

Fall 2004 Handout 9

Pthreads

The purpose of threads is to avoid **fork/exec/wait** and semaphores:

<i>Unix system calls</i>	<i>Pthreads</i>
fork	pthread_create
exec	
waitpid	pthread_join
exit	pthread_exit
kill(, SIGKILL)	pthread_cancel
getpid	pthread_self
semget(IPC_CREAT	pthread_mutex_init
semop(decrement	pthread_mutex_lock
semop(increment	pthread_mutex_unlock
semctl(IPC_RMID	pthread_mutex_destroy

See *Pthreads Programming* by Bradford Nichols, Dick Buttlar, and Jacqueline Proulx Farrell; O'Reilly & Associates, 1996; ISBN 1-56592-115-1.

<http://www.oreilly.com/catalog/pthread/>

Pthreads are like processes, except

- (1) They're faster to create, destroy, and have take turns because the operating system doesn't necessarily know about them (but see the **-L** option of **ps**; **-m** on other systems).
- (2) There is no concept of "parent" and "child": any thread in a process can wait for (or cause) the death of any other thread in the process. The original thread is informally called the *main thread* (pp. 13, 15 in the Pthreads book).
- (3) A child executes the body of an **if** statement. A thread executes the body of a function, called the thread's *start routine*. The start routine can take only one argument, which must be a pointer to **void**. If you need more arguments, put them into a structure and pass a pointer to the structure.
- (4) All the threads of a process share the same global variables.

When does a thread die?

- (1) A process dies by calling **exit**, or by **return**'ing from **main**, or by receiving a fatal signal (e.g., **SIGKILL**). When the process dies, all the threads inside of it die with it.
- (2) A thread dies by calling **pthread_exit**, or by **return**'ing from its start routine. (Another thread can wait for it to die by calling **pthread_join**. If no one will call **pthread_join**, call **pthread_detach** so that the zombie thread will disappear immediately.)
- (3) One thread can kill another by calling **pthread_cancel**. The main thread cannot be cancelled because it has no **pthread_t** to be the first argument of **pthread_cancel**.

An echo client, with two threads instead of two processes

—Source code on the Web at <http://i5.nyu.edu/~mm64/x52.9544/src/pthread1.c>

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

```
2 #include <stdlib.h>
3 #include <unistd.h> /* for getpid */
4 #include <string.h>
5 #include <pthread.h>
6 #include <errno.h> /* for ESRCH */
7
8 #include <sys/types.h>
9 #include <sys/socket.h>
10 #include <netinet/in.h>
11
12 char *progname;
13 void *thread_function(void *s);
14
15 int main(int argc, char **argv)
16 {
17     const int s = socket(AF_INET, SOCK_STREAM, 0);
18     struct sockaddr_in address;
19     char buffer[INET_ADDRSTRLEN]; /* for inet_ntop */
20     pthread_t thread;
21     int retval; /* instead of errno */
22     char c; /* write requires a char: KR p. 170 */
23
24     progname = argv[0];
25     if (s < 0) {
26         perror(progname);
27         return 1;
28     }
29
30     bzero((char *)&address, sizeof address);
31     address.sin_family = AF_INET;
32     address.sin_port = htons(7);
33
34     /* IP address for smail.let.uu.nl: */
35     retval = inet_pton(AF_INET, "131.211.194.40", &address.sin_addr);
36     if (retval == 0) {
37         fprintf(stderr, "%s: bad dotted string to inet_pton\n", argv[0]);
38         return 2;
39     } else if (retval != 1) {
40         perror(argv[0]);
41         return 3;
42     }
43
44     if (inet_ntop(AF_INET, &address.sin_addr, buffer, sizeof buffer) == NULL) {
45         perror(argv[0]);
46         return 4;
47     }
48     printf("Trying %s...\n", buffer);
49
50     if (connect(s, (struct sockaddr *)&address, sizeof address) != 0) {
51         perror(progname);
52         return 5;
53     }
54
55     printf("Connected to smail.let.uu.nl.\n")
```

```
56     "Escape character is '^d'.\n");
57
58     if (pthread_create(&thread, NULL, thread_function, (void *)&s) != 0) {
59         perror(progname);
60         return 6;
61     }
62
63     retval = pthread_detach(thread);
64     if (retval != 0) {
65         fprintf(stderr, "%s: pthread_detach returned %d.\n", argv[0], retval);
66         return 7;
67     }
68
69     sprintf(buffer, "ps -Lf -p %d", getpid());
70     system(buffer);
71
72     /*
73     The main thread will copy from the server to the stdout.
74     */
75     while (read(s, &c, 1) == 1) {
76         putchar(c);
77     }
78
79     /*
80     Arrive here after receiving EOF from the server.
81     */
82     fprintf(stderr, "Connection closed by foreign host.\n");
83
84     /*
85     If pthread_cancel returns ESRCH, it means that the thread has already
86     died before we had a chance to cancel it.
87     */
88     retval = pthread_cancel(thread);
89     if (retval != 0 && retval != ESRCH) {
90         fprintf(stderr, "%s: pthread_cancel returned %d.\n", argv[0], retval);
91         return 8;
92     }
93
94     if (shutdown(s, SHUT_RDWR) != 0) {
95         perror(progname);
96         return 9;
97     }
98
99     return EXIT_SUCCESS;
100 }
101
102 void *thread_function(void *s)
103 {
104     const int fd = *(int *)s;
105     int i;
106
107     /*
108     This thread will copy from the stdin to the server.
109     */
```

```

110  while ((i = getchar()) != EOF) {
111      const char c = i;
112      write(fd, &c, 1);
113  }
114
115  if (shutdown(fd, SHUT_WR) != 0) { /* close socket for writing */
116      perror(progname);
117      exit(10);
118  }
119 }

```

```
3$ gcc -o ~/bin/pthread1 pthread1.c -lsocket -lnsl -lpthread
```

```
4$ ls -l ~/bin/pthread1
```

```
5$ pthread1
```

```
Trying 131.211.194.40...
```

```
Connected to smail.let.uu.nl.
```

```
Escape character is '^d'.
```

UID	PID	PPID	LWP	NLWP	C	STIME	TTY	LTIME	CMD
mm64	24875	23445	1	4	0	15:48:24	pts/2	0:00	pthread1
mm64	24875	23445	2	4	0	15:48:24	pts/2	0:00	pthread1
mm64	24875	23445	3	4	0	15:48:24	pts/2	0:00	pthread1
mm64	24875	23445	4	4	0	15:48:24	pts/2	0:00	pthread1

```
hello
```

```
hello
```

```
goodbye
```

```
goodbye
```

```
control-d
```

```
Connection closed by foreign host.
```

```
6$ echo $?
```

```
0
```

Also try connecting to port 13 (daytime) of 129.206.218.89 (www.urz.uni-heidelberg.de).

Serve more than one client simultaneously with threads

The above program created exactly one thread, so all we had to do was declare exactly one `pthread_t` (line 19) and exactly one `s` (line 16) The following program creates an unpredictable number of threads, so we have to use `malloc` and `free` to manufacture each thread's argument.

—Source code on the Web at <http://i5.nyu.edu/~mm64/x52.9544/src/pthread2.c>

```

1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <string.h>
4 #include <pthread.h>
5
6 #include <sys/types.h>
7 #include <sys/socket.h>
8 #include <netinet/in.h>
9
10 char *progname;
11 void *thread_function(void *s);
12
13 int main(int argc, char **argv)

```

```
14 {
15     const int s = socket(AF_INET, SOCK_STREAM, 0);
16     struct sockaddr_in myaddress;
17     struct sockaddr_in clientaddress;
18     socklen_t length = sizeof clientaddress;
19
20     progname = argv[0];
21     if (s < 0) {
22         perror(progname);
23         return 1;
24     }
25
26     bzero((char *)&myaddress, sizeof myaddress);
27     myaddress.sin_family = AF_INET;
28     myaddress.sin_port = htons(9266);
29     myaddress.sin_addr.s_addr = INADDR_ANY;
30
31     if (bind(s, (const struct sockaddr *)&myaddress, sizeof myaddress) != 0) {
32         perror(progname);
33         return 2;
34     }
35
36     if (listen(s, SOMAXCONN) != 0) {
37         perror(progname);
38         return 3;
39     }
40
41     for (;;) {
42         pthread_t thread;
43         int retval;
44
45         /*
46         file descriptor for talking to each new client
47         */
48         int *const pclient = malloc(sizeof (int));
49         if (pclient == NULL) {
50             perror(progname);
51             return 4;
52         }
53
54         *pclient = accept(s, (struct sockaddr *)&clientaddress, &length);
55         if (*pclient < 0) {
56             perror(progname);
57             return 5;
58         }
59
60         retval = pthread_create(&thread, NULL, thread_function, pclient);
61         if (retval != 0) {
62             fprintf(stderr, "%s: pthread_create returned %d.\n",
63                 argv[0], retval);
64             return 6;
65         }
66
67         retval = pthread_detach(thread);
```

```
68     if (retval) {
69         fprintf(stderr, "%s: pthread_detach returned %d.\n",
70             argv[0], retval);
71         return 7;
72     }
73 }
74 }
75
76 void *thread_function(void *s)
77 {
78     const int client = *(int *)s;
79     char buffer[2];
80
81     /*
82     The service provided by this server is merely to input one character
83     and then output it in lowercase, followed by a newline.
84     */
85
86     if (read(client, buffer, 1) != 1) {
87         perror(progname);
88         exit(8);
89     }
90
91     buffer[0] = tolower(buffer[0]);
92     buffer[1] = '\n';
93
94     if (write(client, buffer, sizeof buffer) != sizeof buffer) {
95         perror(progname);
96         exit(9);
97     }
98
99     if (shutdown(client, SHUT_RDWR) != 0) {
100         perror(progname);
101         exit(10);
102     }
103
104     free(s);
105 }
```

```
1$ gcc -o ~/bin/pthread2 pthread2.c -lsocket -lnsl -lpthread
```

```
2$ ls -l ~/bin/pthread2
```

```
3$ pthread2 &
```

```
4$ netstat -an | grep 9266
```

```
5$ telnet i5.nyu.edu 9266
```

```
Trying 128.122.108.193...
```

```
Connected to i5.nyu.edu.
```

```
Escape character is '^['.
```

```
A
```

```
a
```

```
Connection closed by foreign host.
```

Protect critical sections with a mutex variable

Here's a program that creates one thread. The main thread and the created thread will then both increment the global `int n`.

—Source code on the Web at <http://i5.nyu.edu/~mm64/x52.9544/src/mutex.c>

```
1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <pthread.h>
4
5 void *thread_function(void *p);
6
7 const char *programe;
8 int n = 0;
9 pthread_mutex_t mutex; /* protects n */
10
11 int main(int argc, char **argv)
12 {
13     pthread_t thread;
14     void *status;
15     int retval;
16
17     programe = argv[0];
18
19     retval = pthread_mutex_init(&mutex, NULL);
20     if (retval != 0) {
21         fprintf(stderr, "%s: pthread_mutex_init returned %d.\n",
22             argv[0], retval);
23         return 1;
24     }
25
26     if (pthread_create(&thread, NULL,
27         thread_function, &n) != 0) {
28         perror(programe);
29         return 2;
30     }
31
32     if (pthread_mutex_lock(&mutex) != 0) {
33         perror(programe);
34         return 3;
35     }
36     /* Start of critical section. */
37
38     ++n;
39
40     /* End of critical section. */
41     if (pthread_mutex_unlock(&mutex) != 0) {
42         perror(programe);
43         return 4;
44     }
45
46     if (pthread_join(thread, &status) != 0) { /* like waitpid */
47         perror(programe);
48         return 5;
49     }
```

```

50
51     if (pthread_mutex_destroy(&mutex) < 0) {
52         perror(progname);
53         return 6;
54     }
55
56     printf("n == %d, and the thread returned \"%s\".\n",
57           n, (char *)status);
58 }
59
60 void *thread_function(void *p)
61 {
62     if (pthread_mutex_lock(&mutex) != 0) {
63         perror(progname);
64         exit(7);
65     }
66     /* Start of critical section. */
67
68     ++*(int *)p;
69
70     /* End of critical section. */
71     if (pthread_mutex_unlock(&mutex) != 0) {
72         perror(progname);
73         exit(8);
74     }
75
76     pthread_exit("goodbye");
77 }

```

n == 2 and the thread returned "goodbye".

Wait until something happens

The main thread should wait until the variable `count` assumes the value `n`.

```

1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <pthread.h>
4
5 const int n = 10;
6 int count = 0;
7 pthread_mutex_t mutex; /* protects count */
8 char *progname;
9
10 void thread_function(void *p);
11
12 int main(int argc, char **argv)
13 {
14     pthread_t thread;
15     int keep_looping = 1;
16
17     progname = argv[0];
18
19     if (pthread_mutex_init(&mutex, pthread_mutexattr_default) != 0) {
20         perror(progname);

```

```
21     return 1;
22 }
23
24 if (pthread_create(&thread, pthread_attr_default,
25     (pthread_startroutine_t)thread_function, NULL) != 0) {
26     perror(progname);
27     return 2;
28 }
29
30 if (pthread_detach(&thread) != 0) {
31     perror(progname);
32     return 3;
33 }
34
35 /* Wait until count == n. */
36 while (keep_looping) {
37     if (pthread_mutex_lock(&mutex) != 0) {
38         perror(progname);
39         return 4;
40     }
41     /* Start of critical section. */
42
43     if (count == n) {
44         keep_looping = 0;
45     }
46
47     /* End of critical section. */
48     if (pthread_mutex_unlock(&mutex) != 0) {
49         perror(progname);
50         return 5;
51     }
52 }
53
54 if (pthread_mutex_destroy(&mutex) != 0) {
55     perror(progname);
56     return 6;
57 }
58
59 printf ("count has reached %d.\n", n);
60 return EXIT_SUCCESS;
61 }
62
63 void thread_function(void *p)
64 {
65     int i;
66
67     for (i = 0; i < n; ++i) {
68         if (pthread_mutex_lock(&mutex) != 0) {
69             perror(progname);
70             exit(7);
71         }
72         /* Start of critical section. */
73
74         ++count;
```

```

75
76     /* End of critical section. */
77     if (pthread_mutex_unlock(&mutex) != 0) {
78         perror(progname);
79         exit(8);
80     }
81 }
82
83 for (;;) {
84     /* lots of other work */
85 }
86 }

```

count has reached 10.

Wait until something happens, using condition variables

The main thread should wait until the variable `count` assumes the value `n`.

Write a logical expression (called a *predicate*) in a comment alongside the declaration of a condition variable (line 8). The condition variable will wake all the threads that are waiting for the predicate to become true.

The predicate will usually contain another variable (in this case, `count`) that will be used by more than one thread. `count` must therefore be protected by a `mutex` to make sure that only at most one thread at a time will access it. Whenever you have a condition variable, you therefore usually also need a `mutex`: the condition variable alone is not enough.

The `pthread_cond_wait` in line 48 takes pointers to a condition variable and the `mutex` that protects the variable in the condition variable's predicate. The `mutex` must already be locked (line 41). `pthread_cond_wait` unlocks the `mutex` and then waits until some other thread calls `pthread_cond_signal`. (If `pthread_cond_wait` didn't unlock the `mutex`, then no other thread could change `count` and `pthread_cond_wait` would wait forever.)

When the predicate finally becomes true (line 85), some other thread calls `pthread_cond_signal` in line 86. Note that the other thread locks the `mutex` (line 79) before calling `pthread_cond_signal`, and unlocks the mutex afterward (line 93).

After the `pthread_cond_signal` is called in line 86 and the `mutex` is unlocked in line 93, the `pthread_cond_wait` locks the `mutex` again and returns. To sum up: the `mutex` must be locked before the call to `pthread_cond_wait` in line 86, and is guaranteed to be locked when we return from `pthread_cond_wait`, but is unlocked and locked again during the call.

One final complication. After the `pthread_cond_signal` is called in line 86 and the `mutex` is unlocked in line 93, but before the `pthread_cond_wait` locks the `mutex` again and returns, it is possible for some other thread to quickly lock the `mutex`, decrement `count`, and unlock the `mutex`. When we return from `pthread_cond_wait`, we may therefore find that the predicate we've been waiting for, `count == n`, is false. In this case, we must call `pthread_cond_wait` again, and as many times as necessary. Therefore change the `if` to `while` in line 47. (This is also necessary because of *spurious wakeups*.)

```

41 lock
48 unlock
   79 lock
   86 signal
   93 unlock
48 lock
55 unlock

```

```
1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <pthread.h>
4
5 const int n = 10;
6 int count = 0;
7 pthread_mutex_t mutex;      /* protects count */
8 pthread_cond_t condition;  /* count == n */
9 char *programe;
10
11 void *thread_function(void *p);
12
13 int main(int argc, char **argv)
14 {
15     pthread_t thread;
16
17     programe = argv[0];
18
19     if (pthread_mutex_init(&mutex, pthread_mutexattr_default) != 0) {
20         perror(programe);
21         return 1;
22     }
23
24     if (pthread_cond_init(&condition, pthread_condattr_default) != 0) {
25         perror(programe);
26         return 2;
27     }
28
29     if (pthread_create(&thread, pthread_attr_default,
30         (pthread_startroutine_t)thread_function, NULL) != 0) {
31         perror(programe);
32         return 3;
33     }
34
35     if (pthread_detach(&thread) != 0) {
36         perror(programe);
37         return 4;
38     }
39
40     /* Wait until count == n. */
41     if (pthread_mutex_lock(&mutex) != 0) {
42         perror(programe);
43         return 5;
44     }
45     /* Start of critical section. */
46
47     if (count != n) {                /* change "if" to "while" */
48         if (pthread_cond_wait(&condition, &mutex) != 0) {
49             perror(programe);
50             return 6;
51         }
52     }
53
54     /* End of critical section. */
```

```
55     if (pthread_mutex_unlock(&mutex) != 0) {
56         perror(progname);
57         return 7;
58     }
59
60     if (pthread_cond_destroy(&condition) != 0) {
61         perror(progname);
62         return 8;
63     }
64
65     if (pthread_mutex_destroy(&mutex) != 0) {
66         perror(progname);
67         return 9;
68     }
69
70     printf ("count has reached %d.\n", n);
71     return EXIT_SUCCESS;
72 }
73
74 void *thread_function(void *p)
75 {
76     int i;
77
78     for (i = 0; i < n; ++i) {
79         if (pthread_mutex_lock(&mutex) != 0) {
80             perror(progname);
81             exit(10);
82         }
83         /* Start of critical section. */
84
85         if (++count == n) {
86             if (pthread_cond_signal(&condition) != 0) {
87                 perror(progname);
88                 exit(11);
89             }
90         }
91
92         /* End of critical section. */
93         if (pthread_mutex_unlock(&mutex) != 0) {
94             perror(progname);
95             exit(12);
96         }
97     }
98
99     for (;;) {
100         /* lots of other work */
101     }
102 }
```

count has reached 10.

Use `pthread_cond_timedwait` instead of `pthread_cond_wait` in line 48

```

1 /* Excerpt from /usr/include/sys/timers.h. */
2
3 typedef struct timespec {
4     time_t    tv_sec;    /* seconds */
5     long     tv_nsec;    /* nanoseconds */
6 } timespec_t;

1 #include <errno.h>
2 #include <pthread.h>    /* don't need to include timers.h */
3
4     timespec_t how_long = {1, 0};
5     timespec_t absolute;
6
7     if (pthread_get_expiration_np(&how_long, &absolute) != 0) {
8         perror(progname);
9         return 1;
10    }
11
12    printf ("%d seconds, %ld nanoseconds\n", absolute.tv_sec, absolute.tv_nsec);
13
14    if (pthread_cond_timedwait(&condition, &mutex, &absolute) != 0) {
15        if (errno == EAGAIN) {
16            printf ("The time has expired.\n");
17        } else {
18            perror(progname);
19            return 2;
20        }
21    }

```

```
1072224000 seconds, 809168000 nanoseconds
```

```

1$ bc
(2004 - 1970) * 60 * 60 * 24 * 365
1072224000
control-d
2$

```

Use `pthread_cond_broadcast` instead of `pthread_cond_signal` in line 86

`pthread_cond_signal` wakes only one waiting thread; `pthread_cond_broadcast` wakes them all (in order of scheduling priority).

```

1     if (pthread_cond_broadcast(&condition) != 0) {
2         perror(progname);
3         exit(11);
4     }

```

A spectacular example from the O'Reilly pthreads book, pp. 84–89

Assume that many threads want to read and write the same block of shared memory. It's okay for any number of threads to read the block simultaneously. But while one thread is writing, all other threads should be prevented from writing or reading.

There are two kinds of locks: a read lock and a write lock. A thread that tries to get a read lock will have to wait until there are no other threads writing. A thread that tries to get a write lock will have to wait until there are no other threads reading or writing.

Here's the user code:

```

1 /* Initialization. */
2 #include <pthread.h>
3 pthread_rwlock_t lock;
4
5     if (pthread_rwlock_init_np(&lock, pthread_rwlock_default) != 0) {
6         perror(progname);
7         exit(1);
8     }
9
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```

```
5     pthread_cond_t condition;          /* readers == 0 || writers == 0 */
6 } pthread_rwlock_t;
7
8 typedef void *pthread_rwlockattr_t;
9 #define pthread_rwlock_default ((pthread_rwlockattr_t)NULL)
10
11 int pthread_rwlock_init_np(pthread_rwlock_t *lock, pthread_rwlockattr_t attr)
12 {
13     lock->readers = 0;
14     lock->writers = 0;
15
16     if (pthread_mutex_init(&lock->mutex, pthread_mutexattr_default) != 0) {
17         return -1;
18     }
19
20     if (pthread_cond_init(&lock->condition, pthread_condattr_default) != 0) {
21         return -1;
22     }
23
24     return 0;
25 }
26
27 int pthread_rwlock_rlock_np(pthread_rwlock_t *lock)
28 {
29     if (pthread_mutex_lock(&lock->mutex) != 0) {
30         return -1;
31     }
32     /* Start of critical section. */
33
34     while (lock->writers > 0) {
35         if (pthread_cond_wait(&lock->condition, &lock->mutex) != 0) {
36             return -1;
37         }
38     }
39
40     ++lock->readers;
41
42     /* End of critical section. */
43     if (pthread_mutex_unlock(&lock->mutex) != 0) {
44         return -1;
45     }
46
47     return 0;
48 }
49
50 int pthread_rwlock_wlock_np(pthread_rwlock_t *lock)
51 {
52     if (pthread_mutex_lock(&lock->mutex) != 0) {
53         return -1;
54     }
55     /* Start of critical section. */
56
57     while (lock->readers > 0 || lock->writers > 0) {
58         if (pthread_cond_wait(&lock->condition, &lock->mutex) != 0) {
```

```
59         return -1;
60     }
61 }
62
63 lock->writers = 1;
64
65 /* End of critical section. */
66 if (pthread_mutex_unlock(&lock->mutex) != 0) {
67     return -1;
68 }
69
70 return 0;
71 }
72
73 /*
74 Only writers, not readers, could be waiting for the following signal, and only
75 one writer could take advantage of it. Therefore we call pthread_cond_signal
76 instead of pthread_cond_broadcast.
77 */
78
79 int pthread_rdwr_runlock_np(pthread_rdwr_t *lock)
80 {
81     if (pthread_mutex_lock(&lock->mutex) != 0) {
82         return -1;
83     }
84     /* Start of critical section. */
85
86     if (lock->readers <= 0) {
87         /* User forgot previous call to pthread_rdwr_rlock_np. */
88         return -1;
89     }
90
91     if (--lock->readers == 0) {
92         if (pthread_cond_signal(&lock->condition, &lock->mutex) != 0) {
93             return -1;
94         }
95     }
96
97     /* End of critical section. */
98     if (pthread_mutex_unlock(&lock->mutex) != 0) {
99         return -1;
100    }
101
102    return 0;
103 }
104
105 /*
106 Both writers and readers could be waiting for the following signal, and more
107 than one of them (i.e, all the readers) could take advantage of it. Therefore
108 we call pthread_cond_broadcast instead of pthread_cond_signal.
109 */
110
111 int pthread_rdwr_wunlock_np(pthread_rdwr_t *lock)
112 {
```

```

113     if (pthread_mutex_lock(&lock->mutex) != 0) {
114         return -1;
115     }
116     /* Start of critical section. */
117
118     if (lock->writers != 1) {
119         /* User forgot previous call to pthread_rdwr_rwlock_np. */
120         return -1;
121     }
122
123     lock->writers = 0;
124     if (pthread_cond_broadcast(&lock->condition, &lock->mutex) != 0) {
125         return -1;
126     }
127
128     /* End of critical section. */
129     if (pthread_mutex_unlock(&lock->mutex) != 0) {
130         return -1;
131     }
132
133     return 0;
134 }

```

Set the thread's stack size

```

1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <pthread.h>
4
5 void *thread_function(void *p);
6
7 int main(int argc, char **argv)
8 {
9     pthread_t thread;
10    pthread_attr_t attr;
11    long size;
12
13    if (pthread_attr_create(&attr) != 0) {
14        perror(argv[0]);
15        return 1;
16    }
17
18    if (pthread_attr_setstacksize(&attr, 1024L * 10L) != 0) {
19        perror(argv[0]);
20        return 2;
21    }
22
23    size = pthread_attr_getstacksize(attr);
24    if (size < 0) {
25        perror(argv[0]);
26        return 3;
27    }
28    printf("The stack size is %ld.\n", size);
29

```

```

30     if (pthread_create(&thread, attr,
31         (pthread_startroutine_t)thread_function, NULL) != 0) {
32         perror(argv[0]);
33         return 4;
34     }
35
36     if (pthread_attr_delete(&attr) != 0) {
37         perror(argv[0]);
38         return 5;
39     }
40
41     if (pthread_detach(&thread) != 0) {
42         perror(argv[0]);
43         return 6;
44     }
45
46     return EXIT_SUCCESS;
47 }
48
49 void *thread_function(void *p)
50 {
51 }

```

The stack size is 10240.

Make sure that an initialization is performed exactly once

```

1 void init(void);
2
3 /* not initialized by calling a function: */
4 pthread_once_t once = pthread_once_init;

```

Each thread should do the following. It's more efficient than using a flag protected by a **mutex**.

```

1     if (pthread_once(&once, init) != 0) {
2         perror(progname);
3         exit(1);
4     }
5     /* At this point, init has been called exactly once. */

```

Give each thread its own data

```

1 typedef struct {
2     pthread_t thread;
3     int i;
4 } data;
5
6 #define N 3
7 data d[N];
8
9     int i;
10    for (i = 0; i < N; ++i) {
11        d[i].i = i;
12        if (pthread_create(&d[i].thread, pthread_attr_default,
13            (pthread_startroutine_t)thread_function, NULL) != 0) {

```

```

14         perror(progname);
15         exit(1);
16     }
17 }

```

Now each thread could say

```

1  int i;
2  thread_t thread;
3
4  for (i = 0; i < N; ++i) {
5      thread = pthread_self();
6      if (pthread_equal(&d[i].thread, &thread)) {
7          goto found;
8      }
9  }
10
11  fprintf(stderr, "%s: couldn't find myself\n", progname);
12  exit(1);
13
14  found:;
15  Use d[i].i;

```

Give each thread its own data, using keys

```

1 pthread_key_t key;
2
3  int i;
4  pthread_t thread;
5  char *p;
6
7  if (pthread_key_create(&key, free) != 0) {
8      perror(progname);
9      exit(1);
10 }
11
12 for (i = 0; i < N; ++i) {
13     if (pthread_create(&thread, pthread_attr_default,
14         (pthread_startroutine_t)thread_function, NULL) != 0) {
15         perror(progname);
16         exit(2);
17     }
18
19     p = malloc(10);
20     if (p == NULL) {
21         fprintf("%s: couldn't allocate memory\n", progname);
22         exit(3);
23     }
24
25     if (pthread_setspecific(key, (pthread_addr_t)p) != 0) {
26         perror(progname);
27         exit(4);
28     }
29 }

```

Now each thread could say

```
1  char *p;
2
3  if (pthread_getspecific(key, (pthread_addr_t)&p) != 0) {
4      perror(progname);
5      exit(4);
6  }
7
8  printf ("%s\n", p);
```

□