfds,c);
    a = st_worknull; b = st_dir_search+st_file_search;
    c = (a/b)*100; t += c;
    printf("Work stopped due to no work on Q:         %d Times, %3.2f%%\n",
           st_worknull,c);
    if (tglimit == UNLIMITED)
        strcpy(tl,"Unlimited");
    else
        sprintf(tl,"   %.3d   ",tglimit);
    a = st_worklimit; b = st_dir_search+st_file_search;
    c = (a/b)*100; t += c;
    printf("Work stopped due to TGLIMIT:  (%.9s) %d Times, %3.2f%%\n",
           tl,st_worklimit,c);
    printf("Work continued to be handed out:          %3.2f%%\n",100.00-t);
    printf("----------------------------------------------------\n");
}
/*
 * not running: A glue function to track if any search threads or cascade
 * threads are running. When the count is zero, and the work Q is NULL,
 * we can safely say, WE ARE DONE.
 */
void
notrun (void)
{
    pthread_mutex_lock(&work_q_lk);
    work_cnt--;
    tglimit++;
    current_open_files++;
    pthread_mutex_lock(&running_lk);
    if (flags & FS_STATS) {
        pthread_mutex_lock(&stat_lk);
        if (running > st_maxrun) {
            st_maxrun = running;
            DP(DLEVEL6,("Max Running has increased to %d\n",st_maxrun));
        }
```

Code Example A-1 Source Code for `tgrep` Program

```
        pthread_mutex_unlock(&stat_lk);
    }
    running--;
    if (work_cnt == 0 && running == 0) {
        all_done = 1;
        DP(DLEVEL6,("Setting ALL_DONE flag to TRUE.\n"));
    }
    pthread_mutex_unlock(&running_lk);
    pthread_cond_signal(&work_q_cv);
    pthread_mutex_unlock(&work_q_lk);
}

/*
 * uncase: A glue function. If the -i (case insensitive) flag is set, the
 * target strng and the read in line is converted to lower case before
 * comparing them.
 */
void
uncase(char *s)
{
    char        *p;

    for (p = s; *p != NULL; p++)
        *p = (char)tolower(*p);
}

/*
 * usage: Have to have one of these.
 */

void
usage(void)
{
    fprintf(stderr,"usage: tgrep <options> pattern <{file,dir}>...\n");
    fprintf(stderr,"\n");
    fprintf(stderr,"Where:\n");
#ifdef DEBUG
    fprintf(stderr,"Debug     -d = debug level -d <levels> (-d0 for usage)\n");
    fprintf(stderr,"Debug     -f = block fd's from use (-f #)\n");
#endif
    fprintf(stderr,"          -b = show block count (512 byte block)\n");
    fprintf(stderr,"          -c = print only a line count\n");
    fprintf(stderr,"          -h = Do NOT print file names\n");
    fprintf(stderr,"          -i = case insensitive\n");
```

Code Example A-1 Source Code for `tgrep` Program

```
    fprintf(stderr,"          -l = print file name only\n");
    fprintf(stderr,"          -n = print the line number with the line\n");
    fprintf(stderr,"          -s = Suppress error messages\n");
    fprintf(stderr,"          -v = print all but matching lines\n");
#ifdef NOT_IMP
    fprintf(stderr,"          -w = search for a \"word\"\n");
#endif
    fprintf(stderr,"          -r = Do not search for files in all "
                                "sub-directories\n");
    fprintf(stderr,"          -C = show continued lines (\"\\\")\n");
    fprintf(stderr,"          -p = File name regexp pattern. (Quote it)\n");
    fprintf(stderr,"          -P = show progress. -P 1 prints a DOT on stderr\n"
                  "               for each file it finds, -P 10 prints a DOT\n"
                "             on stderr for each 10 files it finds, etc...\n");
    fprintf(stderr,"          -e = expression search.(regexp) More then one\n");
    fprintf(stderr,"          -B = limit the number of threads to TGLIMIT\n");
    fprintf(stderr,"          -S = Print thread stats when done.\n");
    fprintf(stderr,"          -Z = Print help on the regexp used.\n");
    fprintf(stderr,"\n");
    fprintf(stderr,"Notes:\n");
    fprintf(stderr,"      If you start tgrep with only a directory name\n");
    fprintf(stderr,"     and no file names, you must not have the -r option\n");
    fprintf(stderr,"      set or you will get no output.\n");
    fprintf(stderr,"      To search stdin (piped input), you must set -r\n");
    fprintf(stderr,"      Tgrep will search ALL files in ALL \n");
    fprintf(stderr,"      sub-directories. (like */* */*/* */*/*/* etc..)\n");
    fprintf(stderr,"      if you supply a directory name.\n");
    fprintf(stderr,"      If you do not supply a file, or directory name,\n");
    fprintf(stderr,"      and the -r option is not set, the current \n");
    fprintf(stderr,"      directory \".\" will be used.\n");
    fprintf(stderr,"      All the other options should work \"like\" grep\n");
    fprintf(stderr,"      The -p patten is regexp; tgrep will search only\n");
    fprintf(stderr,"      the file names that match the patten\n");
    fprintf(stderr,"\n");
    fprintf(stderr,"      Tgrep Version %s\n",Tgrep_Version);
    fprintf(stderr,"\n");
    fprintf(stderr,"      Copy Right By Ron Winacott, 1993-1995.\n");
    fprintf(stderr,"\n");
    exit(0);
}

/*
 * regexp usage: Tell the world about tgrep custom (THREAD SAFE) regexp!
 */
```

Code Example A-1 Source Code for `tgrep` Program

```
int
regexp_usage (void)
{
    fprintf(stderr,"usage: tgrep <options> -e \"pattern\" <-e ...> "
            "<{file,dir}>...\n");
    fprintf(stderr,"\n");
    fprintf(stderr,"metachars:\n");
    fprintf(stderr,"    . - match any character\n");
    fprintf(stderr,"    * - match 0 or more occurrences of previous char\n");
    fprintf(stderr,"    + - match 1 or more occurrences of previous char.\n");
    fprintf(stderr,"    ^ - match at beginning of string\n");
    fprintf(stderr,"    $ - match end of string\n");
    fprintf(stderr,"    [ - start of character class\n");
    fprintf(stderr,"    ] - end of character class\n");
    fprintf(stderr,"    ( - start of a new pattern\n");
    fprintf(stderr,"    ) - end of a new pattern\n");
    fprintf(stderr,"    @(n)c - match <c> at column <n>\n");
    fprintf(stderr,"    | - match either pattern\n");
    fprintf(stderr,"    \\ - escape any special characters\n");
    fprintf(stderr,"    \\c - escape any special characters\n");
    fprintf(stderr,"    \\o - turn on any special characters\n");
    fprintf(stderr,"\n");
    fprintf(stderr,"To match two diffrerent patterns in the same command\n");
    fprintf(stderr,"Use the or function. \n"
            "ie: tgrep -e \"(pat1)|(pat2)\" file\n"
            "This will match any line with \"pat1\" or \"pat2\" in it.\n");
    fprintf(stderr,"You can also use up to %d -e expressions\n",MAXREGEXP);
    fprintf(stderr,"RegExp Pattern matching brought to you by Marc Staveley\n");
    exit(0);
}

/*
 * debug usage: If compiled with -DDEBUG, turn it on, and tell the world
 * how to get tgrep to print debug info on different threads.
 */

#ifdef DEBUG
void
debug_usage(void)
{
    int i = 0;

    fprintf(stderr,"DEBUG usage and levels:\n");
    fprintf(stderr,"--------------------------------------------------\n");
```

Code Example A-1 Source Code for `tgrep` Program

```
    fprintf(stderr,"Level                  code\n");
    fprintf(stderr,"--------------------------------------------------\n");
    fprintf(stderr,"0                 This message.\n");
    for (i=0; i<9; i++) {
        fprintf(stderr,"%d                 %s\n",i+1,debug_set[i].name);
    }
    fprintf(stderr,"--------------------------------------------------\n");
    fprintf(stderr,"You can or the levels together like -d134 for levels\n");
    fprintf(stderr,"1 and 3 and 4.\n");
    fprintf(stderr,"\n");
    exit(0);
}
#endif

/* Pthreads NP functions */

#ifdef __sun
void
pthread_setconcurrency_np(int con)
{
    thr_setconcurrency(con);
}

int
pthread_getconcurrency_np(void)
{
    return(thr_getconcurrency());
}

void
pthread_yield_np(void)
{
/*    In Solaris 2.4, these functions always return - 1 and set errno to ENOSYS */
    if (sched_yield())  /* call UI interface if we are older then 2.5 */
        thr_yield();
}

#else
void
pthread_setconcurrency_np(int con)
{
    return;
}
```

Code Example A-1 Source Code for `tgrep` Program

```
int
pthread_getconcurrency_np(void)
{
    return(0);
}

void
pthread_yield_np(void)
{
    return;
}
#endif
```

Solaris Threads Example: barrier.c

B

The `barrier.c` program demonstrates an implementation of a barrier for Solaris threads. (See page 244 for a definition of barriers.)

Code Example A-1 Solaris Threads Example: `barrier.c`

```
#define _REENTRANT

/* Include Files        */

#include<thread.h>
#include<errno.h>

/* Constants & Macros   *

/* Data Declarations    */

typedef struct {
        int     maxcnt;                 /* maximum number of runners    */
        struct _sb {
                cond_t  wait_cv;        /* cv for waiters at barrier    */
                mutex_t wait_lk;        /* mutex for waiters at barrier */
                int     runners;        /* number of running threads    */
        } sb[2];
        struct _sb      *sbp;           /* current sub-barrier          */
} barrier_t;
```

Code Example A-1 Solaris Threads Example: `barrier.c`

```
/*
 * barrier_init - initialize a barrier variable.
 *
 */

int
barrier_init( barrier_t *bp, int count, int type, void *arg ) {
        int n;
        int i;

        if (count < 1)
                return(EINVAL);

        bp->maxcnt = count;
        bp->sbp = &bp->sb[0];

        for (i = 0; i < 2; ++i) {
#if defined(__cplusplus)
                struct barrier_t::_sb *sbp = &( bp->sb[i] );
#else
                struct _sb *sbp = &( bp->sb[i] );
#endif
                sbp->runners = count;

                if (n = mutex_init(&sbp->wait_lk, type, arg))
                        return(n);

                if (n = cond_init(&sbp->wait_cv, type, arg))
                        return(n);
        }
        return(0);
}

/*
 * barrier_wait - wait at a barrier for everyone to arrive.
 *
 */

int
barrier_wait(register barrier_t *bp) {
#if defined(__cplusplus)
        register struct barrier_t::_sb *sbp = bp->sbp;
#else
        register struct _sb *sbp = bp->sbp;
```

Code Example A-1 Solaris Threads Example: barrier.c

```
#endif

        mutex_lock(&sbp->wait_lk);

        if (sbp->runners == 1) {      /* last thread to reach barrier */
                if (bp->maxcnt != 1) {
                        /* reset runner count and switch sub-barriers   */
                        sbp->runners = bp->maxcnt;
                        bp->sbp = (bp->sbp == &bp->sb[0])
            ? &bp->sb[1] : &bp->sb[0];

                        /* wake up the waiters          */
                        cond_broadcast(&sbp->wait_cv);
                }
        } else {
                sbp->runners--;         /* one less runner              */

                while (sbp->runners != bp->maxcnt)
                        cond_wait( &sbp->wait_cv, &sbp->wait_lk);
        }

        mutex_unlock(&sbp->wait_lk);

        return(0);
}

/*
 * barrier_destroy - destroy a barrier variable.
 *
 */

        int
barrier_destroy(barrier_t *bp) {
        int     n;
        int     i;

        for (i=0; i < 2; ++ i) {
                if (n = cond_destroy(&bp->sb[i].wait_cv))
                        return( n );

                if (n = mutex_destroy( &bp->sb[i].wait_lk))
                        return(n);
        }
```

Code Example A-1 Solaris Threads Example: `barrier.c`

```
        return(0);
}


#define NTHR    4
#define NCOMPUTATION 2
#define NITER   1000
#define NSQRT   1000

        void *
compute(barrier_t *ba )
{
    int count = NCOMPUTATION;

    while (count--) {
    barrier_wait( ba );
    /* do parallel computation */
    }
}

main( int argc, char *argv[] ) {
        int             i;
        int             niter;
        int             nthr;
        barrier_t       ba;
        double          et;
        thread_t        *tid;

        switch ( argc ) {
          default:
          case 3 :      niter   = atoi( argv[1] );
                        nthr    = atoi( argv[2] );
                        break;

          case 2 :      niter   = atoi( argv[1] );
                        nthr    = NTHR;
                        break;

          case 1 :      niter   = NITER;
                        nthr    = NTHR;
                        break;
        }

        barrier_init( &ba, nthr + 1, USYNC_THREAD, NULL );
```

Code Example A-1 Solaris Threads Example: `barrier.c`

```
        tid = (thread_t *) calloc(nthr, sizeof(thread_t));

        for (i = 0; i < nthr; ++i) {
                int     n;

             if (n = thr_create(NULL, 0, (void *(*)( void *)) compute, &ba,NULL, &tid[i])) {
                        errno = n;
                        perror("thr_create");
                        exit(1);
                }
        }

    for (i = 0; i < NCOMPUTATION; i++) {
        barrier_wait(&ba );
    /* do parallel algorithm */
    }

    for (i = 0; i < nthr; i++) {
    thr_join(tid[i], NULL, NULL);
    }

}
```

MT Safety Levels: Library Interfaces C

Table C-1 lists the safety levels for interfaces from Section 3 of the *man Pages(3): Library Routines* (see “MT Interface Safety Levels” on page 151 for explanations of the safety categories).

Table B-1 MT Safety Levels of Library Routines

`a64l(3C)`	MT-Safe
`abort(3C)`	Safe
`abs(3C)`	MT-Safe
`accept(3N)`	Safe
`acos(3M)`	MT-Safe
`acosh(3M)`	MT-Safe
`addch(3X)`	Unsafe
`addchnstr(3X)`	Unsafe
`addchstr(3X)`	Unsafe
`addnstr(3X)`	Unsafe
`addnwstr(3X)`	Unsafe
`addsev(3C)`	MT-safe
`addseverity(3C)`	Safe
`addstr(3X)`	Unsafe
`addwch(3X)`	Unsafe
`addwchnstr(3X)`	Unsafe
`addwchstr(3X)`	Unsafe
`addwstr(3X)`	Unsafe
`adjcurspos(3X)`	Unsafe
`advance(3G)`	MT-Safe

Table B-1 MT Safety Levels of Library Routines

aiocancel(3)	Unsafe
aioread(3)	Unsafe
aiowait(3)	Unsafe
aiowrite(3)	Unsafe
aio_cancel(3R)	MT-Safe
aio_error(3R)	Async-Signal-Safe
aio_fsync(3R)	MT-Safe
aio_read(3R)	MT-Safe
aio_return(3R)	Async-Signal-Safe
aio_suspend(3R)	Async-Signal-Safe
aio_write(3R)	MT-Safe
alloca(3C)	Safe
arc(3)	Safe
ascftime(3C)	MT-Safe
asctime(3C)	Unsafe, use asctime_r()
asin(3M)	MT-Safe
asinh(3M)	MT-Safe
assert(3C)	Safe
atan(3M)	MT-Safe
atan2(3M)	MT-Safe
atanh(3M)	MT-Safe
atexit(3C)	Safe
atof(3C)	MT-Safe
atoi(3C)	MT-Safe
atol(3C)	MT-Safe
atoll(3C)	MT-Safe
attroff(3X)	Unsafe
attron(3X)	Unsafe
attrset(3X)	Unsafe
authdes_create(3N)	Unsafe
authdes_getucred(3N)	MT-Safe
authdes_seccreate(3N)	MT-Safe
authkerb_getucred(3N)	Unsafe
authkerb_seccreate(3N)	Unsafe
authnone_create(3N)	MT-Safe
authsys_create(3N)	MT-Safe
authsys_create_default(3N)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

authunix_create(3N)	Unsafe
authunix_create_default(3N)	Unsafe
auth_destroy(3N)	MT-Safe
au_close(3)	Safe
au_open(3)	Safe
au_user_mask(3)	MT-Safe
au_write(3)	Safe
basename(3G)	MT-Safe
baudrate(3X)	Unsafe
beep(3X)	Unsafe
bessel(3M)	MT-Safe
bgets(3G)	MT-Safe
bind(3N)	Safe
bindtextdomain(3I)	Safe with exceptions
bkgd(3X)	Unsafe
bkgdset(3X)	Unsafe
border(3X)	Unsafe
bottom_panel(3X)	Unsafe
box(3)	Safe
box(3X)	Unsafe
bsearch(3C)	Safe
bufsplit(3G)	MT-Safe
byteorder(3N)	Safe
calloc(3C)	Safe
calloc(3X)	Safe
callrpc(3N)	Unsafe
cancellation(3T)	MT-Safe
can_change_color(3X)	Unsafe
catclose(3C)	MT-Safe
catgets(3C)	MT-Safe
catopen(3C)	MT-Safe
cbc_crypt(3)	MT-Safe
cbreak(3X)	Unsafe
cbrt(3M)	MT-Safe
ceil(3M)	MT-Safe
cfgetispeed(3)	MT-Safe, Async-Signal-Safe
cfgetospeed(3)	MT-Safe, Async-Signal-Safe

Table B-1 MT Safety Levels of Library Routines

`cfree(3X)`	Safe
`cfsetispeed(3)`	MT-Safe, Async-Signal-Safe
`cfsetospeed(3)`	MT-Safe, Async-Signal-Safe
`cftime(3C)`	MT-Safe
`circle(3)`	Safe
`clear(3X)`	Unsafe
`clearerr(3S)`	MT-Safe
`clearok(3X)`	Unsafe
`clntraw_create(3N)`	Unsafe
`clnttcp_create(3N)`	Unsafe
`clntudp_bufcreate(3N)`	Unsafe
`clntudp_create(3N)`	Unsafe
`clnt_broadcast(3N)`	Unsafe
`clnt_call(3N)`	MT-Safe
`clnt_control(3N)`	MT-Safe
`clnt_create(3N)`	MT-Safe
`clnt_create_timed(3N)`	MT-Safe
`clnt_create_vers(3N)`	MT-Safe
`clnt_destroy(3N)`	MT-Safe
`clnt_dg_create(3N)`	MT-Safe
`clnt_freeres(3N)`	MT-Safe
`clnt_geterr(3N)`	MT-Safe
`clnt_pcreateerror(3N)`	MT-Safe
`clnt_perrno(3N)`	MT-Safe
`clnt_perror(3N)`	MT-Safe
`clnt_raw_create(3N)`	MT-Safe
`clnt_spcreateerror(3N)`	MT-Safe
`clnt_sperrno(3N)`	MT-Safe
`clnt_sperror(3N)`	MT-Safe
`clnt_tli_create(3N)`	MT-Safe
`clnt_tp_create(3N)`	MT-Safe
`clnt_tp_create_timed(3N)`	MT-Safe
`clnt_vc_create(3N)`	MT-Safe
`clock(3C)`	MT-Safe
`clock_gettime(3R)`	Async-Signal-Safe
`closedir(3C)`	Safe
`closelog(3)`	Safe

Table B-1 MT Safety Levels of Library Routines

closepl(3)	Safe
closevt(3)	Safe
clrtobot(3X)	Unsafe
clrtoeol(3X)	Unsafe
color_content(3X)	Unsafe
compile(3G)	MT-Safe
condition(3T)	MT-Safe
cond_broadcast(3T)	MT-Safe
cond_destroy(3T)	MT-Safe
cond_init(3T)	MT-Safe
cond_signal(3T)	MT-Safe
cond_timedwait(3T)	MT-Safe
cond_wait(3T)	MT-Safe
confstr(3C)	MT-Safe
connect(3N)	Safe
cont(3)	Safe
conv(3C)	MT-Safe with exceptions
copylist(3G)	MT-Safe
copysign(3M)	MT-Safe
copywin(3X)	Unsafe
cos(3M)	MT-Safe
cosh(3M)	MT-Safe
crypt(3C)	Safe
crypt(3X)	Unsafe
cset(3I)	MT-Safe with exceptions
csetcol(3I)	MT-Safe with exceptions
csetlen(3I)	MT-Safe with exceptions
csetno(3I)	MT-Safe with exceptions
ctermid(3S)	Unsafe, use ctermid_r()
ctime(3C)	Unsafe, use ctime_r()
ctype(3C)	MT-Safe with exceptions
current_field(3X)	Unsafe
current_item(3X)	Unsafe
curses(3X)	Unsafe
curs_addch(3X)	Unsafe
curs_addchstr(3X)	Unsafe
curs_addstr(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

curs_addwch(3X)	Unsafe
curs_addwchstr(3X)	Unsafe
curs_addwstr(3X)	Unsafe
curs_alecompat(3X)	Unsafe
curs_attr(3X)	Unsafe
curs_beep(3X)	Unsafe
curs_bkgd(3X)	Unsafe
curs_border(3X)	Unsafe
curs_clear(3X)	Unsafe
curs_color(3X)	Unsafe
curs_delch(3X)	Unsafe
curs_deleteln(3X)	Unsafe
curs_getch(3X)	Unsafe
curs_getstr(3X)	Unsafe
curs_getwch(3X)	Unsafe
curs_getwstr(3X)	Unsafe
curs_getyx(3X)	Unsafe
curs_inch(3X)	Unsafe
curs_inchstr(3X)	Unsafe
curs_initscr(3X)	Unsafe
curs_inopts(3X)	Unsafe
curs_insch(3X)	Unsafe
curs_insstr(3X)	Unsafe
curs_instr(3X)	Unsafe
curs_inswch(3X)	Unsafe
curs_inswstr(3X)	Unsafe
curs_inwch(3X)	Unsafe
curs_inwchstr(3X)	Unsafe
curs_inwstr(3X)	Unsafe
curs_kernel(3X)	Unsafe
curs_move(3X)	Unsafe
curs_outopts(3X)	Unsafe
curs_overlay(3X)	Unsafe
curs_pad(3X)	Unsafe
curs_printw(3X)	Unsafe
curs_refresh(3X)	Unsafe
curs_scanw(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

curs_scroll(3X)	Unsafe
curs_scr_dump(3X)	Unsafe
curs_set(3X)	Unsafe
curs_slk(3X)	Unsafe
curs_termattrs(3X)	Unsafe
curs_termcap(3X)	Unsafe
curs_terminfo(3X)	Unsafe
curs_touch(3X)	Unsafe
curs_util(3X)	Unsafe
curs_window(3X)	Unsafe
cuserid(3S)	MT-Safe
data_ahead(3X)	Unsafe
data_behind(3X)	Unsafe
dbm_clearerr(3)	Unsafe
dbm_close(3)	Unsafe
dbm_delete(3)	Unsafe
dbm_error(3)	Unsafe
dbm_fetch(3)	Unsafe
dbm_firstkey(3)	Unsafe
dbm_nextkey(3)	Unsafe
dbm_open(3)	Unsafe
dbm_store(3)	Unsafe
db_add_entry(3N)	Unsafe
db_checkpoint(3N)	Unsafe
db_create_table(3N)	Unsafe
db_destroy_table(3N)	Unsafe
db_first_entry(3N)	Unsafe
db_free_result(3N)	Unsafe
db_initialize(3N)	Unsafe
db_list_entries(3N)	Unsafe
db_next_entry(3N)	Unsafe
db_remove_entry(3N)	Unsafe
db_reset_next_entry(3N)	Unsafe
db_standby(3N)	Unsafe
db_table_exists(3N)	Unsafe
db_unload_table(3N)	Unsafe
dcgettext(3I)	Safe with exceptions

Table B-1 MT Safety Levels of Library Routines

decimal_to_double(3)	MT-Safe
decimal_to_extended(3)	MT-Safe
decimal_to_floating(3)	MT-Safe
decimal_to_quadruple(3)	MT-Safe
decimal_to_single(3)	MT-Safe
def_prog_mode(3X)	Unsafe
def_shell_mode(3X)	Unsafe
delay_output(3X)	Unsafe
delch(3X)	Unsafe
deleteln(3X)	Unsafe
delscreen(3X)	Unsafe
delwin(3X)	Unsafe
del_curterm(3X)	Unsafe
del_panel(3X)	Unsafe
derwin(3X)	Unsafe
des_crypt(3)	MT-Safe
DES_FAILED(3)	MT-Safe
des_failed(3)	MT-Safe
des_setparity(3)	MT-Safe
dgettext(3I)	Safe with exceptions
dial(3N)	Unsafe
difftime(3C)	MT-Safe
dirname(3G)	MT-Safe
div(3C)	MT-Safe
dladdr(3X)	MT-Safe
dlclose(3X)	MT-Safe
dlerror(3X)	MT-Safe
dlopen(3X)	MT-Safe
dlsym(3X)	MT-Safe
dn_comp(3N)	Unsafe
dn_expand(3N)	Unsafe
doconfig(3N)	Unsafe
double_to_decimal(3)	MT-Safe
doupdate(3X)	Unsafe
drand48(3C)	Safe
dup2(3C)	Unsafe, Async-Signal-Safe
dupwin(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

dup_field(3X)	Unsafe
dynamic_field_info(3X)	Unsafe
ecb_crypt(3)	MT-Safe
echo(3X)	Unsafe
echochar(3X)	Unsafe
echowchar(3X)	Unsafe
econvert(3)	MT-Safe
ecvt(3)	MT-Safe
ecvt(3C)	Unsafe
el(32_fsize.3E)	Unsafe
el(32_getehdr.3E)	Unsafe
el(32_getphdr.3E)	Unsafe
el(32_getshdr.3E)	Unsafe
el(32_newehdr.3E)	Unsafe
el(32_newphdr.3E)	Unsafe
el(32_xlatetof.3E)	Unsafe
el(32_xlatetom.3E)	Unsafe
elf(3E)	Unsafe
elf_begin(3E)	Unsafe
elf_cntl(3E)	Unsafe
elf_end(3E)	Unsafe
elf_errmsg(3E)	Unsafe
elf_errno(3E)	Unsafe
elf_fill(3E)	Unsafe
elf_flagdata(3E)	Unsafe
elf_flagehdr(3E)	Unsafe
elf_flagelf(3E)	Unsafe
elf_flagphdr(3E)	Unsafe
elf_flagscn(3E)	Unsafe
elf_flagshdr(3E)	Unsafe
elf_getarhdr(3E)	Unsafe
elf_getarsym(3E)	Unsafe
elf_getbase(3E)	Unsafe
elf_getdata(3E)	Unsafe
elf_getident(3E)	Unsafe
elf_getscn(3E)	Unsafe
elf_hash(3E)	Unsafe

Table B-1 MT Safety Levels of Library Routines

elf_kind(3E)	Unsafe
elf_memory(3E)	Unsafe
elf_ndxscn(3E)	Unsafe
elf_newdata(3E)	Unsafe
elf_newscn(3E)	Unsafe
elf_next(3E)	Unsafe
elf_nextscn(3E)	Unsafe
elf_rand(3E)	Unsafe
elf_rawdata(3E)	Unsafe
elf_rawfile(3E)	Unsafe
elf_strptr(3E)	Unsafe
elf_update(3E)	Unsafe
elf_version(3E)	Unsafe
encrypt(3C)	Safe
endac(3)	Safe
endauclass(3)	MT-Safe
endauevent(3)	MT-Safe
endauuser(3)	MT-Safe
endnetconfig(3N)	MT-Safe
endnetpath(3N)	MT-Safe
endutent(3C)	Unsafe
endutxent(3C)	Unsafe
endwin(3X)	Unsafe
erand48(3C)	Safe
erase(3)	Safe
erase(3X)	Unsafe
erasechar(3X)	Unsafe
erf(3M)	MT-Safe
erfc(3M)	MT-Safe
errno(3C)	MT-Safe
ethers(3N)	MT-Safe
ether_aton(3N)	MT-Safe
ether_hostton(3N)	MT-Safe
ether_line(3N)	MT-Safe
ether_ntoa(3N)	MT-Safe
ether_ntohost(3N)	MT-Safe
euccol(3I)	Safe

Table B-1 MT Safety Levels of Library Routines

euclen(3I)	Safe
eucscol(3I)	Safe
exit(3C)	Safe
exp(3M)	MT-Safe
expm1(3M)	MT-Safe
extended_to_decimal(3)	MT-Safe
fabs(3M)	MT-Safe
fattach(3C)	MT-Safe
fclose(3S)	MT-Safe
fconvert(3)	MT-Safe
fcvt(3)	MT-Safe
fcvt(3C)	Unsafe
fdatasync(3R)	Async-Signal-Safe
fdetach(3C)	Unsafe
fdopen(3S)	MT-Safe
feof(3S)	MT-Safe
ferror(3S)	MT-Safe
fflush(3S)	MT-Safe
ffs(3C)	MT-Safe
fgetc(3S)	MT-Safe
fgetgrent(3C)	Unsafe, use fgetgrent_r()
fgetpos(3C)	MT-Safe
fgetpwent(3C)	Unsafe, use fgetpwent_r()
fgets(3S)	MT-Safe
fgetspent(3C)	Unsafe, use fgetspent_r()
fgetwc(3I)	MT-Safe
fgetws(3I)	MT-Safe
field_arg(3X)	Unsafe
field_back(3X)	Unsafe
field_buffer(3X)	Unsafe
field_count(3X)	Unsafe
field_fore(3X)	Unsafe
field_index(3X)	Unsafe
field_info(3X)	Unsafe
field_init(3X)	Unsafe
field_just(3X)	Unsafe
field_opts(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

field_opts_off(3X)	Unsafe
field_opts_on(3X)	Unsafe
field_pad(3X)	Unsafe
field_status(3X)	Unsafe
field_term(3X)	Unsafe
field_type(3X)	Unsafe
field_userptr(3X)	Unsafe
fileno(3S)	MT-Safe
file_to_decimal(3)	MT-Safe
filter(3X)	Unsafe
finite(3C)	MT-Safe
flash(3X)	Unsafe
floating_to_decimal(3)	MT-Safe
flockfile(3S)	MT-Safe
floor(3M)	MT-Safe
flushinp(3X)	Unsafe
fmod(3M)	MT-Safe
fmtmsg(3C)	Safe
fnmatch(3C)	MT-Safe
fn_attribute_add(3N)	Safe
fn_attribute_assign(3N)	Safe
fn_attribute_copy(3N)	Safe
fn_attribute_create(3N)	Safe
fn_attribute_destroy(3N)	Safe
fn_attribute_first(3N)	Safe
fn_attribute_identifier(3N)	Safe
fn_attribute_next(3N)	Safe
fn_attribute_remove(3N)	Safe
fn_attribute_syntax(3N)	Safe
FN_attribute_t(3N)	Safe
fn_attribute_valuecount(3N)	Safe
fn_attrmodlist_add(3N)	Safe
fn_attrmodlist_assign(3N)	Safe
fn_attrmodlist_copy(3N)	Safe
fn_attrmodlist_count(3N)	Safe
fn_attrmodlist_create(3N)	Safe
fn_attrmodlist_destroy(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

fn_attrmodlist_first(3N)	Safe
fn_attrmodlist_next(3N)	Safe
FN_attrmodlist_t(3N)	Safe
fn_attrset_add(3N)	Safe
fn_attrset_assign(3N)	Safe
fn_attrset_copy(3N)	Safe
fn_attrset_count(3N)	Safe
fn_attrset_create(3N)	Safe
fn_attrset_destroy(3N)	Safe
fn_attrset_first(3N)	Safe
fn_attrset_get(3N)	Safe
fn_attrset_next(3N)	Safe
fn_attrset_remove(3N)	Safe
FN_attrset_t(3N)	Safe
fn_attr_get(3N)	Safe
fn_attr_get_ids(3N)	Safe
fn_attr_get_values(3N)	Safe
fn_attr_modify(3N)	Safe
fn_attr_multi_get(3N)	Safe
fn_attr_multi_modify(3N)	Safe
fn_bindinglist_destroy(3N)	Safe
fn_bindinglist_next(3N)	Safe
FN_bindinglist_t(3N)	Safe
fn_composite_name_append_comp(3N)	Safe
fn_composite_name_append_name(3N)	Safe
fn_composite_name_assign(3N)	Safe
fn_composite_name_copy(3N)	Safe
fn_composite_name_count(3N)	Safe
fn_composite_name_create(3N)	Safe
fn_composite_name_delete_comp(3N)	Safe
fn_composite_name_destroy(3N)	Safe
fn_composite_name_first(3N)	Safe
fn_composite_name_from_string(3N)	Safe
fn_composite_name_insert_comp(3N)	Safe
fn_composite_name_insert_name(3N)	Safe
fn_composite_name_is_empty(3N)	Safe
fn_composite_name_is_equal(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

fn_composite_name_is_prefix(3N)	Safe
fn_composite_name_is_suffix(3N)	Safe
fn_composite_name_last(3N)	Safe
fn_composite_name_next(3N)	Safe
fn_composite_name_prefix(3N)	Safe
fn_composite_name_prepend_comp(3N)	Safe
fn_composite_name_prepend_name(3N)	Safe
fn_composite_name_prev(3N)	Safe
fn_composite_name_suffix(3N)	Safe
FN_composite_name_t(3N)	Safe
fn_compound_name_append_comp(3N)	Safe
fn_compound_name_assign(3N)	Safe
fn_compound_name_copy(3N)	Safe
fn_compound_name_count(3N)	Safe
fn_compound_name_delete_all(3N)	Safe
fn_compound_name_delete_comp(3N)	Safe
fn_compound_name_destroy(3N)	Safe
fn_compound_name_first(3N)	Safe
fn_compound_name_from_syntax_attrs	Safe
fn_compound_name_get_syntax_attrs(3N)	Safe
fn_compound_name_insert_comp(3N)	Safe
fn_compound_name_is_empty(3N)	Safe
fn_compound_name_is_equal(3N)	Safe
fn_compound_name_is_prefix(3N)	Safe
fn_compound_name_is_suffix(3N)	Safe
fn_compound_name_last(3N)	Safe
fn_compound_name_next(3N)	Safe
fn_compound_name_prefix(3N)	Safe
fn_compound_name_prepend_comp(3N)	Safe
fn_compound_name_prev(3N)	Safe
fn_compound_name_suffix(3N)	Safe
FN_compound_name_t(3N)	Safe
fn_ctx_bind(3N)	Safe
fn_ctx_create_subcontext(3N)	Safe
fn_ctx_destroy_subcontext(3N)	Safe
fn_ctx_get_ref(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

fn_ctx_get_syntax_attrs(3N)	Safe
fn_ctx_handle_destroy(3N)	Safe
fn_ctx_handle_from_initial(3N)	MT-Safe
fn_ctx_handle_from_ref(3N)	Safe
fn_ctx_list_bindings(3N)	Safe
fn_ctx_list_names(3N)	Safe
fn_ctx_lookup(3N)	Safe
fn_ctx_lookup_link(3N)	Safe
fn_ctx_rename(3N)	Safe
FN_ctx_t(3N)	Safe
fn_ctx_unbind(3N)	Safe
fn_multigetlist_destroy(3N)	Safe
fn_multigetlist_next(3N)	Safe
FN_multigetlist_t(3N)	Safe
fn_namelist_destroy(3N)	Safe
fn_namelist_next(3N)	Safe
FN_namelist_t(3N)	Safe
fn_ref_addrcount(3N)	Safe
fn_ref_addr_assign(3N)	Safe
fn_ref_addr_copy(3N)	Safe
fn_ref_addr_create(3N)	Safe
fn_ref_addr_data(3N)	Safe
fn_ref_addr_description(3N)	Safe
fn_ref_addr_destroy(3N)	Safe
fn_ref_addr_length(3N)	Safe
FN_ref_addr_t(3N)	Safe
fn_ref_addr_type(3N)	Safe
fn_ref_append_addr(3N)	Safe
fn_ref_assign(3N)	Safe
fn_ref_copy(3N)	Safe
fn_ref_create(3N)	Safe
fn_ref_create_link(3N)	Safe
fn_ref_delete_addr(3N)	Safe
fn_ref_delete_all(3N)	Safe
fn_ref_description(3N)	Safe
fn_ref_destroy(3N)	Safe
fn_ref_first(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

fn_ref_insert_addr(3N)	Safe
fn_ref_is_link(3N)	Safe
fn_ref_link_name(3N)	Safe
fn_ref_next(3N)	Safe
fn_ref_prepend_addr(3N)	Safe
FN_ref_t(3N)	Safe
fn_ref_type(3N)	Safe
fn_status_advance_by_name(3N)	Safe
fn_status_append_remaining_name(3N)	Safe
fn_status_append_resolved_name(3N)	Safe
fn_status_assign(3N)	Safe
fn_status_code(3N)	Safe
fn_status_copy(3N)	Safe
fn_status_create(3N)	Safe
fn_status_description(3N)	Safe
fn_status_destroy(3N)	Safe
fn_status_diagnostic_message(3N)	Safe
fn_status_is_success(3N)	Safe
fn_status_link_code(3N)	Safe
fn_status_link_diagnostic_message(3N)	Safe
fn_status_link_remaining_name(3N)	Safe
fn_status_link_resolved_name(3N)	Safe
fn_status_link_resolved_ref(3N)	Safe
fn_status_remaining_name(3N)	Safe
fn_status_resolved_name(3N)	Safe
fn_status_resolved_ref(3N)	Safe
fn_status_set(3N)	Safe
fn_status_set_code(3N)	Safe
fn_status_set_diagnostic_message(3N)	Safe
fn_status_set_link_code(3N)	Safe
fn_status_set_link_diagnostic_message	Safe
fn_status_set_link_remaining_name(3N)	Safe
fn_status_set_link_resolved_name(3N)	Safe
fn_status_set_link_resolved_ref(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

fn_status_set_remaining_name(3N)	Safe
fn_status_set_resolved_name(3N)	Safe
fn_status_set_resolved_ref(3N)	Safe
fn_status_set_success(3N)	Safe
FN_status_t(3N)	Safe
fn_string_assign(3N)	Safe
fn_string_bytecount(3N)	Safe
fn_string_charcount(3N)	Safe
fn_string_code_set(3N)	Safe
fn_string_compare(3N)	Safe
fn_string_compare_substring(3N)	Safe
fn_string_contents(3N)	Safe
fn_string_copy(3N)	Safe
fn_string_create(3N)	Safe
fn_string_destroy(3N)	Safe
fn_string_from_composite_name(3N)	Safe
fn_string_from_compound_name(3N)	Safe
fn_string_from_contents(3N)	Safe
fn_string_from_str(3N)	Safe
fn_string_from_strings(3N)	Safe
fn_string_from_str_n(3N)	Safe
fn_string_from_substring(3N)	Safe
fn_string_is_empty(3N)	Safe
fn_string_next_substring(3N)	Safe
fn_string_prev_substring(3N)	Safe
fn_string_str(3N)	Safe
FN_string_t(3N)	Safe
fn_valuelist_destroy(3N)	Safe
fn_valuelist_next(3N)	Safe
FN_valuelist_t(3N)	Safe
fopen(3S)	MT-Safe
forms(3X)	Unsafe
form_cursor(3X)	Unsafe
form_data(3X)	Unsafe
form_driver(3X)	Unsafe
form_field(3X)	Unsafe
form_fields(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

`form_fieldtype(3X)`	Unsafe
`form_field_attributes(3X)`	Unsafe
`form_field_buffer(3X)`	Unsafe
`form_field_info(3X)`	Unsafe
`form_field_just(3X)`	Unsafe
`form_field_new(3X)`	Unsafe
`form_field_opts(3X)`	Unsafe
`form_field_userptr(3X)`	Unsafe
`form_field_validation(3X)`	Unsafe
`form_hook(3X)`	Unsafe
`form_init(3X)`	Unsafe
`form_new(3X)`	Unsafe
`form_new_page(3X)`	Unsafe
`form_opts(3X)`	Unsafe
`form_opts_off(3X)`	Unsafe
`form_opts_on(3X)`	Unsafe
`form_page(3X)`	Unsafe
`form_post(3X)`	Unsafe
`form_sub(3X)`	Unsafe
`form_term(3X)`	Unsafe
`form_userptr(3X)`	Unsafe
`form_win(3X)`	Unsafe
`fpclass(3C)`	MT-Safe
`fpgetmask(3C)`	MT-Safe
`fpgetround(3C)`	MT-Safe
`fpgetsticky(3C)`	MT-Safe
`fprintf(3S)`	MT-Safe except with `setlocale()`
`fpsetmask(3C)`	MT-Safe
`fpsetround(3C)`	MT-Safe
`fpsetsticky(3C)`	MT-Safe
`fputc(3S)`	MT-Safe
`fputs(3S)`	MT-Safe
`fputwc(3I)`	MT-Safe
`fputws(3I)`	MT-Safe
`fread(3S)`	MT-Safe
`free(3C)`	Safe
`free(3X)`	Safe

Table B-1 MT Safety Levels of Library Routines

freenetconfigent(3N)	MT-Safe
free_field(3X)	Unsafe
free_fieldtype(3X)	Unsafe
free_form(3X)	Unsafe
free_item(3X)	Unsafe
free_menu(3X)	Unsafe
freopen(3S)	MT-Safe
frexp(3C)	MT-Safe
fscanf(3S)	MT-Safe
fseek(3S)	MT-Safe
fsetpos(3C)	MT-Safe
fsync(3C)	Async-Signal-Safe
ftell(3S)	MT-Safe
ftok(3C)	MT-Safe
ftruncate(3C)	MT-Safe
ftrylockfile(3S)	MT-Safe
ftw(3C)	Safe
func_to_decimal(3)	MT-Safe
funlockfile(3S)	MT-Safe
fwrite(3S)	MT-Safe
gconvert(3)	MT-Safe
gcvt(3)	MT-Safe
gcvt(3C)	Unsafe
getacdir(3)	Safe
getacflg(3)	Safe
getacinfo(3)	Safe
getacmin(3)	Safe
getacna(3)	Safe
getauclassent(3)	Unsafe
getauclassent_r(3)	MT-Safe
getauclassnam(3)	Unsafe
getauclassnam_r(3)	MT-Safe
getauditflags(3)	MT-Safe
getauditflagsbin(3)	MT-Safe
getauditflagschar(3)	MT-Safe
getauevent(3)	Unsafe
getauevent_r(3)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

getauevnam(3)	Unsafe
getauevnam_r(3)	MT-Safe
getauevnonam(3)	MT-Safe
getauevnum(3)	Unsafe
getauevnum_r(3)	MT-Safe
getauuserent(3)	Unsafe
getauusernam(3)	Unsafe
getbegyx(3X)	Unsafe
getc(3S)	MT-Safe
getch(3X)	Unsafe
getchar(3S)	MT-Safe
getcwd(3C)	Safe
getdate(3C)	MT-Safe
getenv(3C)	Safe
getfauditflags(3)	MT-Safe
getgrent(3C)	Unsafe, use getgrent_r()
getgrgid(3C)	Unsafe, use getgrgid_r()
getgrnam(3C)	Unsafe, use getgrnam_r()
gethostbyaddr(3N)	Unsafe, use gethostbyaddr_r()
gethostbyname(3N)	Unsafe, use gethostbyname_r()
gethrtime(3C)	MT-Safe
gethrvtime(3C)	MT-Safe
getlogin(3C)	Unsafe, use getlogin_r()
getmaxyx(3X)	Unsafe
getmntany(3C)	Safe
getmntent(3C)	Safe
getnetbyaddr(3N)	Unsafe, use getnetbyaddr_r()
getnetbyname(3N)	Unsafe, use getnetbyname_r()
getnetconfig(3N)	MT-Safe
getnetconfigent(3N)	MT-Safe
getnetgrent(3N)	Unsafe, use getnetgrent_r()
getnetname(3N)	MT-Safe
getnetpath(3N)	MT-Safe
getnwstr(3X)	Unsafe
getopt(3C)	Unsafe
getparyx(3X)	Unsafe
getpass(3C)	Unsafe

Table B-1 MT Safety Levels of Library Routines

getpeername(3N)	Safe
getprotobyname(3N)	Unsafe, use getprotobyname_r()
getprotobynumber(3N)	Unsafe, use getprotobynumber_r()
getprotoent(3N)	Unsafe, use getprotoent_r()
getpublickey(3N)	Safe
getpw(3C)	Safe
getpwent(3C)	Unsafe, use getpwent_r()
getpwnam(3C)	Unsafe, use getpwnam_r()
getpwuid(3C)	Unsafe, use getpwuid_r()
getrpcbyname(3N)	Unsafe, use getrpcbyname_r()
getrpcbynumber(3N)	Unsafe, use getrpcbynumber_r()
getrpcent(3N)	Unsafe, use getrpcent_r()
getrpcport(3N)	Unsafe
gets(3S)	MT-Safe
getsecretkey(3N)	Safe
getservbyname(3N)	Unsafe, use getservbyname_r()
getservbyport(3N)	Unsafe, use getservbyport_r()
getservent(3N)	Unsafe, use getservent_r()
getsockname(3N)	Safe
getsockopt(3N)	Safe
getspent(3C)	Unsafe, use getspent_r()
getspnam(3C)	Unsafe, use getspnam_r()
getstr(3X)	Unsafe
getsubopt(3C)	MT-Safe
getsyx(3X)	Unsafe
gettext(3I)	Safe with exceptions
gettimeofday(3C)	MT-Safe
gettxt(3C)	Safe with exceptions
getutent(3C)	Unsafe
getutid(3C)	Unsafe
getutline(3C)	Unsafe
getutmp(3C)	Unsafe
getutmpx(3C)	Unsafe
getutxent(3C)	Unsafe
getutxid(3C)	Unsafe
getutxline(3C)	Unsafe
getvfsany(3C)	Safe

Table B-1 MT Safety Levels of Library Routines

`getvfsent(3C)`	Safe
`getvfsfile(3C)`	Safe
`getvfsspec(3C)`	Safe
`getw(3S)`	MT-Safe
`getwc(3I)`	MT-Safe
`getwch(3X)`	Unsafe
`getwchar(3I)`	MT-Safe
`getwidth(3I)`	MT-Safe with exceptions
`getwin(3X)`	Unsafe
`getws(3I)`	MT-Safe
`getwstr(3X)`	Unsafe
`getyx(3X)`	Unsafe
`get_myaddress(3N)`	Unsafe
`gmatch(3G)`	MT-Safe
`gmtime(3C)`	Unsafe, use `gmtime_r()`
`grantpt(3C)`	Safe
`gsignal(3C)`	Unsafe
`halfdelay(3X)`	Unsafe
`hasmntopt(3C)`	Safe
`has_colors(3X)`	Unsafe
`has_ic(3X)`	Unsafe
`has_il(3X)`	Unsafe
`havedisk(3N)`	MT-Safe
`hcreate(3C)`	Safe
`hdestroy(3C)`	Safe
`hide_panel(3X)`	Unsafe
`host2netname(3N)`	MT-Safe
`hsearch(3C)`	Safe
`htonl(3N)`	Safe
`htons(3N)`	Safe
`hyperbolic(3M)`	MT-Safe
`hypot(3M)`	MT-Safe
`iconv(3)`	MT-Safe
`iconv_close(3)`	MT-Safe
`iconv_open(3)`	MT-Safe
`idcok(3X)`	Unsafe
`idlok(3X)`	Unsafe

Table B-1 MT Safety Levels of Library Routines

ieee_functions(3M)	MT-Safe
ieee_test(3M)	MT-Safe
ilogb(3M)	MT-Safe
immedok(3X)	Unsafe
inch(3X)	Unsafe
inchnstr(3X)	Unsafe
inchstr(3X)	Unsafe
inet(3N)	Safe
inet_addr(3N)	Safe
inet_lnaof(3N)	Safe
inet_makeaddr(3N)	Safe
inet_netof(3N)	Safe
inet_network(3N)	Safe
inet_ntoa(3N)	Safe
initgroups(3C)	Unsafe
initscr(3X)	Unsafe
init_color(3X)	Unsafe
init_pair(3X)	Unsafe
innstr(3X)	Unsafe
innwstr(3X)	Unsafe
insch(3X)	Unsafe
insdelln(3X)	Unsafe
insertln(3X)	Unsafe
insnstr(3X)	Unsafe
insnwstr(3X)	Unsafe
insque(3C)	Unsafe
insstr(3X)	Unsafe
instr(3X)	Unsafe
inswch(3X)	Unsafe
inswstr(3X)	Unsafe
intrflush(3X)	Unsafe
inwch(3X)	Unsafe
inwchnstr(3X)	Unsafe
inwchstr(3X)	Unsafe
inwstr(3X)	Unsafe
isalnum(3C)	MT-Safe with exceptions
isalpha(3C)	MT-Safe with exceptions

Table B-1 MT Safety Levels of Library Routines

isascii(3C)	MT-Safe with exceptions
isastream(3C)	MT-Safe
iscntrl(3C)	MT-Safe with exceptions
isdigit(3C)	MT-Safe with exceptions
isencrypt(3G)	MT-Safe
isendwin(3X)	Unsafe
isenglish(3I)	MT-Safe with exceptions
isgraph(3C)	MT-Safe with exceptions
isideogram(3I)	MT-Safe with exceptions
islower(3C)	MT-Safe with exceptions
isnan(3C)	MT-Safe
isnan(3M)	MT-Safe
isnand(3C)	MT-Safe
isnanf(3C)	MT-Safe
isnumber(3I)	MT-Safe with exceptions
isphonogram(3I)	MT-Safe with exceptions
isprint(3C)	MT-Safe with exceptions
ispunct(3C)	MT-Safe with exceptions
isspace(3C)	MT-Safe with exceptions
isspecial(3I)	MT-Safe with exceptions
isupper(3C)	MT-Safe with exceptions
iswalnum(3I)	MT-Safe with exceptions
iswalpha(3I)	MT-Safe with exceptions
iswascii(3I)	MT-Safe with exceptions
iswcntrl(3I)	MT-Safe with exceptions
iswctype(3I)	MT-Safe
iswdigit(3I)	MT-Safe with exceptions
iswgraph(3I)	MT-Safe with exceptions
iswlower(3I)	MT-Safe with exceptions
iswprint(3I)	MT-Safe with exceptions
iswpunct(3I)	MT-Safe with exceptions
iswspace(3I)	MT-Safe with exceptions
iswupper(3I)	MT-Safe with exceptions
iswxdigit(3I)	MT-Safe with exceptions
isxdigit(3C)	MT-Safe with exceptions
is_linetouched(3X)	Unsafe
is_wintouched(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

item_count(3X)	Unsafe
item_description(3X)	Unsafe
item_index(3X)	Unsafe
item_init(3X)	Unsafe
item_name(3X)	Unsafe
item_opts(3X)	Unsafe
item_opts_off(3X)	Unsafe
item_opts_on(3X)	Unsafe
item_term(3X)	Unsafe
item_userptr(3X)	Unsafe
item_value(3X)	Unsafe
item_visible(3X)	Unsafe
j0(3M)	MT-Safe
j1(3M)	MT-Safe
jn(3M)	MT-Safe
jrand48(3C)	Safe
kerberos(3N)	Unsafe
kerberos_rpc(3N)	Unsafe
keyname(3X)	Unsafe
keypad(3X)	Unsafe
key_decryptsession(3N)	MT-Safe
key_encryptsession(3N)	MT-Safe
key_gendes(3N)	MT-Safe
key_secretkey_is_set(3N)	MT-Safe
key_setsecret(3N)	MT-Safe
killchar(3X)	Unsafe
krb_get_admhst(3N)	Unsafe
krb_get_cred(3N)	Unsafe
krb_get_krbhst(3N)	Unsafe
krb_get_lrealm(3N)	Unsafe
krb_get_phost(3N)	Unsafe
krb_kntoln(3N)	Unsafe
krb_mk_err(3N)	Unsafe
krb_mk_req(3N)	Unsafe
krb_mk_safe(3N)	Unsafe
krb_net_read(3N)	Unsafe
krb_net_write(3N)	Unsafe

Table B-1 MT Safety Levels of Library Routines

krb_rd_err(3N)	Unsafe
krb_rd_req(3N)	Unsafe
krb_rd_safe(3N)	Unsafe
krb_realmofhost(3N)	Unsafe
krb_recvauth(3N)	Unsafe
krb_sendauth(3N)	Unsafe
krb_set_key(3N)	Unsafe
krb_set_tkt_string(3N)	Unsafe
kvm_close(3K)	Unsafe
kvm_getcmd(3K)	Unsafe
kvm_getproc(3K)	Unsafe
kvm_getu(3K)	Unsafe
kvm_kread(3K)	Unsafe
kvm_kwrite(3K)	Unsafe
kvm_nextproc(3K)	Unsafe
kvm_nlist(3K)	Unsafe
kvm_open(3K)	Unsafe
kvm_read(3K)	Unsafe
kvm_setproc(3K)	Unsafe
kvm_uread(3K)	Unsafe
kvm_uwrite(3K)	Unsafe
kvm_write(3K)	Unsafe
l64a(3C)	MT-Safe
label(3)	Safe
labs(3C)	MT-Safe
lckpwdf(3C)	MT-Safe
lcong48(3C)	Safe
ldexp(3C)	MT-Safe
ldiv(3C)	MT-Safe
leaveok(3X)	Unsafe
lfind(3C)	Safe
lfmt(3C)	MT-safe
lgamma(3M)	Unsafe, use lgamma_r()
libpthread(3T)	Fork1-Safe,MT-Safe,Async-Signal-Safe
libthread(3T)	Fork1-Safe,MT-Safe,Async-Signal-Safe
line(3)	Safe
link_field(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

link_fieldtype(3X)	Unsafe
linmod(3)	Safe
lio_listio(3R)	MT-Safe
listen(3N)	Safe
llabs(3C)	MT-Safe
lldiv(3C)	MT-Safe
lltostr(3C)	MT-Safe
localeconv(3C)	Safe with exceptions
localtime(3C)	Unsafe, use localtime_r()
lockf(3C)	MT-Safe
log(3M)	MT-Safe
log10(3M)	MT-Safe
log1p(3M)	MT-Safe
logb(3C)	MT-Safe
logb(3M)	MT-Safe
longjmp(3C)	Unsafe
longname(3X)	Unsafe
lrand48(3C)	Safe
lsearch(3C)	Safe
madvise(3)	MT-Safe
maillock(3X)	Unsafe
major(3C)	MT-Safe
makecontext(3C)	MT-Safe
makedev(3C)	MT-Safe
mallinfo(3X)	Safe
malloc(3C)	Safe
malloc(3X)	Safe
mallopt(3X)	Safe
mapmalloc(3X)	Safe
matherr(3M)	MT-Safe
mbchar(3C)	MT-Safe with exceptions
mblen(3C)	MT-Safe with exceptions
mbstowcs(3C)	MT-Safe with exceptions
mbstring(3C)	MT-Safe with exceptions
mbtowc(3C)	MT-Safe with exceptions
media_findname(3X)	MT-Unsafe
media_getattr(3X)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

media_setattr(3X)	MT-Safe
memalign(3C)	Safe
memccpy(3C)	MT-Safe
memchr(3C)	MT-Safe
memcmp(3C)	MT-Safe
memcpy(3C)	MT-Safe
memmove(3C)	MT-Safe
memory(3C)	MT-Safe
memset(3C)	MT-Safe
menus(3X)	Unsafe
menu_attributes(3X)	Unsafe
menu_back(3X)	Unsafe
menu_cursor(3X)	Unsafe
menu_driver(3X)	Unsafe
menu_fore(3X)	Unsafe
menu_format(3X)	Unsafe
menu_grey(3X)	Unsafe
menu_hook(3X)	Unsafe
menu_init(3X)	Unsafe
menu_items(3X)	Unsafe
menu_item_current(3X)	Unsafe
menu_item_name(3X)	Unsafe
menu_item_new(3X)	Unsafe
menu_item_opts(3X)	Unsafe
menu_item_userptr(3X)	Unsafe
menu_item_value(3X)	Unsafe
menu_item_visible(3X)	Unsafe
menu_mark(3X)	Unsafe
menu_new(3X)	Unsafe
menu_opts(3X)	Unsafe
menu_opts_off(3X)	Unsafe
menu_opts_on(3X)	Unsafe
menu_pad(3X)	Unsafe
menu_pattern(3X)	Unsafe
menu_post(3X)	Unsafe
menu_sub(3X)	Unsafe
menu_term(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

menu_userptr(3X)	Unsafe
menu_win(3X)	Unsafe
meta(3X)	Unsafe
minor(3C)	MT-Safe
mkdirp(3G)	MT-Safe
mkfifo(3C)	MT-Safe, Async-Signal-Safe
mktemp(3C)	Safe
mktime(3C)	Unsafe
mlock(3C)	MT-Safe
mlockall(3C)	MT-Safe
modf(3C)	MT-Safe
modff(3C)	MT-Safe
monitor(3C)	Safe
move(3)	Safe
move(3X)	Unsafe
movenextch(3X)	Unsafe
moveprevch(3X)	Unsafe
move_field(3X)	Unsafe
move_panel(3X)	Unsafe
mq_close(3R)	MT-Safe
mq_getattr(3R)	MT-Safe
mq_notify(3R)	MT-Safe
mq_open(3R)	MT-Safe
mq_receive(3R)	MT-Safe
mq_send(3R)	MT-Safe
mq_setattr(3R)	MT-Safe
mq_unlink(3R)	MT-Safe
mrand48(3C)	Safe
msync(3C)	MT-Safe
munlock(3C)	MT-Safe
munlockall(3C)	MT-Safe
mutex(3T)	MT-Safe
mutex_destroy(3T)	MT-Safe
mutex_init(3T)	MT-Safe
mutex_lock(3T)	MT-Safe
mutex_trylock(3T)	MT-Safe
mutex_unlock(3T)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

mvaddch(3X)	Unsafe
mvaddchnstr(3X)	Unsafe
mvaddchstr(3X)	Unsafe
mvaddnstr(3X)	Unsafe
mvaddnwstr(3X)	Unsafe
mvaddstr(3X)	Unsafe
mvaddwch(3X)	Unsafe
mvaddwchnstr(3X)	Unsafe
mvaddwchstr(3X)	Unsafe
mvaddwstr(3X)	Unsafe
mvcur(3X)	Unsafe
mvdelch(3X)	Unsafe
mvderwin(3X)	Unsafe
mvgetch(3X)	Unsafe
mvgetnwstr(3X)	Unsafe
mvgetstr(3X)	Unsafe
mvgetwch(3X)	Unsafe
mvgetwstr(3X)	Unsafe
mvinch(3X)	Unsafe
mvinchnstr(3X)	Unsafe
mvinchstr(3X)	Unsafe
mvinnstr(3X)	Unsafe
mvinnwstr(3X)	Unsafe
mvinsch(3X)	Unsafe
mvinsnstr(3X)	Unsafe
mvinsnwstr(3X)	Unsafe
mvinsstr(3X)	Unsafe
mvinstr(3X)	Unsafe
mvinswch(3X)	Unsafe
mvinswstr(3X)	Unsafe
mvinwch(3X)	Unsafe
mvinwchnstr(3X)	Unsafe
mvinwchstr(3X)	Unsafe
mvinwstr(3X)	Unsafe
mvprintw(3X)	Unsafe
mvscanw(3X)	Unsafe
mvwaddch(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

mvwaddchnstr(3X)	Unsafe
mvwaddchstr(3X)	Unsafe
mvwaddnstr(3X)	Unsafe
mvwaddnwstr(3X)	Unsafe
mvwaddstr(3X)	Unsafe
mvwaddwch(3X)	Unsafe
mvwaddwchnstr(3X)	Unsafe
mvwaddwchstr(3X)	Unsafe
mvwaddwstr(3X)	Unsafe
mvwdelch(3X)	Unsafe
mvwgetch(3X)	Unsafe
mvwgetnwstr(3X)	Unsafe
mvwgetstr(3X)	Unsafe
mvwgetwch(3X)	Unsafe
mvwgetwstr(3X)	Unsafe
mvwin(3X)	Unsafe
mvwinch(3X)	Unsafe
mvwinchnstr(3X)	Unsafe
mvwinchstr(3X)	Unsafe
mvwinnstr(3X)	Unsafe
mvwinnwstr(3X)	Unsafe
mvwinsch(3X)	Unsafe
mvwinsnstr(3X)	Unsafe
mvwinsnwstr(3X)	Unsafe
mvwinsstr(3X)	Unsafe
mvwinstr(3X)	Unsafe
mvwinswch(3X)	Unsafe
mvwinswstr(3X)	Unsafe
mvwinwch(3X)	Unsafe
mvwinwchnstr(3X)	Unsafe
mvwinwchstr(3X)	Unsafe
mvwinwstr(3X)	Unsafe
mvwprintw(3X)	Unsafe
mvwscanw(3X)	Unsafe
nanosleep(3R)	MT-Safe
napms(3X)	Unsafe
nc_perror(3N)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

nc_sperror(3N)	MT-Safe
ndbm(3)	Unsafe
netdir(3N)	MT-Safe
netdir_free(3N)	MT-Safe
netdir_getbyaddr(3N)	MT-Safe
netdir_getbyname(3N)	MT-Safe
netdir_mergeaddr(3N)	MT-Safe
netdir_options(3N)	MT-Safe
netdir_perror(3N)	MT-Safe
netdir_sperror(3N)	MT-Safe
netname2host(3N)	MT-Safe
netname2user(3N)	MT-Safe
newpad(3X)	Unsafe
newterm(3X)	Unsafe
newwin(3X)	Unsafe
new_field(3X)	Unsafe
new_fieldtype(3X)	Unsafe
new_form(3X)	Unsafe
new_item(3X)	Unsafe
new_menu(3X)	Unsafe
new_page(3X)	Unsafe
new_panel(3X)	Unsafe
nextafter(3C)	MT-Safe
nextafter(3M)	MT-Safe
nftw(3C)	Safe with exceptions
nis_add(3N)	MT-Safe
nis_addmember(3N)	MT-Safe
nis_add_entry(3N)	MT-Safe
nis_checkpoint(3N)	MT-Safe
nis_clone_object(3N)	Safe
nis_creategroup(3N)	MT-Safe
nis_db(3N)	Unsafe
nis_destroygroup(3N)	MT-Safe
nis_destroy_object(3N)	Safe
nis_dir_cmp(3N)	Safe
nis_domain_of(3N)	Safe
nis_error(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

nis_first_entry(3N)	MT-Safe
nis_freenames(3N)	Safe
nis_freeresult(3N)	MT-Safe
nis_freeservlist(3N)	MT-Safe
nis_freetags(3N)	MT-Safe
nis_getnames(3N)	Safe
nis_getservlist(3N)	MT-Safe
nis_groups(3N)	MT-Safe
nis_ismember(3N)	MT-Safe
nis_leaf_of(3N)	Safe
nis_lerror(3N)	Safe
nis_list(3N)	MT-Safe
nis_local_directory(3N)	MT-Safe
nis_local_group(3N)	MT-Safe
nis_local_host(3N)	MT-Safe
nis_local_names(3N)	MT-Safe
nis_local_principal(3N)	MT-Safe
nis_lookup(3N)	MT-Safe
nis_map_group(3N)	MT-Safe
nis_mkdir(3N)	MT-Safe
nis_modify(3N)	MT-Safe
nis_modify_entry(3N)	MT-Safe
nis_names(3N)	MT-Safe
nis_name_of(3N)	Safe
nis_next_entry(3N)	MT-Safe
nis_perror(3N)	Safe
nis_ping(3N)	MT-Safe
nis_print_group_entry(3N)	MT-Safe
nis_print_object(3N)	Safe
nis_remove(3N)	MT-Safe
nis_removemember(3N)	MT-Safe
nis_remove_entry(3N)	MT-Safe
nis_rmdir(3N)	MT-Safe
nis_server(3N)	MT-Safe
nis_servstate(3N)	MT-Safe
nis_sperrno(3N)	Safe
nis_sperror(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

nis_sperror_r(3N)	Safe
nis_stats(3N)	MT-Safe
nis_subr(3N)	Safe
nis_tables(3N)	MT-Safe
nis_verifygroup(3N)	MT-Safe
nl(3X)	Unsafe
nlist(3E)	Safe
nlsgetcall(3N)	Unsafe
nlsprovider(3N)	Unsafe
nlsrequest(3N)	Unsafe
nl_langinfo(3C)	Safe with exceptions
nocbreak(3X)	Unsafe
nodelay(3X)	Unsafe
noecho(3X)	Unsafe
nonl(3X)	Unsafe
noqiflush(3X)	Unsafe
noraw(3X)	Unsafe
NOTE(3X)	Safe
notimeout(3X)	Unsafe
nrand48(3C)	Safe
ntohl(3N)	Safe
ntohs(3N)	Safe
offsetof(3C)	MT-Safe
opendir(3C)	Safe
openlog(3)	Safe
openpl(3)	Safe
openvt(3)	Safe
overlay(3X)	Unsafe
overwrite(3X)	Unsafe
p2close(3G)	Unsafe
p2open(3G)	Unsafe
pair_content(3X)	Unsafe
panels(3X)	Unsafe
panel_above(3X)	Unsafe
panel_below(3X)	Unsafe
panel_hidden(3X)	Unsafe
panel_move(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

`panel_new(3X)`	Unsafe
`panel_show(3X)`	Unsafe
`panel_top(3X)`	Unsafe
`panel_update(3X)`	Unsafe
`panel_userptr(3X)`	Unsafe
`panel_window(3X)`	Unsafe
`pathfind(3G)`	MT-Safe
`pclose(3S)`	Unsafe
`pechochar(3X)`	Unsafe
`pechowchar(3X)`	Unsafe
`perror(3C)`	MT-Safe
`pfmt(3C)`	MT-safe
`plot(3)`	Safe
`pmap_getmaps(3N)`	Unsafe
`pmap_getport(3N)`	Unsafe
`pmap_rmtcall(3N)`	Unsafe
`pmap_set(3N)`	Unsafe
`pmap_unset(3N)`	Unsafe
`pnoutrefresh(3X)`	Unsafe
`point(3)`	Safe
`popen(3S)`	Unsafe
`post_form(3X)`	Unsafe
`post_menu(3X)`	Unsafe
`pos_form_cursor(3X)`	Unsafe
`pos_menu_cursor(3X)`	Unsafe
`pow(3M)`	MT-Safe
`prefresh(3X)`	Unsafe
`printf(3S)`	MT-Safe except with `setlocale()`
`printw(3X)`	Unsafe
`psiginfo(3C)`	Safe
`psignal(3C)`	Safe
`pthreads(3T)`	Fork1-Safe,MT-Safe,Async-Signal-Safe
`pthread_atfork(3T)`	MT-Safe
`pthread_attr_destroy(3T)`	MT-Safe
`pthread_attr_getdetachstate(3T)`	MT-Safe
`pthread_attr_getinheritsched(3T)`	MT-Safe
`pthread_attr_getschedparam(3T)`	MT-Safe

Table B-1 MT Safety Levels of Library Routines

pthread_attr_getschedpolicy(3T)	MT-Safe
pthread_attr_getscope(3T)	MT-Safe
pthread_attr_getstackaddr(3T)	MT-Safe
pthread_attr_getstacksize(3T)	MT-Safe
pthread_attr_init(3T)	MT-Safe
pthread_attr_setdetachstate(3T)	MT-Safe
pthread_attr_setinheritsched(3T)	MT-Safe
pthread_attr_setschedparam(3T)	MT-Safe
pthread_attr_setschedpolicy(3T)	MT-Safe
pthread_attr_setscope(3T)	MT-Safe
pthread_attr_setstackaddr(3T)	MT-Safe
pthread_attr_setstacksize(3T)	MT-Safe
pthread_cancel(3T)	MT-Safe
pthread_cleanup_pop(3T)	MT-Safe
pthread_cleanup_push(3T)	MT-Safe
pthread_condattr_destroy(3T)	MT-Safe
pthread_condattr_getpshared(3T)	MT-Safe
pthread_condattr_init(3T)	MT-Safe
pthread_condattr_setpshared(3T)	MT-Safe
pthread_cond_broadcast(3T)	MT-Safe
pthread_cond_destroy(3T)	MT-Safe
pthread_cond_init(3T)	MT-Safe
pthread_cond_signal(3T)	MT-Safe
pthread_cond_timedwait(3T)	MT-Safe
pthread_cond_wait(3T)	MT-Safe
pthread_create(3T)	MT-Safe
pthread_detach(3T)	MT-Safe
pthread_equal(3T)	MT-Safe
pthread_exit(3T)	MT-Safe
pthread_getschedparam(3T)	MT-Safe
pthread_getspecific(3T)	MT-Safe
pthread_join(3T)	MT-Safe
pthread_key_create(3T)	MT-Safe
pthread_key_delete(3T)	MT-Safe
pthread_kill(3T)	MT-Safe, Async-Signal-Safe
pthread_mutexattr_destroy(3T)	MT-Safe
pthread_mutexattr_getprioceiling(3T)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

pthread_mutexattr_getprotocol(3T)	MT-Safe
pthread_mutexattr_getpshared(3T)	MT-Safe
pthread_mutexattr_init(3T)	MT-Safe
pthread_mutexattr_setprioceiling(3T)	MT-Safe
pthread_mutexattr_setprotocol(3T)	MT-Safe
pthread_mutexattr_setpshared(3T)	MT-Safe
pthread_mutex_destroy(3T)	MT-Safe
pthread_mutex_getprioceiling(3T)	MT-Safe
pthread_mutex_init(3T)	MT-Safe
pthread_mutex_lock(3T)	MT-Safe
pthread_mutex_setprioceiling(3T)	MT-Safe
pthread_mutex_trylock(3T)	MT-Safe
pthread_mutex_unlock(3T)	MT-Safe
pthread_once(3T)	MT-Safe
pthread_self(3T)	MT-Safe
pthread_setcancelstate(3T)	MT-Safe
pthread_setcanceltype(3T)	MT-Safe
pthread_setschedparam(3T)	MT-Safe
pthread_setspecific(3T)	MT-Safe
pthread_sigmask(3T)	MT-Safe, Async-Signal-Safe
pthread_testcancel(3T)	MT-Safe
ptsname(3C)	Safe
publickey(3N)	Safe
putc(3S)	MT-Safe
putchar(3S)	MT-Safe
putenv(3C)	Safe
putmntent(3C)	Safe
putp(3X)	Unsafe
putpwent(3C)	Unsafe
puts(3S)	MT-Safe
putspent(3C)	Unsafe
pututline(3C)	Unsafe
pututxline(3C)	Unsafe
putw(3S)	MT-Safe
putwc(3I)	MT-Safe
putwchar(3I)	MT-Safe
putwin(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

putws(3I)	MT-Safe
qeconvert(3)	MT-Safe
qfconvert(3)	MT-Safe
qgconvert(3)	MT-Safe
qiflush(3X)	Unsafe
qsort(3C)	Safe
quadruple_to_decimal(3)	MT-Safe
rac_drop(3N)	Unsafe
rac_poll(3N)	Unsafe
rac_recv(3N)	Unsafe
rac_send(3N)	Unsafe
raise(3C)	MT-Safe
rand(3C)	Unsafe, use rand_r()
random(3C)	Unsafe
raw(3X)	Unsafe
rcmd(3N)	Unsafe
readdir(3C)	Unsafe, use readdir_r()
read_vtoc(3X)	Unsafe
realloc(3C)	Safe
realloc(3X)	Safe
realpath(3C)	MT-Safe
recv(3N)	Safe
recvfrom(3N)	Safe
recvmsg(3N)	Safe
redrawwin(3X)	Unsafe
refresh(3X)	Unsafe
regcmp(3G)	MT-Safe
regcomp(3C)	MT-Safe
regerror(3C)	MT-Safe
regex(3G)	MT-Safe
regexec(3C)	MT-Safe
regexpr(3G)	MT-Safe
regfree(3C)	MT-Safe
registerrpc(3N)	Unsafe
remainder(3M)	MT-Safe
remove(3C)	MT-Safe
remque(3C)	Unsafe

Table B-1 MT Safety Levels of Library Routines

replace_panel(3X)	Unsafe
resetty(3X)	Unsafe
reset_prog_mode(3X)	Unsafe
reset_shell_mode(3X)	Unsafe
resolver(3N)	Unsafe
restartterm(3X)	Unsafe
res_init(3N)	Unsafe
res_mkquery(3N)	Unsafe
res_search(3N)	Unsafe
res_send(3N)	Unsafe
rewind(3S)	MT-Safe
rewinddir(3C)	Safe
rexec(3N)	Unsafe
rint(3M)	MT-Safe
ripoffline(3X)	Unsafe
rmdirp(3G)	MT-Safe
rnusers(3N)	MT-Safe
rpc(3N)	MT-Safe with exceptions
rpcbind(3N)	MT-Safe
rpcb_getaddr(3N)	MT-Safe
rpcb_getmaps(3N)	MT-Safe
rpcb_gettime(3N)	MT-Safe
rpcb_rmtcall(3N)	MT-Safe
rpcb_set(3N)	MT-Safe
rpcb_unset(3N)	MT-Safe
rpc_broadcast(3N)	MT-Safe
rpc_broadcast_exp(3N)	MT-Safe
rpc_call(3N)	MT-Safe
rpc_clnt_auth(3N)	MT-Safe
rpc_clnt_calls(3N)	MT-Safe
rpc_clnt_create(3N)	MT-Safe
rpc_control(3N)	MT-Safe
rpc_createerr(3N)	MT-Safe
rpc_rac(3N)	Unsafe
rpc_reg(3N)	MT-Safe
rpc_soc(3N)	Unsafe
rpc_svc_create(3N)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

rpc_svc_err(3N)	MT-Safe
rpc_svc_reg(3N)	MT-Safe
rpc_xdr(3N)	Safe
rresvport(3N)	Unsafe
rstat(3N)	MT-Safe
ruserok(3N)	Unsafe
rusers(3N)	MT-Safe
rwall(3N)	MT-Safe
rwlock(3T)	MT-Safe
rwlock_destroy(3T)	MT-Safe
rwlock_init(3T)	MT-Safe
rw_rdlock(3T)	MT-Safe
rw_tryrdlock(3T)	MT-Safe
rw_trywrlock(3T)	MT-Safe
rw_unlock(3T)	MT-Safe
rw_wrlock(3T)	MT-Safe
savetty(3X)	Unsafe
scalb(3C)	MT-Safe
scalb(3M)	MT-Safe
scalbn(3M)	MT-Safe
scale_form(3X)	Unsafe
scale_menu(3X)	Unsafe
scanf(3S)	MT-Safe
scanw(3X)	Unsafe
sched_getparam(3R)	MT-Safe
sched_getscheduler(3R)	MT-Safe
sched_get_priority_max(3R)	MT-Safe
sched_get_priority_min(3R)	MT-Safe
sched_rr_get_interval(3R)	MT-Safe
sched_setparam(3R)	MT-Safe
sched_setscheduler(3R)	MT-Safe
sched_yield(3R)	MT-Safe
scrl(3X)	Unsafe
scroll(3X)	Unsafe
scrollok(3X)	Unsafe
scr_dump(3X)	Unsafe
scr_init(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

scr_restore(3X)	Unsafe
scr_set(3X)	Unsafe
seconvert(3)	MT-Safe
secure_rpc(3N)	MT-Safe
seed48(3C)	Safe
seekdir(3C)	Safe
select(3C)	MT-Safe
sema_destroy(3T)	MT-Safe
sema_init(3T)	MT-Safe
sema_post(3T)	MT-Safe, Async-Signal-Safe
sema_trywait(3T)	MT-Safe
sema_wait(3T)	MT-Safe
sem_close(3R)	MT-Safe
sem_destroy(3R)	MT-Safe
sem_getvalue(3R)	MT-Safe
sem_init(3R)	MT-Safe
sem_open(3R)	MT-Safe
sem_post(3R)	Async-Signal-Safe
sem_trywait(3R)	MT-Safe
sem_unlink(3R)	MT-Safe
sem_wait(3R)	MT-Safe
send(3N)	Safe
sendmsg(3N)	Safe
sendto(3N)	Safe
setac(3)	Safe
setauclass(3)	MT-Safe
setauevent(3)	MT-Safe
setauuser(3)	MT-Safe
setbuf(3S)	MT-Safe
setcat(3C)	MT-safe
setjmp(3C)	Unsafe
setkey(3C)	Safe
setlabel(3C)	MT-safe
setlocale(3C)	Safe with exceptions
setlogmask(3)	Safe
setnetconfig(3N)	MT-Safe
setnetpath(3N)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

setscrreg(3X)	Unsafe
setsockopt(3N)	Safe
setsyx(3X)	Unsafe
setterm(3X)	Unsafe
settimeofday(3C)	MT-Safe
setupterm(3X)	Unsafe
setutent(3C)	Unsafe
setutxent(3C)	Unsafe
setvbuf(3S)	MT-Safe
set_current_field(3X)	Unsafe
set_current_item(3X)	Unsafe
set_curterm(3X)	Unsafe
set_fieldtype_arg(3X)	Unsafe
set_fieldtype_choice(3X)	Unsafe
set_field_back(3X)	Unsafe
set_field_buffer(3X)	Unsafe
set_field_fore(3X)	Unsafe
set_field_init(3X)	Unsafe
set_field_just(3X)	Unsafe
set_field_opts(3X)	Unsafe
set_field_pad(3X)	Unsafe
set_field_status(3X)	Unsafe
set_field_term(3X)	Unsafe
set_field_type(3X)	Unsafe
set_field_userptr(3X)	Unsafe
set_form_fields(3X)	Unsafe
set_form_init(3X)	Unsafe
set_form_opts(3X)	Unsafe
set_form_page(3X)	Unsafe
set_form_sub(3X)	Unsafe
set_form_term(3X)	Unsafe
set_form_userptr(3X)	Unsafe
set_form_win(3X)	Unsafe
set_item_init(3X)	Unsafe
set_item_opts(3X)	Unsafe
set_item_term(3X)	Unsafe
set_item_userptr(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

set_item_value(3X)	Unsafe
set_max_field(3X)	Unsafe
set_menu_back(3X)	Unsafe
set_menu_fore(3X)	Unsafe
set_menu_format(3X)	Unsafe
set_menu_grey(3X)	Unsafe
set_menu_init(3X)	Unsafe
set_menu_items(3X)	Unsafe
set_menu_mark(3X)	Unsafe
set_menu_opts(3X)	Unsafe
set_menu_pad(3X)	Unsafe
set_menu_pattern(3X)	Unsafe
set_menu_sub(3X)	Unsafe
set_menu_term(3X)	Unsafe
set_menu_userptr(3X)	Unsafe
set_menu_win(3X)	Unsafe
set_new_page(3X)	Unsafe
set_panel_userptr(3X)	Unsafe
set_term(3X)	Unsafe
set_top_row(3X)	Unsafe
sfconvert(3)	MT-Safe
sgconvert(3)	MT-Safe
shm_open(3R)	MT-Safe
shm_unlink(3R)	MT-Safe
show_panel(3X)	Unsafe
shutdown(3N)	Safe
sigaddset(3C)	MT-Safe, Async-Signal-Safe
sigdelset(3C)	MT-Safe, Async-Signal-Safe
sigemptyset(3C)	MT-Safe, Async-Signal-Safe
sigfillset(3C)	MT-Safe, Async-Signal-Safe
sigfpe(3)	Safe
sigismember(3C)	MT-Safe, Async-Signal-Safe
siglongjmp(3C)	Unsafe
significand(3M)	MT-Safe
sigqueue(3R)	Async-Signal-Safe
sigsetjmp(3C)	Unsafe
sigsetops(3C)	MT-Safe, Async-Signal-Safe

Table B-1 MT Safety Levels of Library Routines

sigtimedwait(3R)	Async-Signal-Safe
sigwaitinfo(3R)	Async-Signal-Safe
sin(3M)	MT-Safe
single_to_decimal(3)	MT-Safe
sinh(3M)	MT-Safe
sleep(3B)	Async-Signal-Safe
sleep(3C)	Safe
slk_attroff(3X)	Unsafe
slk_attron(3X)	Unsafe
slk_attrset(3X)	Unsafe
slk_clear(3X)	Unsafe
slk_init(3X)	Unsafe
slk_label(3X)	Unsafe
slk_noutrefresh(3X)	Unsafe
slk_refresh(3X)	Unsafe
slk_restore(3X)	Unsafe
slk_set(3X)	Unsafe
slk_touch(3X)	Unsafe
socket(3N)	Safe
socketpair(3N)	Safe
space(3)	Safe
spray(3N)	Unsafe
sprintf(3S)	MT-Safe
sqrt(3M)	MT-Safe
srand(3C)	Unsafe
srand48(3C)	Safe
srandom(3C)	Unsafe
sscanf(3S)	MT-Safe
ssignal(3C)	Unsafe
standend(3X)	Unsafe
standout(3X)	Unsafe
start_color(3X)	Unsafe
step(3G)	MT-Safe
str(3G)	MT-Safe
strcadd(3G)	MT-Safe
strcasecmp(3C)	Safe
strcat(3C)	Safe

Table B-1 MT Safety Levels of Library Routines

strccpy(3G)	MT-Safe
strchr(3C)	Safe
strcmp(3C)	Safe
strcoll(3C)	Safe with exceptions
strcpy(3C)	Safe
strcspn(3C)	Safe
strdup(3C)	Safe
streadd(3G)	MT-Safe
strecpy(3G)	MT-Safe
strerror(3C)	Safe
strfind(3G)	MT-Safe
strfmon(3C)	MT-Safe
strftime(3C)	MT-Safe
string(3C)	Safe
string_to_decimal(3)	MT-Safe
strlen(3C)	Safe
strncasecmp(3C)	Safe
strncat(3C)	Safe
strncmp(3C)	Safe
strncpy(3C)	Safe
strpbrk(3C)	Safe
strptime(3C)	MT-Safe
strrchr(3C)	Safe
strrspn(3G)	MT-Safe
strsignal(3C)	Safe
strspn(3C)	Safe
strstr(3C)	Safe
strtod(3C)	MT-Safe
strtok(3C)	Unsafe, use strtok_r()
strtol(3C)	MT-Safe
strtoll(3C)	MT-Safe
strtoul(3C)	MT-Safe
strtoull(3C)	MT-Safe
strtrns(3G)	MT-Safe
strxfrm(3C)	Safe with exceptions
subpad(3X)	Unsafe
subwin(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

svcerr_auth(3N)	MT-Safe
svcerr_decode(3N)	MT-Safe
svcerr_noproc(3N)	MT-Safe
svcerr_noprog(3N)	MT-Safe
svcerr_progvers(3N)	MT-Safe
svcerr_systemerr(3N)	MT-Safe
svcerr_weakauth(3N)	MT-Safe
svcfd_create(3N)	Unsafe
svcraw_create(3N)	Unsafe
svctcp_create(3N)	Unsafe
svcudp_bufcreate(3N)	Unsafe
svcudp_create(3N)	Unsafe
svc_auth_reg(3N)	MT-Safe
svc_control(3N)	MT-Safe
svc_create(3N)	MT-Safe
svc_destroy(3N)	MT-Safe
svc_dg_create(3N)	MT-Safe
svc_fds(3N)	Unsafe
svc_fd_create(3N)	MT-Safe
svc_getcaller(3N)	Unsafe
svc_getreq(3N)	Unsafe
svc_kerb_reg(3N)	Unsafe
svc_raw_create(3N)	MT-Safe
svc_reg(3N)	MT-Safe
svc_register(3N)	Unsafe
svc_tli_create(3N)	MT-Safe
svc_tp_create(3N)	MT-Safe
svc_unreg(3N)	MT-Safe
svc_unregister(3N)	Unsafe
svc_vc_create(3N)	MT-Safe
swab(3C)	MT-Safe
swapcontext(3C)	MT-Safe
syncok(3X)	Unsafe
sysconf(3C)	MT-Safe, Async-Signal-Safe
syslog(3)	Safe
system(3S)	MT-Safe
taddr2uaddr(3N)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

tan(3M)	MT-Safe
tanh(3M)	MT-Safe
tcdrain(3)	MT-Safe, Async-Signal-Safe
tcflow(3)	MT-Safe, Async-Signal-Safe
tcflush(3)	MT-Safe, Async-Signal-Safe
tcgetattr(3)	MT-Safe, Async-Signal-Safe
tcgetpgrp(3)	MT-Safe, Async-Signal-Safe
tcgetsid(3)	MT-Safe
tcsendbreak(3)	MT-Safe, Async-Signal-Safe
tcsetattr(3)	MT-Safe, Async-Signal-Safe
tcsetpgrp(3)	MT-Safe, Async-Signal-Safe
tcsetpgrp(3C)	MT-Safe
tdelete(3C)	Safe
telldir(3C)	Safe
tempnam(3S)	Safe
termattrs(3X)	Unsafe
termname(3X)	Unsafe
textdomain(3I)	Safe with exceptions
tfind(3C)	Safe
tgetent(3X)	Unsafe
tgetflag(3X)	Unsafe
tgetnum(3X)	Unsafe
tgetstr(3X)	Unsafe
tgoto(3X)	Unsafe
threads(3T)	Fork1-Safe,MT-Safe,Async-Signal-Safe
thr_continue(3T)	MT-Safe
thr_create(3T)	MT-Safe
thr_exit(3T)	MT-Safe
thr_getconcurrency(3T)	MT-Safe
thr_getprio(3T)	MT-Safe
thr_getspecific(3T)	MT-Safe
thr_join(3T)	MT-Safe
thr_keycreate(3T)	MT-Safe
thr_kill(3T)	MT-Safe, Async-Signal-Safe
thr_main(3T)	MT-Safe
thr_min_stack(3T)	MT-Safe
thr_self(3T)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

thr_setconcurrency(3T)	MT-Safe
thr_setprio(3T)	MT-Safe
thr_setspecific(3T)	MT-Safe
thr_sigsetmask(3T)	MT-Safe, Async-Signal-Safe
thr_stksegment(3T)	MT-Safe
thr_suspend(3T)	MT-Safe
thr_yield(3T)	MT-Safe
tigetflag(3X)	Unsafe
tigetnum(3X)	Unsafe
tigetstr(3X)	Unsafe
timeout(3X)	Unsafe
timer_create(3R)	MT-Safe with exceptions
timer_delete(3R)	MT-Safe with exceptions
timer_getoverrun(3R)	Async-Signal-Safe
timer_gettime(3R)	Async-Signal-Safe
timer_settime(3R)	Async-Signal-Safe
tmpfile(3S)	Safe
tmpnam(3S)	Unsafe, use tmpnam_r()
TNF_DECLARE_RECORD(3X)	MT-Safe
TNF_DEFINE_RECORD(3.3X)	MT-Safe
TNF_DEFINE_RECORD_1(3X)	MT-Safe
TNF_DEFINE_RECORD_2(3X)	MT-Safe
TNF_DEFINE_RECORD_4(3X)	MT-Safe
TNF_DEFINE_RECORD_5(3X)	MT-Safe
TNF_PROBE(3.3X)	MT-Safe
TNF_PROBE(3X)	MT-Safe
TNF_PROBE_0(3X)	MT-Safe
TNF_PROBE_1(3X)	MT-Safe
TNF_PROBE_2(3X)	MT-Safe
TNF_PROBE_4(3X)	MT-Safe
TNF_PROBE_5(3X)	MT-Safe
tnf_process_disable(3X)	MT-Safe
tnf_process_enable(3X)	MT-Safe
tnf_thread_disable(3X)	MT-Safe
tnf_thread_enable(3X)	MT-Safe
toascii(3C)	MT-Safe with exceptions
tolower(3C)	MT-Safe with exceptions

Table B-1 MT Safety Levels of Library Routines

top_panel(3X)	Unsafe
top_row(3X)	Unsafe
touchline(3X)	Unsafe
touchwin(3X)	Unsafe
toupper(3C)	MT-Safe with exceptions
towlower(3I)	MT-Safe with exceptions
towupper(3I)	MT-Safe with exceptions
tparm(3X)	Unsafe
tputs(3X)	Unsafe
trig(3M)	MT-Safe
truncate(3C)	MT-Safe
tsearch(3C)	Safe
ttyname(3C)	Unsafe, use ttyname_r()
ttyslot(3C)	Safe
twalk(3C)	Safe
typeahead(3X)	Unsafe
t_accept(3N)	MT-Safe
t_alloc(3N)	MT-Safe
t_bind(3N)	MT-Safe
t_close(3N)	MT-Safe
t_connect(3N)	MT-Safe
t_error(3N)	MT-Safe
t_free(3N)	MT-Safe
t_getinfo(3N)	MT-Safe
t_getstate(3N)	MT-Safe
t_listen(3N)	MT-Safe
t_look(3N)	MT-Safe
t_open(3N)	MT-Safe
t_optmgmt(3N)	MT-Safe
t_rcv(3N)	MT-Safe
t_rcvconnect(3N)	MT-Safe
t_rcvdis(3N)	MT-Safe
t_rcvrel(3N)	MT-Safe
t_rcvudata(3N)	MT-Safe
t_rcvuderr(3N)	MT-Safe
t_snd(3N)	MT-Safe
t_snddis(3N)	MT-Safe

Table B-1 MT Safety Levels of Library Routines

t_sndrel(3N)	MT-Safe
t_sndudata(3N)	MT-Safe
t_strerror(3N)	Unsafe
t_sync(3N)	MT-Safe
t_unbind(3N)	MT-Safe
uaddr2taddr(3N)	MT-Safe
ulckpwdf(3C)	MT-Safe
ulltostr(3C)	MT-Safe
unctrl(3X)	Unsafe
ungetc(3S)	MT-Safe
ungetch(3X)	Unsafe
ungetwc(3I)	MT-Safe
ungetwch(3X)	Unsafe
unlockpt(3C)	Safe
unordered(3C)	MT-Safe
unpost_form(3X)	Unsafe
unpost_menu(3X)	Unsafe
untouchwin(3X)	Unsafe
update_panels(3X)	Unsafe
updwtmp(3C)	Unsafe
updwtmpx(3C)	Unsafe
user2netname(3N)	MT-Safe
use_env(3X)	Unsafe
utmpname(3C)	Unsafe
utmpxname(3C)	Unsafe
valloc(3C)	Safe
vfprintf(3S)	Async-Signal-Safe
vidattr(3X)	Unsafe
vidputs(3X)	Unsafe
vlfmt(3C)	MT-safe
volmgt_check(3X)	MT-Safe
volmgt_inuse(3X)	MT-Safe
volmgt_root(3X)	MT-Safe
volmgt_running(3X)	MT-Safe
volmgt_symdev(3X)	MT-Safe
volmgt_symname(3X)	MT-Safe
vpfmt(3C)	MT-safe

Table B-1 MT Safety Levels of Library Routines

vprintf(3S)	Async-Signal-Safe
vsprintf(3S)	MT-Safe
vsyslog(3)	Safe
vwprintw(3X)	Unsafe
vwscanw(3X)	Unsafe
waddch(3X)	Unsafe
waddchnstr(3X)	Unsafe
waddchstr(3X)	Unsafe
waddnstr(3X)	Unsafe
waddnwstr(3X)	Unsafe
waddstr(3X)	Unsafe
waddwch(3X)	Unsafe
waddwchnstr(3X)	Unsafe
waddwchstr(3X)	Unsafe
waddwstr(3X)	Unsafe
wadjcurspos(3X)	Unsafe
watof(3I)	MT-Safe
watoi(3I)	MT-Safe
watol(3I)	MT-Safe
watoll(3I)	MT-Safe
wattroff(3X)	Unsafe
wattron(3X)	Unsafe
wattrset(3X)	Unsafe
wbkgd(3X)	Unsafe
wbkgdset(3X)	Unsafe
wborder(3X)	Unsafe
wclear(3X)	Unsafe
wclrtobot(3X)	Unsafe
wclrtoeol(3X)	Unsafe
wconv(3I)	MT-Safe with exceptions
wcscat(3I)	MT-Safe
wcschr(3I)	MT-Safe
wcscmp(3I)	MT-Safe
wcscoll(3I)	MT-Safe
wcscpy(3I)	MT-Safe
wcscspn(3I)	MT-Safe
wcsetno(3I)	MT-Safe with exceptions

Table B-1 MT Safety Levels of Library Routines

wcslen(3I)	MT-Safe
wcsncat(3I)	MT-Safe
wcsncmp(3I)	MT-Safe
wcsncpy(3I)	MT-Safe
wcspbrk(3I)	MT-Safe
wcsrchr(3I)	MT-Safe
wcsspn(3I)	MT-Safe
wcstod(3I)	MT-Safe
wcstok(3I)	MT-Safe
wcstol(3I)	MT-Safe
wcstombs(3C)	MT-Safe with exceptions
wcstoul(3I)	MT-Safe
wcstring(3I)	MT-Safe
wcswcs(3I)	MT-Safe
wcswidth(3I)	MT-Safe
wcsxfrm(3I)	MT-Safe
wctomb(3C)	MT-Safe with exceptions
wctype(3I)	MT-Safe
wcursyncup(3X)	Unsafe
wcwidth(3I)	MT-Safe
wdelch(3X)	Unsafe
wdeleteln(3X)	Unsafe
wechochar(3X)	Unsafe
wechowchar(3X)	Unsafe
werase(3X)	Unsafe
wgetch(3X)	Unsafe
wgetnstr(3X)	Unsafe
wgetnwstr(3X)	Unsafe
wgetstr(3X)	Unsafe
wgetwch(3X)	Unsafe
wgetwstr(3X)	Unsafe
whline(3X)	Unsafe
winch(3X)	Unsafe
winchnstr(3X)	Unsafe
winchstr(3X)	Unsafe
windex(3I)	MT-Safe
winnstr(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

winnwstr(3X)	Unsafe
winsch(3X)	Unsafe
winsdelln(3X)	Unsafe
winsertln(3X)	Unsafe
winsnstr(3X)	Unsafe
winsnwstr(3X)	Unsafe
winsstr(3X)	Unsafe
winstr(3X)	Unsafe
winswch(3X)	Unsafe
winswstr(3X)	Unsafe
winwch(3X)	Unsafe
winwchnstr(3X)	Unsafe
winwchstr(3X)	Unsafe
winwstr(3X)	Unsafe
wmove(3X)	Unsafe
wmovenextch(3X)	Unsafe
wmoveprevch(3X)	Unsafe
wnoutrefresh(3X)	Unsafe
wordexp(3C)	MT-Safe
wordfree(3C)	MT-Safe
wprintw(3X)	Unsafe
wredrawln(3X)	Unsafe
wrefresh(3X)	Unsafe
wrindex(3I)	MT-Safe
write_vtoc(3X)	Unsafe
wscanw(3X)	Unsafe
wscasecmp(3I)	MT-Safe
wscat(3I)	MT-Safe
wschr(3I)	MT-Safe
wscmp(3I)	MT-Safe
wscol(3I)	MT-Safe
wscoll(3I)	MT-Safe
wscpy(3I)	MT-Safe
wscrl(3X)	Unsafe
wscspn(3I)	MT-Safe
wsdup(3I)	MT-Safe
wsetscrreg(3X)	Unsafe

Table B-1 MT Safety Levels of Library Routines

wslen(3I)	MT-Safe
wsncasecmp(3I)	MT-Safe
wsncat(3I)	MT-Safe
wsncmp(3I)	MT-Safe
wsncpy(3I)	MT-Safe
wspbrk(3I)	MT-Safe
wsprintf(3I)	MT-Safe
wsrchr(3I)	MT-Safe
wsscanf(3I)	MT-Safe
wsspn(3I)	MT-Safe
wstandend(3X)	Unsafe
wstandout(3X)	Unsafe
wstod(3I)	MT-Safe
wstok(3I)	MT-Safe
wstol(3I)	MT-Safe
wstring(3I)	MT-Safe
wsxfrm(3I)	MT-Safe
wsyncdown(3X)	Unsafe
wsyncup(3X)	Unsafe
wtimeout(3X)	Unsafe
wtouchln(3X)	Unsafe
wvline(3X)	Unsafe
xdr(3N)	Safe
xdrmem_create(3N)	MT-Safe
xdrrec_create(3N)	MT-Safe
xdrrec_endofrecord(3N)	Safe
xdrrec_eof(3N)	Safe
xdrrec_readbytes(3N)	Safe
xdrrec_skiprecord(3N)	Safe
xdrstdio_create(3N)	MT-Safe
xdr_accepted_reply(3N)	Safe
xdr_admin(3N)	Safe
xdr_array(3N)	Safe
xdr_authsys_parms(3N)	Safe
xdr_authunix_parms(3N)	Unsafe
xdr_bool(3N)	Safe
xdr_bytes(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

xdr_callhdr(3N)	Safe
xdr_callmsg(3N)	Safe
xdr_char(3N)	Safe
xdr_complex(3N)	Safe
xdr_control(3N)	Safe
xdr_create(3N)	MT-Safe
xdr_destroy(3N)	MT-Safe
xdr_double(3N)	Safe
xdr_enum(3N)	Safe
xdr_float(3N)	Safe
xdr_free(3N)	Safe
xdr_getpos(3N)	Safe
xdr_hyper(3N)	Safe
xdr_inline(3N)	Safe
xdr_int(3N)	Safe
xdr_long(3N)	Safe
xdr_longlong_t(3N)	Safe
xdr_opaque(3N)	Safe
xdr_opaque_auth(3N)	Safe
xdr_pointer(3N)	Safe
xdr_quadruple(3N)	Safe
xdr_reference(3N)	Safe
xdr_rejected_reply(3N)	Safe
xdr_replymsg(3N)	Safe
xdr_setpos(3N)	Safe
xdr_short(3N)	Safe
xdr_simple(3N)	Safe
xdr_sizeof(3N)	Safe
xdr_string(3N)	Safe
xdr_union(3N)	Safe
xdr_u_char(3N)	Safe
xdr_u_hyper(3N)	Safe
xdr_u_int(3N)	Safe
xdr_u_long(3N)	Safe
xdr_u_longlong_t(3N)	Safe
xdr_u_short(3N)	Safe
xdr_vector(3N)	Safe

Table B-1 MT Safety Levels of Library Routines

xdr_void(3N)	Safe
xdr_wrapstring(3N)	Safe
xprt_register(3N)	MT-Safe
xprt_unregister(3N)	MT-Safe
y0(3M)	MT-Safe
y1(3M)	MT-Safe
yn(3M)	MT-Safe
ypclnt(3N)	Unsafe
yperr_string(3N)	Unsafe
ypprot_err(3N)	Unsafe
yp_all(3N)	Unsafe
yp_bind(3N)	Unsafe
yp_first(3N)	Unsafe
yp_get_default_domain(3N)	Unsafe
yp_master(3N)	Unsafe
yp_match(3N)	Unsafe
yp_next(3N)	Unsafe
yp_order(3N)	Unsafe
yp_unbind(3N)	Unsafe
yp_update(3N)	Unsafe
_NOTE(3X)	Safe
_tolower(3C)	MT-Safe with exceptions
_toupper(3C)	MT-Safe with exceptions
__nis_map_group(3N)	MT-Safe

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