OPERATING SYSTEMS: COMMUNICATION AND SYNCHRONIZATION AMONG PROCESSES

Threads and communication and synchronization mechanisms

To remember…

Before classes	Class	After class

Prepare the prerequisites.

Study the material associated with the **bibliography**: slides alone are not enough.
Please ask questions (especially after study).

Exercising skills:

- Perform all **exercises**.
- Carrying out the **practice notebooks** and **the practical exercises** progressively.

Recommended reading

Alejandro Calderón Mateos

Base

1. Carretero 2020:
   1. Cap. 6
2. Carretero 2007:
   1. Cap. 6.1 and 6.2

Suggested

1. Tanenbaum 2006:
   1. (es) Chap. 5
   2. (en) Chap. 5
2. Stallings 2005:
   1. 5.1, 5.2 and 5.3
3. Silberschatz 2006:
   1. 6.1, 6.2, 6.5 and 6.6

Contents

- Introduction (definitions):
  - Concurrent processes.
  - Concurrency, communication and synchronization.
  - Critical section and Race conditions.
  - Mutual exclusion and critical section.
- Synchronization mechanisms (I):
  - Initial basic primitives.
  - Semaphores.
- Classic concurrency problems (I):
  - Producer-consumer
  - Reader-writers
- Synchronization mechanisms of threads (II)
  - Semaphores
    - System calls for semaphores.
    - Classic concurrency problems.
  - Mutex and condition variables
    - System calls for mutex.
    - Classic concurrency problems.
- Case study: concurrent server development

Contents

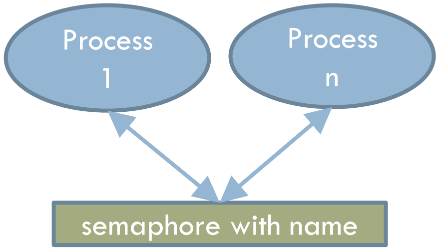
- Introduction (definitions):
  - Concurrent processes.
  - Concurrency, communication and synchronization.
  - Critical section and Race conditions.
  - Mutual exclusion and critical section.
- Synchronization mechanisms (I):
  - Initial basic primitives.
  - Semaphores.
- Classic concurrency problems (I):
  - Producer-consumer
  - Reader-writers
- Synchronization mechanisms of threads (II)
  - Semaphores
    - **System calls for semaphores.**
    - Classic concurrency problems.
  - Mutex and condition variables
    - System calls for mutex.
    - Classic concurrency problems.
- Case study: concurrent server development

POSIX Semaphores

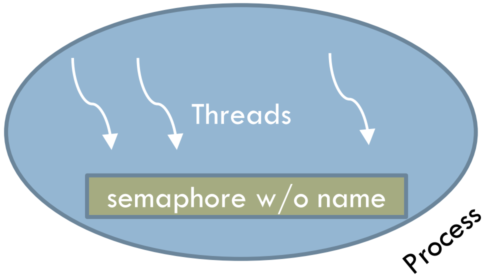
- Synchronization mechanism for processes and/or threads on the same machine.

```
#include <semaphore.h>
```

- Two types of POSIX semaphores:
  - **Semaphores with name:**
    - It can be used by different processes that know the name.
    - No shared memory required.
    - `sem_t *semaphore; // named`

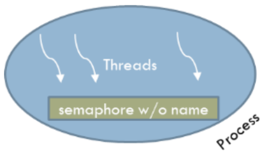


  - **Semaphores without name:**
    - They can be used only by the processes that create them (and their threads) or by processes that have a shared memory area.
    - `sem_t  semaphore; // no named`

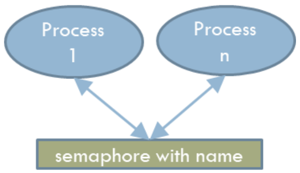


POSIX Semaphores

- `int sem_init(sem_t *sem, int shared, int val);`
  - Initializing an **unnamed** semaphore
- `int sem_destroy(sem_t *sem);`
  - Destroy an **unnamed** semaphore



- `sem_t *sem_open(char *name, int flag, mode_t mode, int val);`
  - Creates (or opens) a **named** semaphore.
- `int sem_close(sem_t *sem);`
  - Closes a **named** semaphore.
- `int sem_unlink(char *name);`
  - Remove a **named** semaphore.



- `int sem_wait(sem_t *sem);`
  - Performs the `wait` operation on the semaphore.
- `int sem_trywait (sem_t *sem)`
  - Attempts to `wait` but if it needs to block the process -> it does not block and gives -1
- `int sem_post(sem_t *sem);`
  - Performs the `signal` operation on the semaphore.

Semaphores operations


```
sem_wait(s) {
     s = s - 1;
     if (s < 0) {
         <Blocking
          the process>
     }
}
```

```
sem_post(s) {
     s = s + 1;
     if (s <= 0)
         <Unblock a
          process blocked
          by a wait
          operation>
     }
}
```

Contents

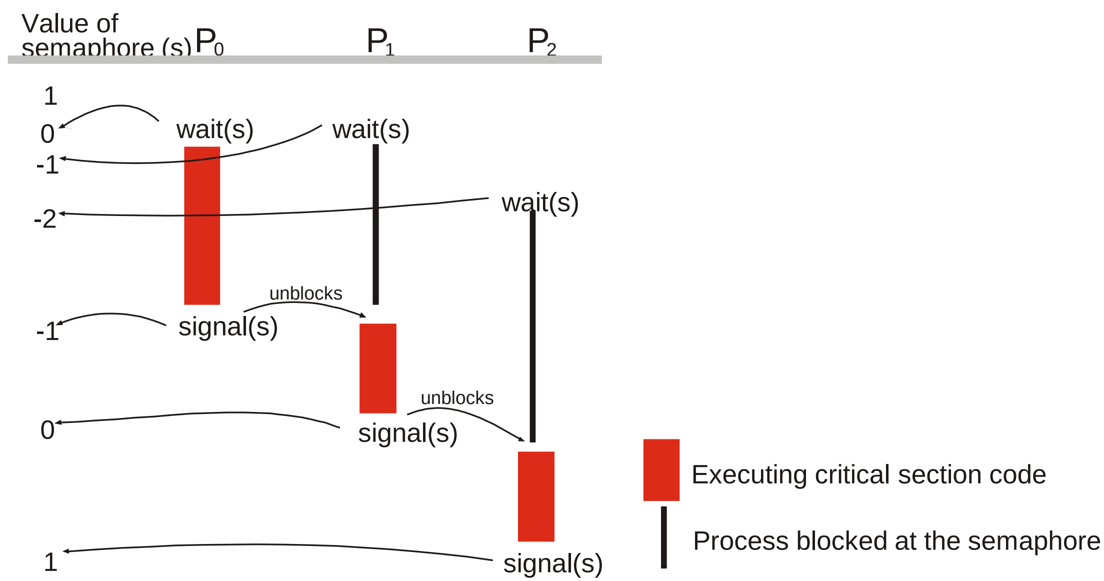
- Introduction (definitions):
  - Concurrent processes.
  - Concurrency, communication and synchronization.
  - Critical section and Race conditions.
  - Mutual exclusion and critical section.
- Synchronization mechanisms (I):
  - Initial basic primitives.
  - Semaphores.
- Classic concurrency problems (I):
  - Producer-consumer
  - Reader-writers
- Synchronization mechanisms of threads (II)
  - Semaphores
    - System calls for semaphores.
    - **Classic concurrency problems.**
  - Mutex and condition variables
    - System calls for mutex.
    - Classic concurrency problems.
- Case study: concurrent server development

Critical sections with semaphores

- The semaphore must have an initial value of 1:

```
sem_wait(s);  /* enter in the critical section */
   < critical section >
 sem_post(s);  /* leave the critical section */
```

- Example:



Producer-consumer with bounded buffered
Semaphores without name


```
/* buffer size*/
#define     MAX_BUFFER  1024
int buffer[MAX_BUFFER];    /* búfer común */
sem_t mutex;               /* critical section */
sem_t elements;            /* elements in buffer*/
sem_t huecos;              /* spaces in the buffer */
```

```
void Producer(void)
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      dato = i;
      sem_wait(&huecos);
      sem_wait(&mutex);
      buffer[pos] = i;
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&elements);
  }
  pthread_exit(0);
}
```

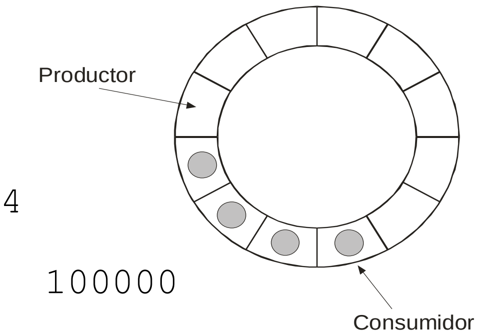
```
void Consumer ( void )
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      sem_wait(&elements);
      sem_wait(&mutex);
      dato = buffer[pos];
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&huecos);
      /* consume data */
   }
   pthread_exit(0);
}
```

Producer-consumer with bounded buffered

Semaphores without name (1/4)

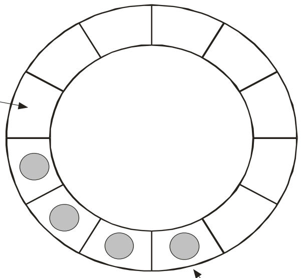

```
//...
#include <semaphore.h>

/* buffer size */
#define MAX_BUFFER          1024
/* datos a producir */
#define DATA_TO_PRODUCE  100000

sem_t mutex;              /* critical section */
sem_t elements;           /* elements in the buffer */
sem_t huecos;             /* spaces in the buffer */
int buffer[MAX_BUFFER]; /* shared buffer */

int main ( int argc, char*argv[] )
{
   pthread_t th1, th2;

   /* initialize the semaphores */
   sem_init(&mutex, 0, 1);
   sem_init(&elements, 0, 0);
   sem_init(&huecos, 0, MAX_BUFFER);

   /* create threads */
   pthread_create(&th1, NULL, Producer, NULL);
   pthread_create(&th2, NULL, Consumer, NULL);

   /* wait for its completion */
   pthread_join(th1, NULL);
   pthread_join(th2, NULL);

   sem_destroy(&mutex);
   sem_destroy(&huecos);
   sem_destroy(&elements);
   return (0);
}

void Producer(void)
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      dato = i;
      sem_wait(&huecos);
      sem_wait(&mutex);
      buffer[pos] = i;
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&elements);
   }
   pthread_exit(0);
}

void Consumer ( void )
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      sem_wait(&elements);
      sem_wait(&mutex);
      dato = buffer[pos];
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&huecos);
      /* consume data */
   }
   pthread_exit(0);
}
```

```
// ...
#include <semaphore.h>

/* buffer size*/
#define MAX_BUFFER  1024
/* data to produce */
#define DATA_TO_PRODUCE  100000

sem_t mutex;    /* critical section */
sem_t elements; /* eltos in the buffer */
sem_t huecos;   /* spaces in the buffer */
int buffer[MAX_BUFFER]; /* shared buffer */


int main ( int argc, char *argv[])
{
   pthread_t th1, th2;

   /* initialize the semaphores */
   sem_init(&mutex,     0, 1);
   sem_init(&elements, 0, 0);
   sem_init(&huecos,    0, MAX_BUFFER);
```



Producer-consumer with bounded buffered
Semaphores without name (2/4)


```c
//...
#include <semaphore.h>

/* buffer size */
#define MAX_BUFFER          1024
/* datos a producir */
#define DATA_TO_PRODUCE  100000

sem_t mutex;            /* critical section */
sem_t elements;         /* elements in the buffer */
sem_t huecos;           /* spaces in the buffer */
int buffer[MAX_BUFFER]; /* shared buffer */

int main ( int argc, char*argv[] )
{
   pthread_t th1, th2;

   /* initialize the semaphores */
   sem_init(&mutex, 0, 1);
   sem_init(&elements, 0, 0);
   sem_init(&huecos, 0, MAX_BUFFER);

   /* create threads */
   pthread_create(&th1, NULL, Producer, NULL);
   pthread_create(&th2, NULL, Consumer, NULL);

   /* wait for its completion */
   pthread_join(th1, NULL);
   pthread_join(th2, NULL);

   sem_destroy(&mutex);
   sem_destroy(&huecos);
   sem_destroy(&elements);
   return (0);
}

void Producer(void)
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      dato = i;
      sem_wait(&huecos);
      sem_wait(&mutex);
      buffer[pos] = i;
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&elements);
   }
   pthread_exit(0);
}

void Consumer ( void )
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      sem_wait(&elements);
      sem_wait(&mutex);
      dato = buffer[pos];
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&huecos);
      /* consume data */
   }
   pthread_exit(0);
}
```




```c
   /* create threads */
   pthread_create(&th1, NULL, Producer, NULL);
   pthread_create(&th2, NULL, Consumer, NULL);

   /* wait for its completion */
   pthread_join(th1, NULL);
   pthread_join(th2, NULL);

   sem_destroy(&mutex);
   sem_destroy(&huecos);
   sem_destroy(&elements);
   return (0);
}
```

Producer-consumer with bounded buffered

Semaphores without name (3/4)


```c
//...
#include <semaphore.h>

/* buffer size */
#define MAX_BUFFER          1024
/* datos a producir */
#define DATA_TO_PRODUCE  100000

sem_t mutex;             /* critical section */
sem_t elements;          /* elements in the buffer */
sem_t huecos;            /* spaces in the buffer */
int buffer[MAX_BUFFER]; /* shared buffer */

int main ( int argc, char*argv[] )
{
   pthread_t th1, th2;

   /* initialize the semaphores */
   sem_init(&mutex, 0, 1);
   sem_init(&elements, 0, 0);
   sem_init(&huecos, 0, MAX_BUFFER);

   /* create threads */
   pthread_create(&th1, NULL, Producer, NULL);
   pthread_create(&th2, NULL, Consumer, NULL);

   /* wait for its completion */
   pthread_join(th1, NULL);
   pthread_join(th2, NULL);

   sem_destroy(&mutex);
   sem_destroy(&huecos);
   sem_destroy(&elements);
   return (0);
}

void Producer(void)
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      dato = i;
      sem_wait(&huecos);
      sem_wait(&mutex);
      buffer[pos] = i;
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&elements);
   }
   pthread_exit(0);
}
void Consumer ( void )
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      sem_wait(&elements);
      sem_wait(&mutex);
      dato = buffer[pos];
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&huecos);
      /* consume data */
   }
   pthread_exit(0);
}
```

```c
void Producer(void)
{
   int pos = 0;
   int dato;
   int i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      dato = i; /* produce... */
      sem_wait(&huecos);
      sem_wait(&mutex);
      buffer[pos] = i;
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&elements);

   }

   pthread_exit(0);
}
```

Producer-consumer with bounded buffered

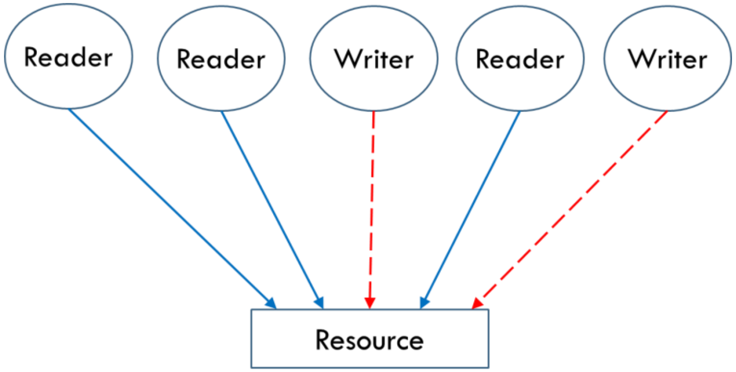
Semaphores without name (4/4)


```c
//...
#include <semaphore.h>

/* buffer size */
#define MAX_BUFFER          1024
/* datos a producir */
#define DATA_TO_PRODUCE  100000

sem_t mutex;            /* critical section */
sem_t elements;         /* elements in the buffer */
sem_t huecos;           /* spaces in the buffer */
int buffer[MAX_BUFFER]; /* shared buffer */

int main ( int argc, char*argv[] )
{
   pthread_t th1, th2;

   /* initialize the semaphores */
   sem_init(&mutex, 0, 1);
   sem_init(&elements, 0, 0);
   sem_init(&huecos, 0, MAX_BUFFER);

   /* create threads */
   pthread_create(&th1, NULL, Producer, NULL);
   pthread_create(&th2, NULL, Consumer, NULL);

   /* wait for its completion */
   pthread_join(th1, NULL);
   pthread_join(th2, NULL);

   sem_destroy(&mutex);
   sem_destroy(&huecos);
   sem_destroy(&elements);
   return (0);
}

void Producer(void)
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      dato = i;
      sem_wait(&huecos);
      sem_wait(&mutex);
      buffer[pos] = i;
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&elements);
   }
   pthread_exit(0);
}

void Consumer ( void )
{
   int pos = 0;
   int dato, i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {
      sem_wait(&elements);
      sem_wait(&mutex);
      dato = buffer[pos];
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&huecos);
      /* consume data */
   }
   pthread_exit(0);
}
```

```c
void Consumer ( void )
{
   int pos = 0;
   int dato;
   int i;

   for (i=0; i<DATA_TO_PRODUCE; i++)
   {

      sem_wait(&elements);
      sem_wait(&mutex);
      dato = buffer[pos];
      pos = (pos + 1) % MAX_BUFFER;
      sem_post(&mutex);
      sem_post(&huecos);
      /* consume data */
   }

   pthread_exit(0);
}
```

Reader-writer problem

- Problem that arises when you have:
  - A shared storage area.
  - Multiple processes read information.
  - Multiple processes write information.



- Conditions:
  - Any number of readers can read from the data zone concurrently: multiple readers possible at the same time.
  - Only one writer can modify the information at a time.
  - During a writing no reader can read

Readers and writers

Semaphores without name


```c
int dato = 5;          /* resource */
int n_readers = 0;     /* num. of readers */
sem_t sem_reader;      /* control access to n_readers */
sem_t mutex;           /* control access to dato */
```

```c
void Reader(void)
{
  sem_wait(&sem_reader);
  n_readers = n_readers + 1;
  if (n_readers == 1)
      sem_wait(&mutex);
  sem_post(&sem_reader);

  printf("%d\n", dato);

  sem_wait(&sem_reader);
  n_readers = n_readers - 1;
  if (n_readers == 0)
      sem_post(&mutex);
  sem_post(&sem_reader);
  pthread_exit(0);
}
```

```c
void Writer(void)
{
    sem_wait(&mutex);
    dato = dato + 2;
    sem_post(&mutex);

    pthread_exit(0);
}
```

Readers and writers

Semaphores without name


```
int dato = 5;          /* resource */
int n_readers = 0;     /* num. of readers */
sem_t sem_reader;      /* control access to n_readers */
sem_t mutex;           /* control access to dato */

int main ( int argc, char *argv[] )
{
   pthread_t th1, th2, th3, th4;
   sem_init(&mutex, 0, 1);
   sem_init(&sem_reader, 0, 1);

   pthread_create(&th1, NULL, Reader, NULL);
   pthread_create(&th2, NULL, Writer, NULL);
   pthread_create(&th3, NULL, Reader, NULL);
   pthread_create(&th4, NULL, Writer, NULL);
   pthread_join(th1, NULL);
   pthread_join(th2, NULL);
   pthread_join(th3, NULL);
   pthread_join(th4, NULL);

   sem_destroy(&mutex);
   sem_destroy(&sem_reader);

   return 0;
}
```

Reader-writers (readers have priority)

Semaphores without name

http://faculty.juniata.edu/rhodes/os/ch5d.htm

Alejandro Calderón Mateos

REVIEW

SHARED MEMORY:

```
int nreaders; semaphore s_read=1; semaphore s_write=1;
```

READER:

```
for(;;) {
  sem_wait(s_read);
  nreaders++;
  if (nreaders==1)
      sem_wait(s_write);
  sem_signal(s_read);

  perform_read();

  sem_wait(s_read);
  nreaders--;
  if (nreaders==0)
      sem_signal(s_write);
  sem_signal(s_read);
}
```

WRITER:

```
for(;;) {
  sem_wait(s_write);
  perform_write();
  sem_signal(s_write);
}
```

Reader-writers (writers have priority)

Semaphores without name

https://computationstructures.org/lectures/synchronization/synchronization.html

Alejandro Calderón Mateos

REVIEW

SHARED MEMORY:

```
int nreaders, nescr = 0;  semaphore lect, s_write = 1;
semaphore x, y, z = 1;
```

READER:

```
for(;;) {
  sem_wait(z);
  sem_wait(lect);
  sem_wait(x);
    nreaders++;
    if (nreaders==1)
        sem_wait(s_write);
  sem_signal(x);
  sem_signal(lect);
  sem_signal(z);
    // doReading();
  sem_wait(x);
    nreaders--;
    if (nreaders==0)
        sem_signal(s_write);
  sem_signal(x);
}
```

WRITER:

```
for(;;) {
  sem_wait(y);
    nescr++;
    if (nescr==1)
        sem_wait(lect);
  sem_signal(y);
  sem_wait(s_write);
    // doWriting();
  sem_signal(s_write);
  sem_wait(y);
    nescr--;
    if (nescr==0)
        sem_signal(s_readt);
  sem_signal(y);
}
```

Semaphores with name
Naming

- Allow synchronization of different processes without using shared memory.
- The name of a semaphore is a string of characters (with the same restrictions as a filename).
  - If the name (path) is relative, only the process that creates it and its children can access the semaphore.
  - If the name is absolute (starts with "/") the semaphore can be shared by any process that knows its name and has permissions.
- Common mechanism for creating semaphores shared by parents and children
  - "Unnamed" does not apply -> processes do NOT share memory.

Semaphores with name

Creation and use

- To create:

```
sem_t *sem_open(char *name, int flag, mode_t mode,int val);
```

  - Flag = O_CREAT will create it.
  - Flag: O_CREAT | O_EXECL will create it if it does not exist. -1 in case it exists.
  - Mode: access permissions;
  - Val: initial value of the semaphore (>=0);

- To use:

```
sem_t *sem_open(char *name, int flag);
```

  - With flag 0. If it does not exist, it returns -1.

- Important:
  - All processes must know "name" and use the same name.

Readers and writers
semaphores with name


```
int main ( int argc, char *argv[] )
{
    int i, n= 5; pid_t pid;

    /* Creates the named semaphore */
    if ((mutex=sem_open("/tmp/sem_1", O_CREAT, 0644, 1))==(sem_t *)-1)
        { perror("Cannot create a semaphore: "); exit(1); }
    if((sem_reader=sem_open("/tmp/sem_2", O_CREAT, 0644, 1))==(sem_t *)-1)
        { perror("Cannot create a semaphore: "); exit(1); }

    /* Creates the processes */
    for (i = 1; i< atoi(argv[1]); ++i)
    {
      pid = fork();
      if (pid ==-1)
         { perror("The process cannot be created: "); exit(-1);}
      if (pid==0)
         { reader(getpid()); break; }
      else writer(pid);
    }
    sem_close(mutex);
    sem_close(sem_reader);
    sem_unlink("/tmp/sem_1");
    sem_unlink("/tmp/sem_2");

    return 0;
}
```

Readers and writers
semaphores with name


```c
int dato = 5;              /* resource */
int n_readers = 0;         /* num. of readers */
sem_t *sem_reader;
sem_t *mutex;
```

```c
void reader (int pid)
{
  sem_wait(sem_reader);
  n_readers = n_readers + 1;
  if (n_readers == 1)
      sem_wait(mutex);
  sem_post(sem_reader);

  printf("reader %d  dato: %d\n",
         pid, dato);

  sem_wait(sem_reader);
  n_readers = n_readers - 1;
  if (n_readers == 0)
      sem_post(mutex);
  sem_post(sem_reader);
}
```

```c
void writer (int pid)
{
   sem_wait(mutex);
   dato = dato + 2;

   printf("writer %d  dato: %d\n",
          pid, dato);

   sem_post(mutex);
}
```

Contents

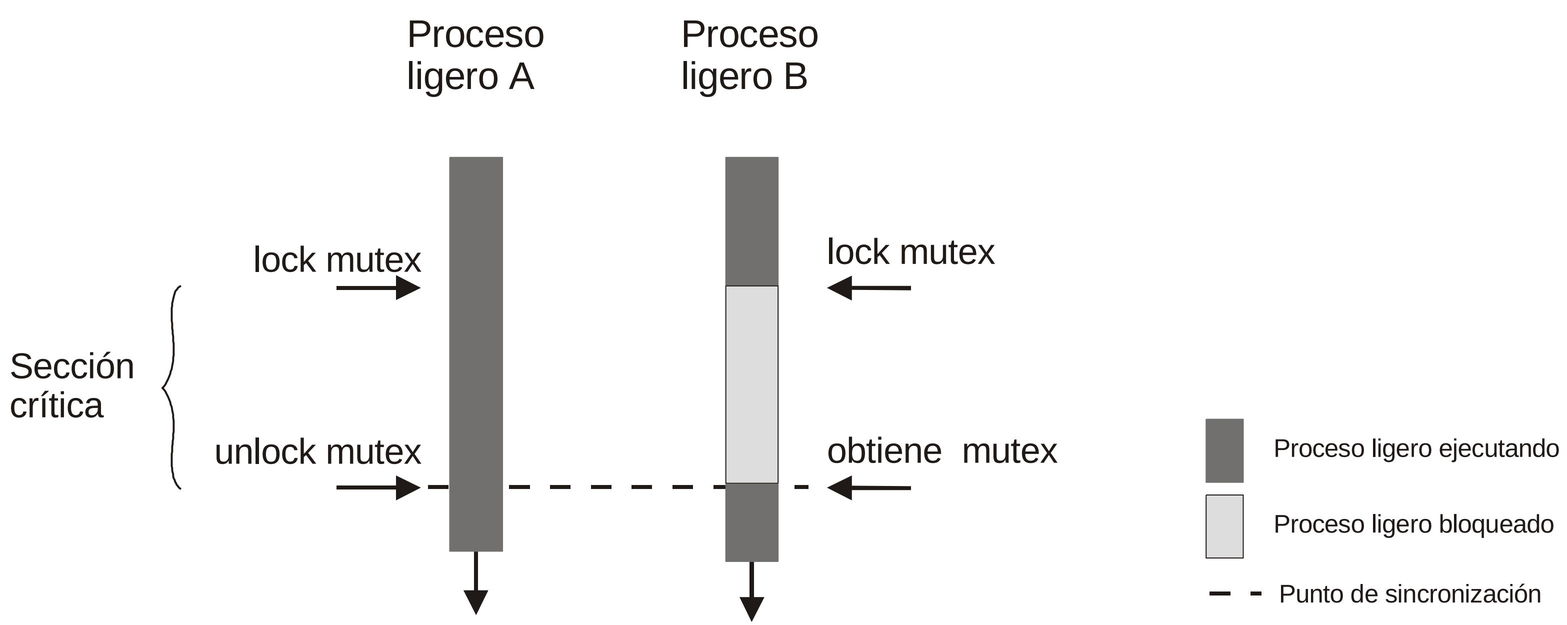
- Introduction (definitions):
  - Concurrent processes.
  - Concurrency, communication and synchronization.
  - Critical section and Race conditions.
  - Mutual exclusion and critical section.
- Synchronization mechanisms (I):
  - Initial basic primitives.
  - Semaphores.
- Classic concurrency problems (I):
  - Producer-consumer
  - Reader-writers
- Synchronization mechanisms of threads (II)
  - Semaphores
    - System calls for semaphores.
    - Classic concurrency problems.
  - **Mutex and condition variables**
    - System calls for mutex.
    - Classic concurrency problems.
- Case study: concurrent server development

Mutex and conditional variables

- A mutex is a synchronization mechanism suitable for threads.
- It is a binary semaphore with 2 atomic operations:
  - **lock(m)** Lock the mutex and if the mutex is already locked the process is suspended.
  - **unlock(m)** Unlocks the mutex and if there are suspended processes in the mutex then it unblock one.
- TIP: The `unlock` operation must be performed by the thread that executed `lock`

Critical sections with mutex

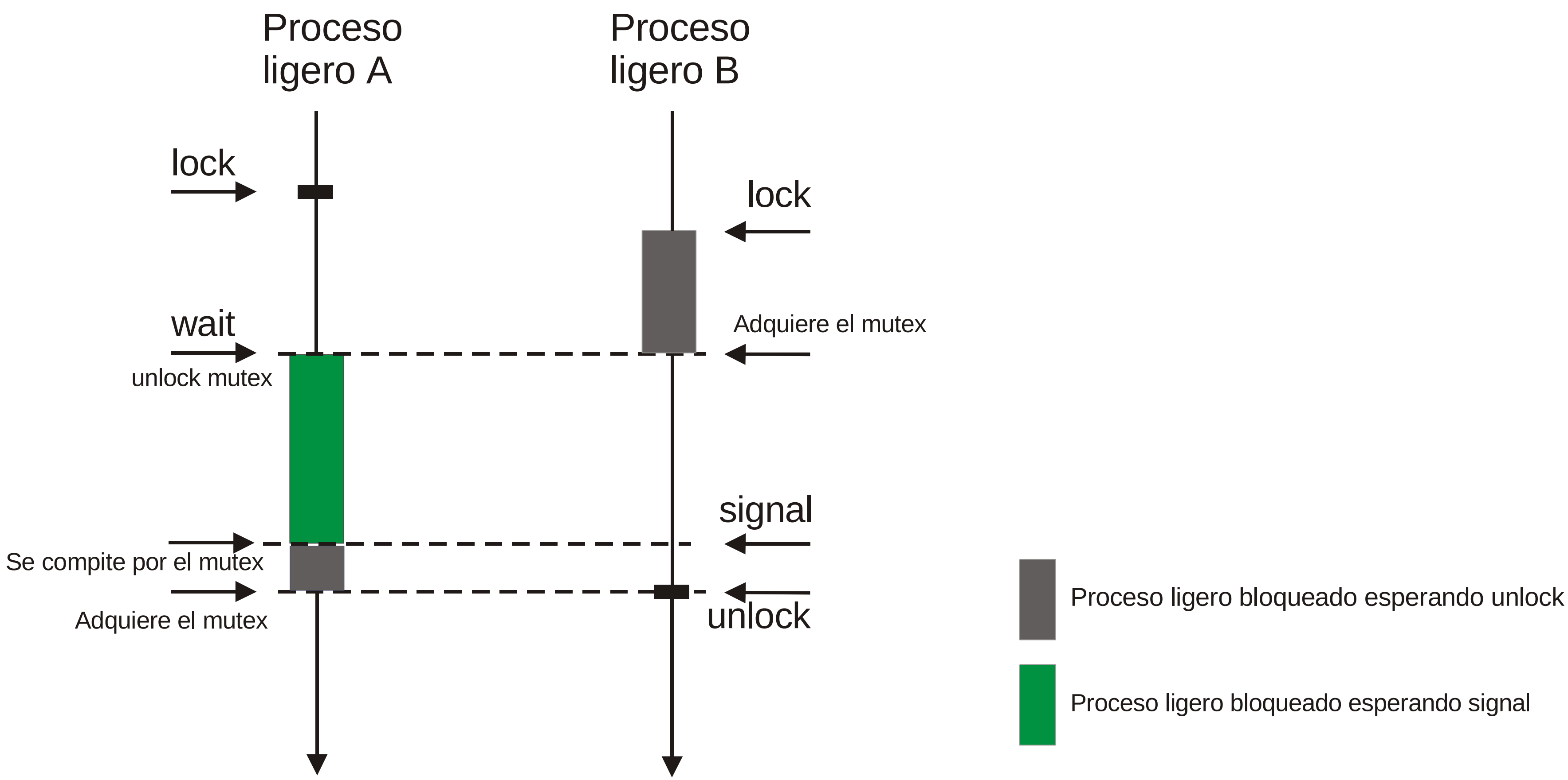

```
lock(m);     /* enter in the critical section */
 < critical section >
unlock(m);  /* leave the critical section */
```



Conditional variables

- Synchronization variables associated with a mutex
- Two atomic operations:
  - **`wait`:** Blocks the thread that executes it and ejects it from the mutex
  - **`signal`:** Unblocks one or more suspended processes in the conditional variable and the waking process competes again to lock the mutex
- Convenient to execute between `lock` and `unlock`

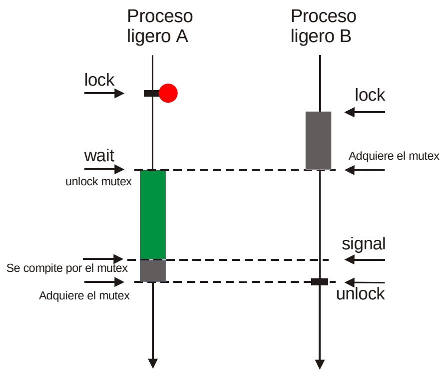
Conditional variables



Use of mutex and conditional variables

- Thread A

```
lock(mutex);    /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



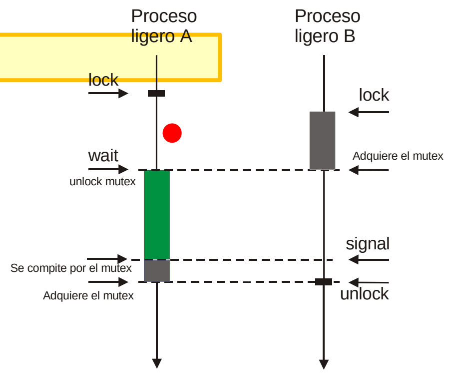
- Thread B

```
lock(mutex);    /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
lock(mutex);   /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



- Thread B

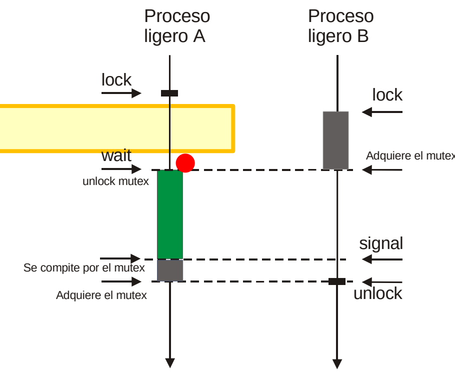
```
lock(mutex);   /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

Alejandro Calderón Mateos

- Thread A

```
lock(mutex);   /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



- Thread B

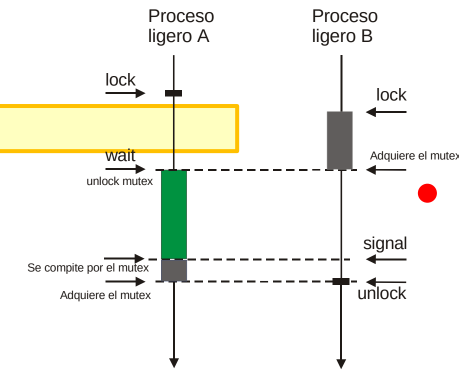
```
lock(mutex);   /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

Alejandro Calderón Mateos

- Thread A

```
lock(mutex);  /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



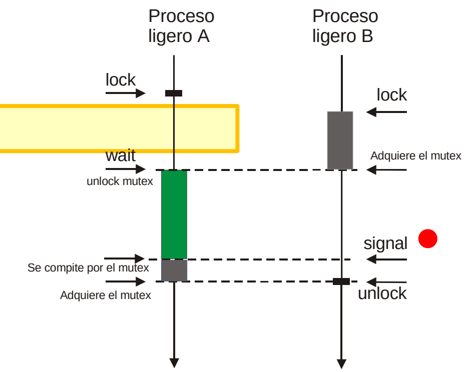
- Thread B

```
lock(mutex);  /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
lock(mutex);   /* access to the resource */
check the data structures;
while (busy resource)
      wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



- Thread B

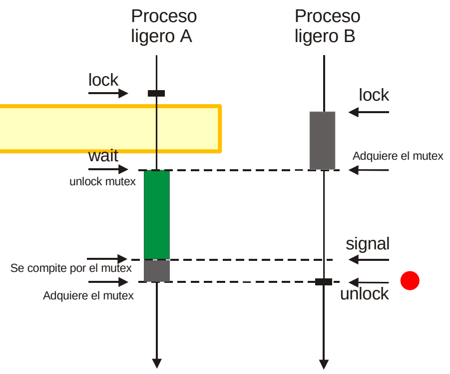
```
lock(mutex);   /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

Alejandro Calderón Mateos

- Thread A

```
 lock(mutex);  /* access to the resource */
check the data structures;
while (busy resource)
         wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



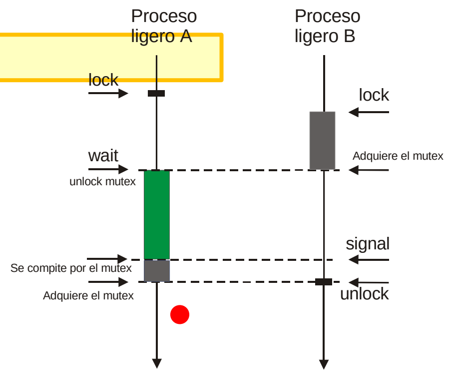
- Thread B

```
 lock(mutex);  /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
 lock(mutex);  /* access to the resource */
check the data structures;
while (busy resource)
      wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```



- Thread B

```
 lock(mutex);  /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
 lock(mutex);   /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```

Important to use `while` to re-evaluate condition

- Thread B

```
 lock(mutex);   /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
 lock(mutex);  /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```

- Thread B

```
 lock(mutex);  /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
lock(mutex);  /* access to the resource */
check the data structures;
while (busy resource)
        wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```

- Thread B

```
lock(mutex);  /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

Use of mutex and conditional variables

- Thread A

```
lock(mutex);   /* access to the resource */
check the data structures;
while (busy resource)
      wait(condition, mutex);
mark the resource as busy;
unlock(mutex);
```

- Thread B

```
lock(mutex);   /* access to the resource */
mark the resource as free;
signal(condition);
unlock(mutex);
```

- **A signal before the wait is "lost".**
- Herefore, the Boolean condition (free/busy resource) is important.

Contents

- Introduction (definitions):
  - Concurrent processes.
  - Concurrency, communication and synchronization.
  - Critical section and Race conditions.
  - Mutual exclusion and critical section.
- Synchronization mechanisms (I):
  - Initial basic primitives.
  - Semaphores.
- Classic concurrency problems (I):
  - Producer-consumer
  - Reader-writers
- Synchronization mechanisms of threads (II)
  - Semaphores
    - System calls for semaphores.
    - Classic concurrency problems.
  - Mutex and condition variables
    - **System calls for mutex.**
    - Classic concurrency problems.
- Case study: concurrent server development

POSIX Services


```
int pthread_mutex_init  ( pthread_mutex_t *mutex,
                           pthread_mutexattr_t * attr );
```

- Initializes a mutex.

```
int pthread_mutex_destroy ( pthread_mutex_t *mutex ) ;
```

- Destroy a mutex.

```
int pthread_mutex_lock    ( pthread_mutex_t *mutex );
```

- Try to obtain the `mutex`.
- locks the thread if the `mutex` is acquired by another thread.

```
int pthread_mutex_unlock ( pthread_mutex_t *mutex );
```

- Unlock the `mutex`.

POSIX Services


```
int pthread_cond_init ( pthread_cond_t*cond,
                        pthread_condattr_t*attr );
```

- Initializes a conditional variable.

```
int pthread_cond_destroy ( pthread_cond_t *cond );
```

- Destroys a conditional variable.

```
int pthread_cond_signal  ( pthread_cond_t *cond );
```

- At least one of the threads suspended in `cond` is reactivated.
- No effect if there is no thread waiting (different from semaphores).

```
int pthread_cond_wait   ( pthread_cond_t*cond,
                          pthread_mutex_t*mutex );
```

- At the same time suspends the calling thread and releases `mutex`.
- When another thread calls …_cond_signal on `cond` the thread wakes up and competes again for the `mutex`.

POSIX Services

Alejandro Calderón Mateos

```
int pthread_cond_broadcast ( pthread_cond_t *cond );
```

- All suspended threads in the conditional variable `cond` are reactivated.
- It has no effect if no thread is waiting.

Contents

- Introduction (definitions):
  - Concurrent processes.
  - Concurrency, communication and synchronization.
  - Critical section and Race conditions.
  - Mutual exclusion and critical section.
- Synchronization mechanisms (I):
  - Initial basic primitives.
  - Semaphores.
- Classic concurrency problems (I):
  - Producer-consumer
  - Reader-writers
- Synchronization mechanisms of threads (II)
  - Semaphores
    - System calls for semaphores.
    - Classic concurrency problems.
  - Mutex and condition variables
    - System calls for mutex.
    - **Classic concurrency problems.**
- Case study: concurrent server development

Producer-consumer with mutex


```
int main ( int argc, char *argv[] )
{
    pthread_t th1, th2;

    pthread_mutex_init(&mutex, NULL);
    pthread_cond_init(&no_full, NULL);
    pthread_cond_init(&no_empty, NULL);

    pthread_create(&th1, NULL, Producer, NULL);
    pthread_create(&th2, NULL, Consumer, NULL);
    pthread_join(th1, NULL);
    pthread_join(th2, NULL);

    pthread_mutex_destroy(&mutex);
    pthread_cond_destroy(&no_full);
    pthread_cond_destroy(&no_empty);
    return 0;
}
```

Producer-consumer with mutex


```c
#define MAX_BUFFER        1024    /* buffer size */
#define DATA_TO_PRODUCE  100000   /* data to be produced */

pthread_mutex_t mutex;            /* shared buffer access mutex */
pthread_cond_t no_full;           /* controls the filling of the buffer */
pthread_cond_t no_empty;          /* controls the emptying of the buffer */
int n_elements;                   /* number of elements in the buffer */
int buffer[MAX_BUFFER];           /* common buffer */
```

```c
void Producer ( void )
{
  int dato, i ,pos = 0;

  for(i=0; i<DATA_TO_PRODUCE; i++)
  {
    dato = i;
    pthread_mutex_lock(&mutex);
    while (n_elements == MAX_BUFFER)
           pthread_cond_wait(&no_full,
                             &mutex);
    buffer[pos] = i;
    pos = (pos + 1) % MAX_BUFFER;
    n_elements ++;
    pthread_cond_signal(&no_empty);
    pthread_mutex_unlock(&mutex);
  }
  pthread_exit(0);
}
```

```c
void Consumer(void)
{
  int dato, i ,pos = 0;

  for(i=0; i<DATA_TO_PRODUCE; i++)
  {
    pthread_mutex_lock(&mutex);
    while (n_elements == 0)
           pthread_cond_wait(&no_empty,
                             &mutex);
    dato = buffer[pos];
    pos = (pos + 1) % MAX_BUFFER;
    n_elements --;
    pthread_cond_signal(&no_full);
    pthread_mutex_unlock(&mutex);
    printf("Consume %d \n", dato);
  }
  pthread_exit(0);
}
```

Producer-consumer with mutex


```
#define MAX_BUFFER        1024    /* buffer size */
#define DATA_TO_PRODUCE  100000   /* data to be produced */

pthread_mutex_t mutex;            /* shared buffer access mutex */
pthread_cond_t no_full;           /* controls the filling of the buffer */
pthread_cond_t no_empty;          /* controls the emptying of the buffer */
int n_elements;                   /* number of elements in the buffer */
int buffer[MAX_BUFFER];           /* common buffer */
```

```
void Producer ( void )
{
  int dato, i ,pos = 0;

  for(i=0; i<DATA_TO_PRODUCE; i++)
  {
    dato = i;
    pthread_mutex_lock(&mutex);
    while (n_elements == MAX_BUFFER)
           pthread_cond_wait(&no_full,
                             &mutex);
    buffer[pos] = i;
    pos = (pos + 1) % MAX_BUFFER;
    n_elements ++;
    pthread_cond_signal(&no_empty);
    pthread_mutex_unlock(&mutex);
  }
  pthread_exit(0);
}
```

```
void Consumer(void)
{
  int dato, i ,pos = 0;

  for(i=0; i<DATA_TO_PRODUCE; i++)
  {
    pthread_mutex_lock(&mutex);
    while (n_elements == 0)
           pthread_cond_wait(&no_empty,
                             &mutex);
    dato = buffer[pos];
    pos = (pos + 1) % MAX_BUFFER;
    n_elements --;
    pthread_cond_signal(&no_full);
    pthread_mutex_unlock(&mutex);
    printf("Consume %d \n", dato);
  }
  pthread_exit(0);
}
```

Reader-writers with mutex


```
int main ( int argc, char *argv[] )
{
    pthread_t th1, th2, th3, th4;

    pthread_mutex_init(&mutex, NULL);
    pthread_mutex_init(&mutex_readers, NULL);

    pthread_create(&th1, NULL, Reader, NULL);
    pthread_create(&th2, NULL, Writer, NULL);
    pthread_create(&th3, NULL, Reader, NULL);
    pthread_create(&th4, NULL, Writer, NULL);
    pthread_join(th1, NULL);
    pthread_join(th2, NULL);
    pthread_join(th3, NULL);
    pthread_join(th4, NULL);

    pthread_mutex_destroy(&mutex);
    pthread_mutex_destroy(&mutex_readers);
    return 0;
}
```

Reader-writers with mutex


```
int dato = 5;                      /* resource */
int n_readers = 0;                 /* number of readers*/
pthread_mutex_t mutex;             /* control access to dato */
pthread_mutex_t mutex_readers;     /* control access to n_readers */
```

```
void *Reader( void *arg )
{
  pthread_mutex_lock(&mutex_readers);
  n_readers++;
  if (n_readers == 1)
      pthread_mutex_lock(&mutex);
  pthread_mutex_unlock(&mutex_readers);

  /* read dato */
  printf("%d\n", dato);

  pthread_mutex_lock(&mutex_readers);
  n_readers--;
  if (n_readers == 0)
      pthread_mutex_unlock(&mutex);
  pthread_mutex_unlock(&mutex_readers);

  pthread_exit(0);
}
```

```
void *Writer ( void *arg )
{
    pthread_mutex_lock(&mutex);

    /* modify the resource */
    dato = dato + 2;

    pthread_mutex_unlock(&mutex);

    pthread_exit(0);
}
```

OPERATING SYSTEMS: COMMUNICATION AND SYNCHRONIZATION AMONG PROCESSES

Threads and communication and synchronization mechanisms