# Fall 2004 Handout 5

**Create a region of shared memory: Bach pp. 367−370; Curry pp. 383−385**

See **shmget**(2), **shmat**(2), **shmctl**(2), **ipcs**(1), and **ipcrm**(1).

```
1$ pr -l60 /usr/include/sys/shm.h | lpr
```
*minus lowercase L sixty*

Create a **.h** file for each region of memory that many C programs will share. Put the **.h** file into the directory you will be in when you give the **gcc** command to compile your **.c** files. See K&R pp. 88, 231.

```
1 /* This file is shm_array.h. */
2 #define SHM_KEY 12345         /* key number of region: Bach p. 359 */
3 #define SHM_SIZE 8            /* number of bytes in the region */
```

```
1 /* Excerpt from /usr/include/sys/ipc.h. */
2 #define IPC_CREAT 01000       /* create the region if it doesn't already exist */
3 #define IPC_RMID 0            /* remove the region */
```

```
1 /* Excerpt from /usr/include/sys/types.h. */
2 /* If you need a variable to hold the value used as the first argument of
3 shmget, declare the variable to be of type key_t. */
4
5 typedef int key_t;
```

```
 1 #include <stdio.h>
 2 #include <stdlib.h>
 3 #include <sys/types.h>
 4 #include <sys/stat.h>
 5 #include <sys/ipc.h>
 6 #include <sys/shm.h>
 7 #include "shm_array.h"
 8
 9 int main(int argc, char **argv)
10 {
11     /* shared memory ID number */
12     const int shmid = shmget(SHM_KEY, SHM_SIZE, IPC_CREAT |
13     S_IRUSR | S_IWUSR | S_IRGRP | S_IWGRP | S_IROTH | S_IWOTH);
14
15     if (shmid < 0) {
16         perror(argv[0]);
17         return EXIT_FAILURE;
18     }
19
20     printf("shmid == %d, key == %d\n", shmid, SHM_KEY);
21     return EXIT_SUCCESS;
22 }
```

```
2$ prog
shmid == 7, key == 12345
```

| | | *octal* | *binary* |
|---|---|---|---|
| IPC_CREAT | | 001000 | 00000010 00000000 |
| S_IRUSR | r-------- | 000400 | 00000001 00000000 |
| S_IWUSR | -w------- | 000200 | 00000000 10000000 |
| S_IRGRP | ---r----- | 000040 | 00000000 00100000 |
| S_IWGRP | ----w---- | 000020 | 00000000 00010000 |
| S_IROTH | ------r-- | 000004 | 00000000 00000100 |
| S_IWOTH | -------w- | 000002 | 00000000 00000010 |
| decimal 950 | rw-rw-rw- | 001666 | 00000011 10110110 |

```
3$ ipcs -m                      first and last lines of output are empty
4$ ipcs -ma                     for even more information ("all")

Shared Memory:
T      ID     KEY      MODE        OWNER    GROUP
m       0     1234 --rw-------      root   system
m       1 101798102 --rw-r-----    oracle      dba
m       7    12345 --rw-rw-rw-      mm64 instruct
```

**http://i5.nyu.edu/~mm64/x52.9544/src/shm_array.ph**

```
#This file is shm_array.ph.  It is not executable and has no #!.

$SHM_KEY = 12345;   #identification number of region
$SHM_SIZE = 8;      #number of bytes in the region
```

**http://i5.nyu.edu/~mm64/x52.9544/src/shmget**

```
#!/bin/perl
use POSIX;
require 'shm_array.ph';

$shmid = shmget($SHM_KEY, $SHM_SIZE, IPC_CREAT |
    S_IRUSR | S_IWUSR |
    S_IRGRP | S_IWGRP |
    S_IROTH | S_IWOTH);

defined $shmid || die "$0: $!";

print "shmid == $shmid, key == $SHM_KEY\n";
exit 0;
```

**Attach a region of shared memory to a process**

After one process has created a region of shared memory as shown above, many processes can use the region as if it were an array of **`char`**'s whose subscripts go from **`0`** to **`SHM_SIZE - 1`** inclusive:

```
1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <sys/types.h>
4 #include <sys/ipc.h>
5 #include <sys/shm.h>
```

```
 6 #include "shm_array.h"
 7
 8 int main(int argc, char **argv)
 9 {
10     /* Don't create a region: get one that already exists. */
11     const int shmid = shmget(SHM_KEY, 0, 0);
12     char *p;      /* address of first byte in region of shared memory */
13
14     if (shmid < 0) {
15         perror(argv[0]);
16         return 1;
17     }
18
19     p = shmat(shmid, NULL, 0);
20     if (p == (char *)-1) {
21         perror(argv[0]);
22         return 2;
23     }
24
25     p[0] = 'A';
26     p[1] = 'B';
27     /* etc. */
28     p[SHM_SIZE - 1] = '\0';
29
30     /* Output the ID number, key, number of processes attached, and size
31     of each region of shared memory. */
32     system("ipcs -ma | awk 'NR >= 3 {print $2, $3, $9, $10}'");
33
34     if (shmdt(p) != 0) {
35         perror(argv[0]);
36         return 3;
37     }
38
39     return EXIT_SUCCESS;
40 }
```

```
1$ prog
        ID        KEY     NATTCH      SEGSZ
       300         -1          0      35176
         7      12345          1          8
```

Actually, the above output was produced with **awk printf** to right-justify the columns:

```
31     system("ipcs -ma |"
32         "awk 'NR >= 3 {printf \"%10s %10s %10s %10s\\n\", $2, $3, $9, $10}'");
```

**perl shmwrite** automatically calls **shmat** before writing and **shmdt** after writing; **perl shmread** automatically calls **shmat** before reading and **shmdt** after reading. The third argument of **shmwrite** and **shmread** is the position at which to write or read, measured in bytes from the start of the region. The fourth argument is the number of bytes.

```
#!/bin/perl
require 'shm_array.ph';

$shmid = shmget($SHM_KEY, 0, 0);
defined $shmid || die "$0: $!";

shmwrite($shmid, "hello", 0, 5) || die "$0: $!";
shmread($shmid, $line, 0, 5) || die "$0: $!";

print "$line\n";
exit 0;
```

**Remove a region of shared memory**

```
 1 #include <stdio.h>
 2 #include <stdlib.h>
 3 #include <sys/types.h>
 4 #include <sys/ipc.h>
 5 #include <sys/shm.h>
 6 #include "shm_array.h"
 7
 8 int main(int argc, char **argv)
 9 {
10     const int shmid = shmget(SHM_KEY, 0, 0);
11
12     if (shmid < 0) {
13         perror(argv[0]);
14         return 1;
15     }
16
17     if (shmctl(shmid, IPC_RMID, NULL) != 0) {
18         perror(argv[0]);
19         return 2;
20     }
21
22     return EXIT_SUCCESS;
23 }
```

```
#!/bin/perl
use POSIX;
require 'shm_array.ph';

$shmid = shmget($SHM_KEY, 0 , 0);
defined $shmid || die "$0: $!";

$value = shmctl($shmid, IPC_RMID, 0);
defined $value || die "$0: $!";
exit 0;
```

```
1$ ipcrm -m 7          remove the region with ID 7
2$ ipcrm -M 12345      remove the region with key 12345
3$ ipcs -m             make sure the region is removed
```

**Access variables in a region of shared memory**

Use the above notation to treat the region as an array (of **`char`**'s, or **`int`**'s, etc.) Use the following notation to treat the region as a set of variables of different types:

```
 1 /* This file is shm_grabbag.h. */
 2
 3 #define SHM_KEY 12345         /* key number of region */
 4 #define NROWS 24
 5 #define NCOLS 80
 6
 7 typedef struct {
 8     double d;                 /* comment explaining each variable */
 9     int i;
10     char c;
11     char a[NROWS][NCOLS];
12 } shm_grabbag_t;
13
14 #define SHM_SIZE (sizeof (shm_grabbag_t)) /* number of bytes in the region */
```

```
 1 /* Create a region of shared memory, and initialize the variables it contains. */
 2 #include <stdio.h>
 3 #include <stdlib.h>
 4 #include <sys/types.h>
 5 #include <sys/stat.h>
 6 #include <sys/ipc.h>
 7 #include <sys/shm.h>
 8 #include "shm_grabbag.h"
 9
10 int main(int argc, char **argv)
11 {
12     const int shmid = shmget(SHM_KEY, SHM_SIZE, IPC_CREAT |
13         S_IRUSR | S_IWUSR | S_IRGRP | S_IWGRP | S_IROTH | S_IWOTH);
14     shm_grabbag_t *p;
15     int row, col;
16
17     if (shmid < 0) {
18         perror(argv[0]);
19         return 1;
20     }
21
22     p = (shm_grabbag_t *)shmat(shmid, NULL, 0);
23     if (p == (shm_grabbag_t *)-1) {
24         perror(argv[0]);
25         return 2;
26     }
27
28     /* Initialize the variables in the region of shared memory. */
29     p->d = 3.14159;
30     p->i = 10;
31     p->c = 'A';
32
33     for (row = 0; row < NROWS; ++row) {
34         for (col = 0; col < NCOLS; ++col) {
35             p->a[row][col] = ' ';
36         }
```

```
37      }
38
39      if (shmdt(p) != 0) {
40          perror(argv[0]);
41          return 3;
42      }
43
44      return EXIT_SUCCESS;
45  }
```

**Access variables in a region of shared memory in perl**

```
#This file is shm_grabbag.ph.

$SHM_KEY = 12345;
$NROWS = 24;
$NCOLS = 80;

$product = $NROWS * $NCOLS;
$shm_grabbag = "d i A A$product";
$SHM_SIZE = length pack($shm_grabbag, ());
```

```
#!/bin/perl
use POSIX;
require 'shm_grabbag.ph';

$shmid = shmget($SHM_KEY, $SHM_SIZE, IPC_CREAT |
    S_IRUSR | S_IWUSR |
    S_IRGRP | S_IWGRP |
    S_IROTH | S_IWOTH);
defined $shmid || die "$0: $!";

$contents = pack($shm_grabbag, 3.14159, 10, 'A', ' ' x ($NROWS * $NCOLS));
shmwrite($shmid, $contents, 0, $SHM_SIZE) || die "$0: $!";
shmread($shmid, $verify, 0, $SHM_SIZE) || die "$0: $!";

($d, $i, $c, $a) = unpack($shm_grabbag, $verify);
print "d == $d, i == $i, c == $c\n";
print substr($a, 0, 1) , "\n";
exit 0;
```

**▼ Homework 5.1: store a value in an array in shared memory**

I ran the following C program to create a region of shared memory and initialized the variables that it contains:

```
1 /* Excerpts from the file /usr/include/sys/types.h */
2 typedef short uid_t;          /* data type of variable that holds a UID number */

1 /* This file is /home1/m/mm64/44/data/shm_abc1234.h. */
2
3 #define SHM_KEY 12345         /* identification key of region of shared memory */
4 #define MAX 50                /* maximum number of UID's that the array can hold */
5
```

```
 6 typedef struct {
 7     int n;                    /* number of UID's currently in the array */
 8     uid_t uid[MAX];
 9 } shm_abc1234;

 1 /* Create the region of shared memory declared in shm_abc1234.h.
 2 Initialize the variable n that the region contains. */
 3 #include <stdio.h>
 4 #include <stdlib.h>
 5 #include <sys/types.h>        /* for uid_t */
 6 #include <sys/stat.h>         /* for S_IRUSR */
 7 #include <sys/ipc.h>
 8 #include <sys/shm.h>
 9 #include <sys/unistd.h>
10 #include "/home1/m/mm64/44/data/shm_abc1234.h"
11
12 int main(int argc, char **argv)
13 {
14     const int shmid = shmget(SHM_KEY, sizeof (shm_abc1234),
15         IPC_CREAT | S_IRUSR | S_IWUSR | S_IRGRP | S_IWGRP | S_IROTH | S_IWOTH);
16     shm_abc1234 *p;
17
18     if (shmid < 0) {
19         perror(argv[0]);
20         return 1;
21     }
22
23     p = (shm_abc1234 *)shmat(shmid, NULL, 0);
24     if (p == (shm_abc1234 *)-1) {
25         perror(argv[0]);
26         return 2;
27     }
28
29     p->n = 0;
30     p->uid[p->n] = getuid();
31     p->n++;
32
33     if (shmdt(p) != 0) {
34         perror(argv[0]);
35         return 3;
36     }
37
38     return EXIT_SUCCESS;
39 }
```

Use **`ipcs -m`** to make sure the region with key number 12345 still exists.

Then write a program that will

(1) Attach this region to itself. The second and third arguments you give to **`shmget`** must be **`0`** because you're not creating the region.

(2) If the value of the variable **`n`** in the region is illegal, output an error message and skip steps (3) through (5). Legal values are from **`0`** to **`MAX-1`** inclusive.

(3) Loop through the **`uid`** array from subscript **`0`** to subscript **`n-1`** inclusive and print its contents to the standard output. The last line you output will be your line. Output three columns: the value of the subscript (starting from **`0`**), the UID number read from the array, and the corresponding login name obtained

from **getpwuid** (Handout 1, pp. 37−38). Right-justify each column of numbers, and left-justify the column of login names:

```
 0  9413 oic200
 1  9429 mse233
 2  8841 rf254
```

(4) Detach the region of shared memory from your program, but do not remove it (i.e., do not use **IPC_RMID**).

Now write another program that will write into the region of shared memory. Do steps (1) and (2) above, and then

(3) Call the **getuid** system call to find your UID number. Store this number into the **uid** array in the region of shared memory. Use the variable **n** in the region as the array subscript.

(4) Add one to **n**.

Then do step (3) above. Warning: do not add more than one to **n**. This means that the program must work correctly the first (and only) time you run it. Practice on a structure in normal (non-shared) memory before you use the structure in shared memory.

▲

**Create a (very small) array of semaphores: Bach pp. 370−381, 447; Curry pp. 385−389**

```
1$ man -t 2 semget semctl semop | grops | lpr
2$ pr -l60 /usr/include/sys/sem.h | lpr          minus lowercase L sixty
```

A *semaphore* is an **unsigned int** variable—it can contain only non-negative numbers. The only way to create semaphores is to make an array of them, so we will create an array containing one semaphore:

```
 1 /* Excerpt from /usr/include/sys/types.h.
 2 typedef unsigned short u_short;

 1 /* Excerpt from /usr/include/sys/ipc.h. */
 2 #define IPC_CREAT 01000 /* 3rd arg of semget: create array if it doesn't exist */
 3 #define IPC_RMID 0      /* 3rd arg of semctl: remove the array of semaphores */

 1 /* Excerpt from /usr/include/sys/sem.h. */
 2 #define SEM_UNDO 010000 /* 3rd field of struct sembuf: set up adjust on exit entry*/
 3 #define GETALL 6        /* 3rd arg of semctl: copy all values into an array */
 4 #define SETALL 9        /* 3rd arg of semctl: copy an array into the semaphores */

 1 /* This file is sem_critical.h. */
 2 #define SEM_KEY 12345
 3 #define N 1  /* number of semaphores in the array */

 1 /* This program is semaphore.c. */
 2 #include <stdio.h>
 3 #include <stdlib.h>
 4 #include <sys/types.h>
 5 #include <sys/stat.h>
 6 #include <sys/ipc.h>
 7 #include <sys/sem.h>
 8 #include "sem_critical.h"
 9
10 int main(int argc, char **argv)
11 {
```

```
12      int semid;
13      u_short initial[N] = {1}; /* semaphores' initial values */
14      u_short current[N];       /* semaphores' current values */
15      int i;
16
17      /* Create an array of N semaphores. */
18      semid = semget(SEM_KEY, N, IPC_CREAT |
19          S_IRUSR | S_IWUSR | S_IRGRP | S_IWGRP | S_IROTH | S_IWOTH);
20      if (semid < 0) {
21          perror(argv[0]);
22          return 1;
23      }
24
25      /* Give an initial value to each semaphore in the array. */
26      if (semctl(semid, 0, SETALL, initial) != 0) {
27          perror(argv[0]);
28          return 2;
29      }
30
31      /* Print the current value of each semaphore in the array. */
32      if (semctl(semid, 0, GETALL, current) != 0) {
33          perror(argv[0]);
34          return 3;
35      }
36
37      printf ("semid == %d\n", semid);
38      for (i = 0; i < N; ++i) {
39          printf ("semaphore number %d == %u\n", i, current[i]);
40      }
41
42      return EXIT_SUCCESS;
43  }
```

```
3$ gcc -o semaphore semaphore.c
4$ semaphore
semid == 30
semaphore number 0 == 1

5$ ipcs -s                                  a means "alter"—see man -t ipcs

Semaphores:
T     ID     KEY        MODE       OWNER    GROUP
s     30      12345 --ra-ra-ra- mm64 instruct
```

| | *octal* | | *binary* |
|---|---|---|---|
| IPC_CREAT | 001000 | | 00000010 00000000 |
| S_IRUSR | 000400 | r-------- | 00000001 00000000 |
| S_IWUSR | 000200 | -w------- | 00000000 10000000 |
| S_IRGRP | 000040 | ---r----- | 00000000 00100000 |
| S_IWGRP | 000020 | ----w---- | 00000000 00010000 |
| S_IROTH | 000004 | ------r-- | 00000000 00000100 |
| S_IWOTH | 000002 | -------w- | 00000000 00000010 |
| decimal 950 | 001666 | rw-rw-rw- | 00000011 10110110 |

**Create an array of semaphores in perl**

```
#This file is sem_critical.ph.

$SEM_KEY = 12345;
$N = 1;                 #number of semaphores in array
```

```
#!/bin/perl
require 'sys/stat.ph';
require 'sys/ipc.ph';
require 'sys/sem.ph';
require 'sem_critical.ph';

$semid = semget($SEM_KEY, $N, IPC_CREAT() |
    S_IRUSR() | S_IWUSR() |
    S_IRGRP() | S_IWGRP() |
    S_IROTH() | S_IWOTH());
defined $semid || die "$0: $!";

$val = semctl($semid, 0, SETALL(), pack('s', 1));
defined $val || die "$0: $!";

$val = semctl($semid, 0, GETALL(), $current);
defined $val || die "$0: $!";

print unpack('s', $current) . "\n";
exit 0;
```

**Use a semaphore to protect shared memory**

Since we initialized the semaphore to 1, any process can decrement it to 0. But this is as low as a semaphore can go. If a second process then tries to decrement the semaphore to −1, the kernel will put it to sleep until the first process has incremented the semaphore back to 1.

```
1 /* Excerpt from /usr/include/sys/sem.h */
2 struct sembuf {
3     unsigned short sem_num;   /* index of semaphore in array */
4     short sem_op;             /* -1 to decrement the semaphore, 1 to increment */
5     short sem_flg;            /* flags: IPC_NOWAIT, SEM_UNDO, or just 0 */
6 };
```

```
1 /* This program is share.c. */
2 #include <stdio.h>
3 #include <stdlib.h>
```

```
 4 #include <sys/types.h>
 5 #include <sys/ipc.h>
 6 #include <sys/sem.h>
 7 #include "sem_critical.h"
 8
 9 #define NDEC (sizeof decrement / sizeof decrement[0])
10 #define NINC (sizeof increment / sizeof increment[0])
11
12 int main(int argc, char **argv)
13 {
14     int semid;
15     struct sembuf decrement[] = {
16         {0, -1, 0}
17     };
18     struct sembuf increment[] = {
19         {0, 1, 0}
20     };
21
22     semid = semget(SEM_KEY, 0, 0);
23     if (semid < 0) {
24         perror (argv[0]);
25         return 1;
26     }
27
28     /* If another process is executing its critical section, this semop
29     will make us sleep.  semop will return when it's our turn. */
30     if (semop(semid, decrement, NDEC) != 0) {
31         perror (argv[0]);
32         return 2;
33     }
34
35     /* Critical section starts here. */
36     p->i++;                                  /* i is in shared memory. */
37     /* Critical section ends here. */
38
39     /* Now give other processes a chance to execute their critical sections. */
40     if (semop(semid, increment, NINC) != 0) {
41         perror (argv[0]);
42         return 3;
43     }
44
45     return EXIT_SUCCESS;
46 }
```

```
#!/bin/perl
require 'sys/ipc.ph';
require 'sys/sem.ph';
require 'sem_critical.ph';

$semid = semget($SEM_KEY, 0, 0);
defined $semid || die "$0: $!";

semop($semid, pack('sss', 0, -1, 0)) || die "$0: $!";

#Critical section starts here.
print "I am in the critical section.\n";
#Critical section ends here.

semop($semid, pack('sss', 0, 1, 0)) || die "$0: $!";

exit 0;
```

The **WCHAN** column of **ps -l** tells if a process is asleep because it's waiting for an event to happen, i.e., a semaphore to become positive. See Bach pp. 33−34.

**Remove an array of semaphores**

```
 1 #include <stdio.h>
 2 #include <stdlib.h>
 3 #include <sys/types.h>
 4 #include <sys/ipc.h>
 5 #include <sys/sem.h>
 6 #include "sem_critical.h"
 7
 8 int main(int argc, char **argv)
 9 {
10     int semid;
11
12     semid = semget(SEM_KEY, 0, 0);
13     if (semid < 0) {
14         perror (argv[0]);
15         return 1;
16     }
17
18     if (semctl(semid, 0, IPC_RMID, 0) < 0) {
19         perror (argv[0]);
20         return 2;
21     }
22
23     return EXIT_SUCCESS;
24 }
```

```
1$ ipcrm -s 30          remove the array of semaphores with ID 30
2$ ipcrm -S 12345       remove the array of semaphores with key 12345
3$ ipcs -s              make sure the array of semaphores is gone
```

```
#!/bin/perl
require 'sys/ipc.ph';
require 'sys/sem.ph';
require 'sem_critical.ph';

$semid = semget($SEM_KEY, 0, 0);
defined $semid || die "$0: $!";

$val = semctl($semid, 0, &IPC_RMID, 0);
defined $val || die "$0: $!";

exit 0;
```

**▼ Homework 5.2: the Semaphore Version of Wuthering Heights**

Create a region of shared memory containing a variable whose value can be changed by two or more processes. Use a semaphore to make sure that no more than once process at a time will do this.

Or create a guestbook like the one on the World Wide Web at the URL **`http://i5.nyu.edu/~mm64/david`**, but make sure that only one person at a time signs it.
▲

**Miscellaneous semaphoria**

(1) We have initialized our semaphore to **`1`** so that no more than one process can use a resource (e.g., shared memory) simultaneously. What would you do if you had a resource that no more than three processes could use simultaneously? And what if some processes made heavier use of the resource than others?

(2) Why do semaphores come in arrays? Suppose you have two variables in two different regions of shared memory, each protected by a semaphore. A process that wants to change the values of both variables at the same time (e.g., swap their values) must decrement both semaphores. If both semaphores belong to the same array, you can do this with one call to **`semop`**. **`semop`** will sleep until both semaphores become positive, and will then subtract 1 simultaneously from each semaphore and return. This avoids deadly embrace.

(3) Using semaphores is a bit like Russian roulette: you don't know if you will be put to sleep until you actually pull the trigger. Can you attempt to decrement a semaphore, but call the whole thing off if the semaphore is already zero? Put **`IPC_NOWAIT`** into the **`sem_flg`** field of one of the structures in the array passed as the second argument to **`semop`**. This will make **`semop`** set **`errno = EAGAIN`** and return **`-1`** immediately instead of going to sleep. You must then set **`errno`** back to **`0`** by hand; see Handout 1, p. 21.

(4) Suppose a process decrements a semaphore and is killed before it has a chance to increment the semaphore. Then no other program can use the segment of shared memory. Clean up after a dead process by putting **`SEM_UNDO`** into the **`sem_flg`** field. This will cause the kernel to keep count of how many increments and decrements your process has done to each semaphore. When the process dies, the kernel will undo all of these increments and decrements automatically.

**Pthreads**

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

| *Unix system calls* | *Pthreads* |
|---|---|
| `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 *progname;
```

```
 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     progname = 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(progname);
29         return 2;
30     }
31
32     if (pthread_mutex_lock(&mutex) != 0) {
33         perror(progname);
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(progname);
43         return 4;
44     }
45
46     if (pthread_join(thread, &status) != 0) {     /* like waitpid */
47         perror(progname);
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 *progname;
10
11 void *thread_function(void *p);
12
13 int main(int argc, char **argv)
```

```
14 {
15     pthread_t thread;
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_cond_init(&condition, pthread_condattr_default) != 0) {
25         perror(progname);
26         return 2;
27     }
28
29     if (pthread_create(&thread, pthread_attr_default,
30         (pthread_startroutine_t)thread_function, NULL) != 0) {
31         perror(progname);
32         return 3;
33     }
34
35     if (pthread_detach(&thread) != 0) {
36         perror(progname);
37         return 4;
38     }
39
40     /* Wait until count == n. */
41     if (pthread_mutex_lock(&mutex) != 0) {
42         perror(progname);
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(progname);
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_rdwr_t lock;
4
5      if (pthread_rdwr_init_np(&lock, pthread_rdwr_default) != 0) {
6          perror(progname);
7          exit(1);
8      }
```

```
1      if (pthread_rdwr_rlock_np(&lock) != 0) {
```

```
 2          perror(progname);
 3          exit(2);
 4      }
 5
 6      /* Read the block of shared memory. */
 7
 8      if (pthread_rdwr_runlock_np(&lock) != 0) {
 9          perror(progname);
10          exit(3);
11      }
```

```
 1      if (pthread_rdwr_wlock_np(&lock) != 0) {
 2          perror(progname);
 3          exit(4);
 4      }
 5
 6      /* Write the block of shared memory. */
 7
 8      if (pthread_rdwr_wunlock_np(&lock) != 0) {
 9          perror(progname);
10          exit(5);
11      }
```

**The implementation**

Here's the catch: the data type **pthread_rdwr_t**, the value **pthread_rdrw_default**, and the five functions

```
pthread_rdwr_init_np
pthread_rdwr_rlock_np              pthread_rdwr_wlock_np
pthread_rdwr_runlock_np            pthread_rdwr_wunlock_np
```

don't exist: we have to write them ourselves. For simplicity, we just **return -1** when anything goes wrong without trying to unlock the locks.

```
 1 typedef struct {
 2     int readers;
 3     int writers;
 4     pthread_mutex_t mutex;          /* protects readers and writers */
 5     pthread_cond_t condition;       /* readers == 0 || writers == 0 */
 6 } pthread_rdwr_t;
 7
 8 typedef void *pthread_rdwrattr_t;
 9 #define pthread_rdwr_default ((pthread_rdwrarttr_t)NULL)
10
11 int pthread_rdwr_init_np(pthread_rdwr_t *lock, pthread_rdwrattr_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_rdwr_rlock_np(pthread_rdwr_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_rdwr_wlock_np(pthread_rdwr_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_rwock_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);
```

**Create a named pipe: Bach pp. 107−109, 113, 116−117; Curry pp. 364−366**

See **mknod**(2) for the **mknod** system call (''make node''), and **mknod**(8) for the **mknod** command.

```
1$ cd
2$ /usr/sbin/mknod aorta p                    Create a named pipe.

3$ ls -l
prw-------  1 abc1234         0 Mar 22 14:54 aorta
```

```
#!/bin/perl

system ('/usr/sbin/mknod aorta p');
exit 0;
```

If your **umask** doesn't let this C program give the 9-bit mode that you specified to the named pipe, follow the **mknod** with a **chmod**.

```
 1 /* Create a named pipe. */
 2 #include <stdio.h>
 3 #include <stdlib.h>
 4 #include <sys/types.h>
 5 #include <sys/stat.h>
 6
 7 int main(int argc, char **argv)
 8 {
 9     if (mknod("/home1/a/abc1234/aorta",
10         S_IFIFO | S_IRUSR | S_IWUSR, 0) != 0) {
11         perror (argv[0]);
12         return EXIT_FAILURE;
13     }
14
15     return EXIT_SUCCESS;
16 }
```

| | | *octal* | | *binary* |
|---|---|---|---|---|
| | S_IFIFO | 010000 | 0001 --- --------- | 0001 000 000000000 |
| \| | S_IRUSR | 000400 | 0000 --- r-------- | 0000 000 100000000 |
| \| | S_IWUSR | 000200 | 0000 --- -w------- | 0000 000 010000000 |
| | | 010600 | 0001 --- rw------- | 0001 000 110000000 |

**▼ Homework 5.3: a simple experiment with a named pipe**

Log in on two terminals. On the first terminal (e.g., **/dev/ttypa**), create a named pipe and say

```
1$ cd
2$ date > aorta
```

Why does **date** freeze up? (In an emergency, you can kill it with control-\ if control-**c** doesn't work.) Leave **date** in limbo and on the second terminal (e.g., **/dev/ttypb**) say

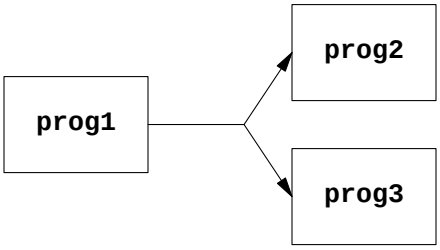
```
3$ ps -f | more

USER       PID  PPID %CPU STARTED  TTY              TIME COMMAND
mm64     22734 22730  0.0 14:06:42 ttypa        0:00.54 -ksh
mm64     22735 22734  0.0 14:06:42 ttypa        0:00.05 -ksh
mm64     26645 22740  0.0 14:15:25 ttypb        0:00.05 -ksh
root     22746 26645  0.0 11:40:14 ttypb        0:03.88 ps -f
```

```
4$ cd
5$ tr '[A-Z]' '[a-z]' < aorta
```

Keep your eyes on both terminals when you press **RETURN** on the second terminal. Why does **date** suddenly terminate normally and the **6$** prompt reappear on the first terminal?
▲

**Connect three processes with pipes**




See KP pp. 73−74 for **&**.

```
#!/bin/sh
#Make two copies of the output of date,
#and send them to two different tr commands.

mknod ~/aorta p

date |
tee ~/aorta |
tr '[A-Z]' '[a-z]'           > ~/lower &
tr '[a-z]' '[A-Z]' < ~/aorta > ~/upper

wait                    #wait for all background children: KP p. 34
rm ~/aorta
exit 0
```

```
1$ prog                                          run the above shellscript
2$ cd

3$ cat lower
fri jan  9 00:08:47 est 2004

4$ cat upper
FRI JAN  9 00:08:47 EST 2004
```

**Update a file continuously: index.html, .plan, etc.**

See *Managing Internet Information Services* by Cricket Liu, Jerry Peek, Russ Jones, Bryan Buus, and Adrian Nye; O'Reilly & Associates, ISBN 1-56592-062-7, pp. 39−40. To download the source code of the example,

```
1$ lynx -source \
ftp://ftp.ora.com/pub/examples/nutshell/miis/miis.9412.tar.Z > miis.9412.tar.Z
```

Use **zcat** and **tar** to extract **other_services/plan/plan.c**.

```
#!/bin/ksh
#This file is /home1/m/mm64/bin/makepage.

if [[ ! -f ~/number ]]
then
    echo 0 > ~/number
fi

n=‘cat ~/number‘
let n=n+1
echo $n > ~/number

echo ’<HTML>’
echo ’<HEAD>’
echo ’<TITLE>Visitor number</TITLE>’
echo ’</HEAD>’
echo ’<BODY>’
echo ’<H1>Visitor number</H1>’
echo You are visitor number $n.
echo ’</BODY>’
echo ’</HTML>’

exit 0
```

The child in the following C program blocks (i.e., gets stuck) at line 35 until another process (e.g., the **cat** below) tries to draw input from the named pipe. Meanwhile, the parent in the C program blocks at line 53 until the child gets unstuck.

```
 1 #include <stdio.h>
 2 #include <stdlib.h>
 3 #include <fcntl.h>
 4 #include <sys/stat.h>
 5 #include <sys/types.h>
 6
 7 int main(int argc, char **argv)
 8 {
 9     char *const pipename = "/home1/m/mm64/public_html/visitor.html";
10     int status;
11
12     if (mknod(pipename, S_IFIFO) != 0) {
13         perror (argv[0]);
14         return 1;
15     }
16
17     /* chmod rw-r--r-- visitor.html */
18     if (chmod(pipename, S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH) != 0) {
19         perror (argv[0]);
20         return 2;
21     }
22
23     for (;;) {
24         const pid_t pid = fork();
25         if (pid < 0) {
26             perror (argv[0]);
27             return 3;
```

```
28          }
29
30          if (pid == 0) {
31              /* Arrive here if I am the child.  The child will be
32              blocked at this open until another process draws
33              input from the pipe. */
34
35              const int fd = open(pipename, O_WRONLY, 0);
36              if (fd < 0) {
37                  perror(argv[0]);
38                  return 1;
39              }
40
41              /* Redirect the child's standard outputto the file
42              opened in line 35. */
43              if (dup2(fd, 1) < 0) {
44                  perror(argv[0]);
45                  return 2;
46              }
47              close(fd);
48
49              execl("/home1/m/mm64/makepage", "makepage", (char *)0);
50              perror (argv[0]);
51              return 3;
52          }
53
54          /* Arrive here if I am the parent. */
55          if (waitpid(pid, &status, 0) < 0) {
56              perror (argv[0]);
57              return 4;
58          }
59      }
60  }
```

```
2$ cd /home1/m/mm64/public_html
3$ ls -l visitor.html
prw-r--r--   1 mm64     users      0 Mar 15 10:47 visitor.html
4$ cat visitor.html                cat produces different output each time
5$ cat visitor.html
6$ cat visitor.html
```

```
<HTML>
<HEAD>
<TITLE>Visitor number</TITLE>
</HEAD>
<BODY>
<H1>Visitor number</H1>
You are visitor number 1.
</BODY>
</HTML>
```

```
<HTML>
<HEAD>
<TITLE>Visitor number</TITLE>
</HEAD>
<BODY>
<H1>Visitor number</H1>
You are visitor number 2.
</BODY>
</HTML>
```

□