OPERATING SYSTEMS:

Lesson 7:
Threads Communication and Synchronization

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Content

- Communication and synchronization.
- Semaphores.
- The readers/writers problem.
- Mutex and condition variables.

Communication mechanisms

- **Communication mechanisms** allow for information **transfer** between two processes.

- Files.
- Pipes (pipes, FIFOs).
- Shared memory variables.
- Message passing.

Synchronization mechanisms

- Synchronization mechanisms allow to enforce that a process stops its execution until an event happens in another process.

- Concurrent languages constructs (threads).
- Operating system services:
  - Signals (asynchrony).
  - Pipes (pipes, FIFOs).
  - **Semaphores.**
  - **Mutex and condition variables.**
  - Message passing.

- Synchronization operations must be **atomic**.

Content

- Communication and synchronization.
- **Semaphores.**
- The readers/writers problem.
  - Semaphores based solution.
- Mutex and condition variables.

Semaphores

- Synchronization mechanism.
- Within the same machine.
- Object with an associated integer value.
- Two **atomic** operations.
  - **wait**
  - **signal**

Operations on semaphores

```
wait(s) {
   s = s - 1;
   if (s < 0) {
      <Block process>
   }
}

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

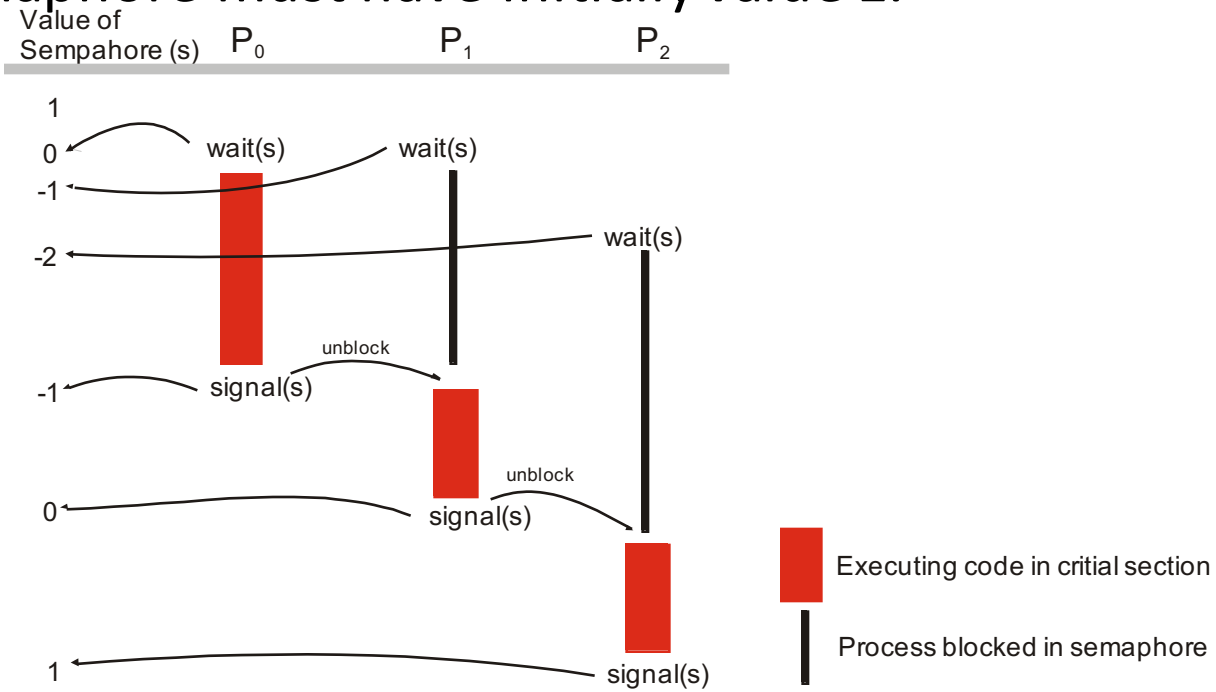
Critical sections with semaphores

wait(s); */* critical section entry*/*

< critical section>

signal(s); */* critical section exit */*

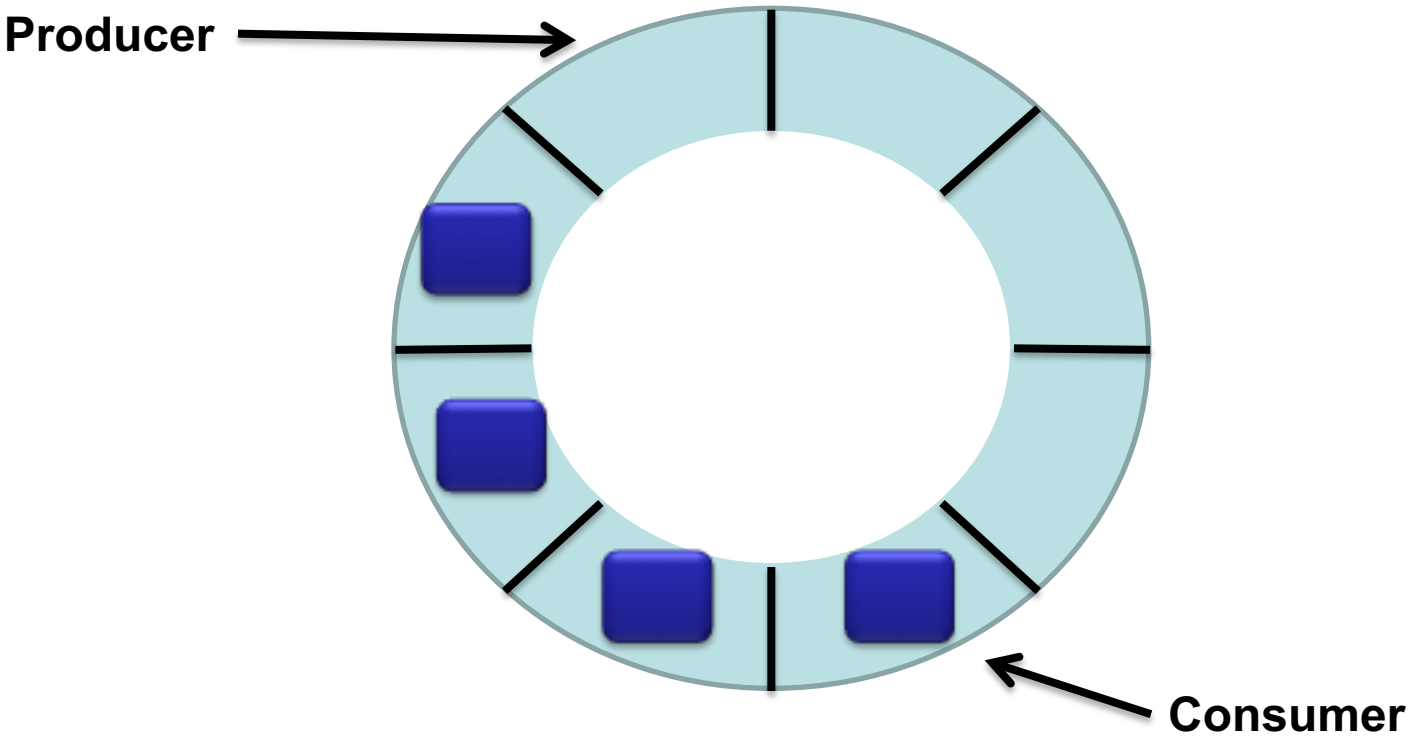
- Semaphore must have initially value 1.



POSIX semaphores

- **int sem_init(sem_t *sem, int shared, int val);**
  - Initializes unnamed semaphore.
- **int sem_destroy(sem_t *sem);**
  - Destroys unnamed semaphore.
- **sem_t *sem_open(char *name, int flag, mode_t mode, int val);**
  - Opens (creates) a named semaphore.
- **int sem_close(sem_t *sem);**
  - Closes a named semaphore.
- **int sem_unlink(char *name);**
  - Deletes a named semaphore.
- **int sem_wait(sem_t *sem);**
  - Performs **wait** operation on a semaphore.
- **int sem_post(sem_t *sem);**
  - Performs **signal** operation on a semaphore.

Producer-consumer (Bounded circular buffer)



Producer consumer with semaphores

```
#define MAX_BUFFER       1024    /* buffer size*/
#define DATA_SIZE  100000    /* number of data items to produce */

sem_t elements;                  /* elements in buffer*/
sem_t holes;                     /* holes in buffer*/
int buffer[MAX_BUFFER];          /* common buffer*/

void main(void)
{
  pthread_t th1, th2;  /* threads identifiers*/

  /* Initialize semaphores*/
  sem_init(&elements, 0, 0);
  sem_init(&holes, 0, MAX_BUFFER);
```

Producer consumer with semaphores

```
  /* create threads*/
  pthread_create(&th1, NULL, producer, NULL);
  pthread_create(&th2, NULL, consumer, NULL);

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

  sem_destroy(&holes);
  sem_destroy(&elements);

  exit(0);
}
```

Producer-Consumer: Producer thread

```
void producer() {   /* Producer code*/
  int pos = 0;  /* position in buffer*/
  int data;     /* data to be produced */
  int i;

  for(i=0; i < DATA_SIZE; i++ )   {
    data = i;          /* produce data*/

    sem_wait(&holes);  /* Reduce holes by 1*/
    buffer[pos] = data;
    pos = (pos + 1) % MAX_BUFFER;
    sem_post(&elements);  /* one element more*/
  }
  pthread_exit(0);
}
```

Producer-consumer: consumer thread

```
void consumer()  { /* Consumer code */
  int pos = 0;
  int data;
  int i;

  for(i=0; i < DATA_SIZE; i++ ) {
    sem_wait(&elements);    /* one element less*/
    data= buffer[pos];
    pos = (pos + 1) % MAX_BUFFER;
    sem_post(&holes);    /* one hole more*/

    store_data(data); /* consume data */
  }
  pthread_exit(0);
}
```

Producer-consumer: consumer thread

```
void consumer()  { /* Consumer code */
  int pos = 0;
  int data;
  int i;

  for(i=0; i < DATA_SIZE; i++ ) {
    sem_wait(&elements);   /* one element less*/
    data= buffer[pos];
    pos = (pos + 1) % MAX_BUFFER;
    sem_post(&holes);   /* one hole more*/

    store_data(data); /* consume data */
  }
  pthread_exit(0);
}
```

```
void producer() {   /* Producer code*/
  int pos = 0;  /* position in buffer*/
  int data;    /* data to be produced */
  int i;

  for(i=0; i < DATA_SIZE; i++ )   {
    data = i;          /* produce data*/

    sem_wait(&holes);  /* Reduce holes by 1*/
    buffer[pos] = data;
    pos = (pos + 1) % MAX_BUFFER;
    sem_post(&elements);  /* one element more*/
  }
  pthread_exit(0);
}
```

Content

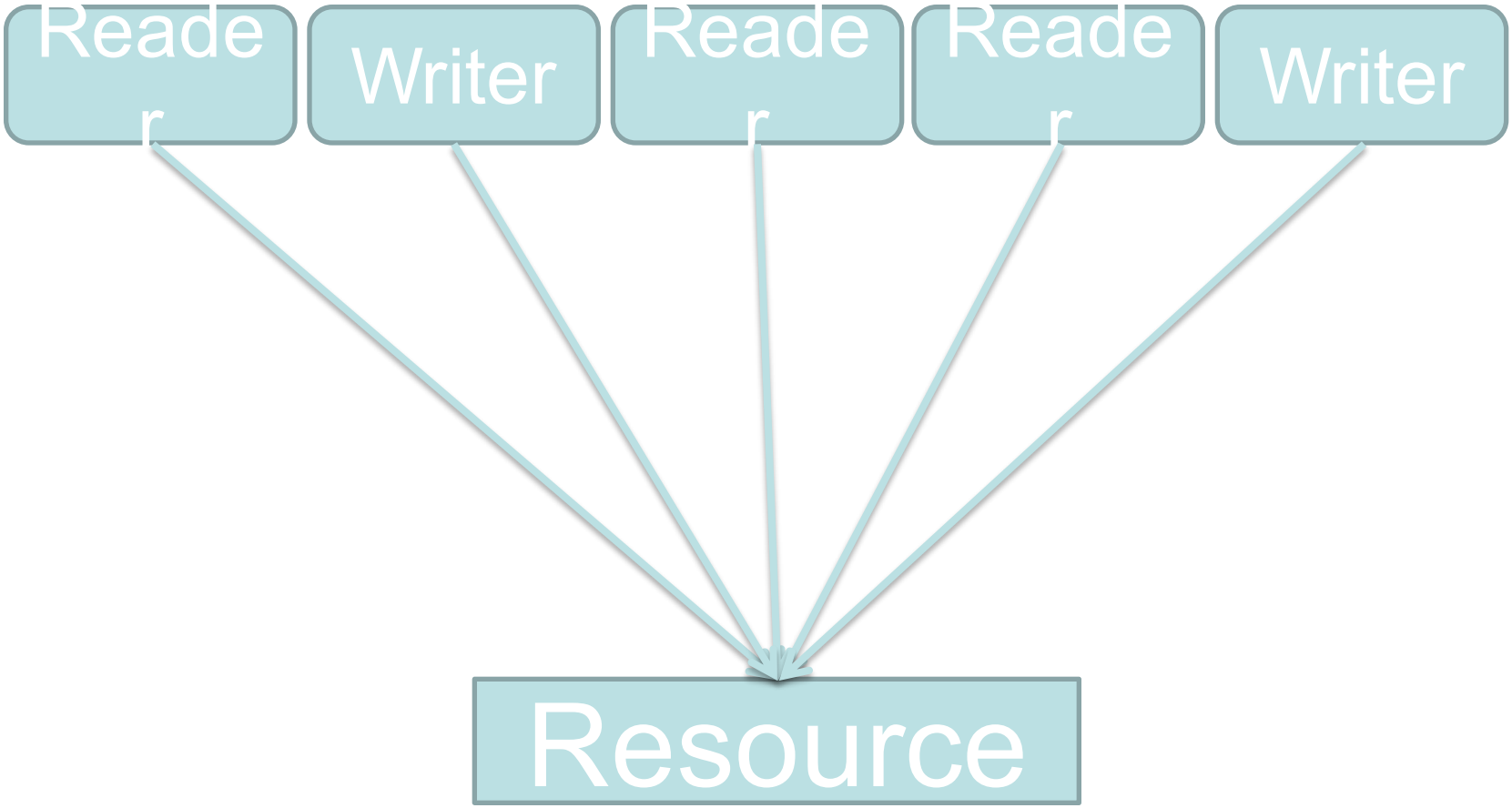
- Communication and synchronization.
- Semaphores.
- **The readers/writers problem.**
  - Semaphores based solution.
- Mutex and condition variables.

Readers-writes problem

- Problem when using a shared storage area.
  - Multiple processes reading information.
  - Multiple processes writing information.

- **Conditions:**
  - Any number of readers may read from the data area concurrently.
    - Read concurrency allowed.
  - Only one writer may modify information at once.
    - No concurrent writes allowed.
  - During a write no reader may perform a query.
    - No read/write concurrency allowed.

Readers-writers problem



Differences with other problems

- **Mutual exclusion**
  - Mutual exclusion would only allow a process to access at the same time to information.
  - No concurrency allowed between readers.
  - Higher contention.
- **Producer/Consumer**:
  - In producer/consumer both processes modify the shared data area.

- Goals of additional constraints:
  - **Provide a more efficient solution.**

Management alternatives

- **Readers have priority.**
  - If there is some reader in critical section other readers may enter.
  - A writer can only enter the critical section if there is no process there.
  - **Problem**: Starvation for writers.

- **Writers have priority.**
  - When a writer wishes to access to the critical section no more readers are admitted.

Readers have priority

```
int nreaders; sempahore rd=1; semaphore wr=1;
```

Lector

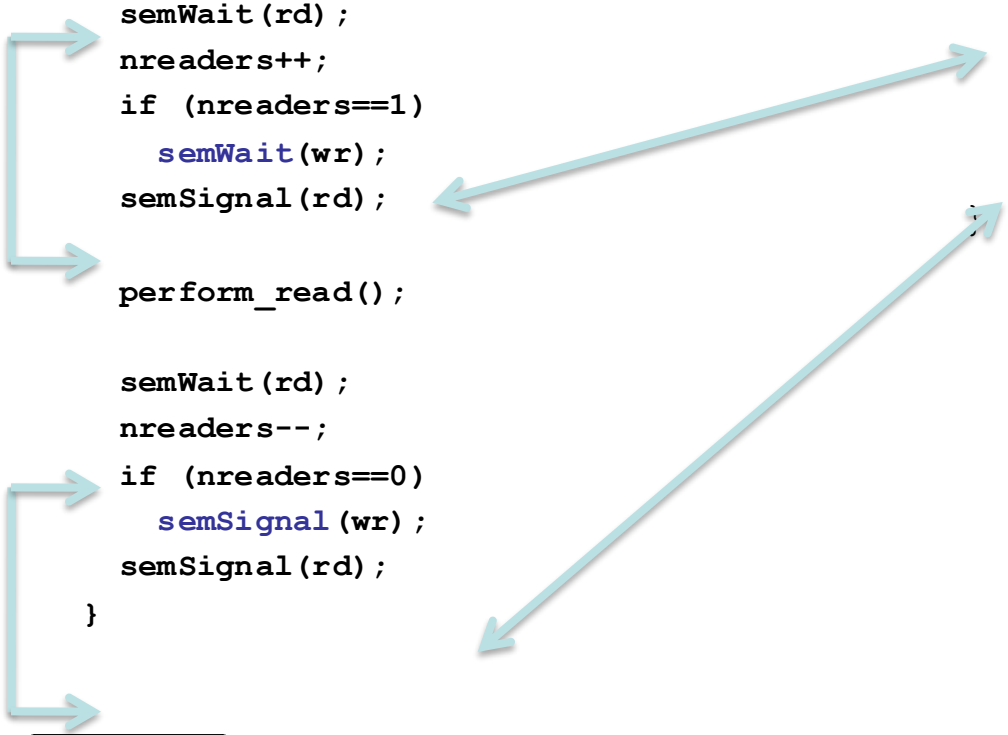
```
for(;;) {
  semWait(rd);
  nreaders++;
  if (nreaders==1)
    semWait(wr);
  semSignal(rd);

  perform_read();

  semWait(rd);
  nreaders--;
  if (nreaders==0)
    semSignal(wr);
  semSignal(rd);
}
```

- **Escritor**

```
for(;;) {
  semWait(wr);
  perform_write();
  semSignal(wr);
}
```



Management alternatives

- **Readers have priority.**
  - If there is some reader in the critical section other readers may enter.
  - A writer may only enter into the critical section if there is no other process already in the critical section.
  - Problem: Starvation for writers.

- **Writers have priority.**
  - When a writer wants to enter into the critical section, no new reader as allowed to enter into the critical section.

Readers-writers with semaphores

```
int data = 5;      /* resource*/
int nreaders = 0; /* number of readers */
sem_t sem_rd;      /* controls access to nreaders*/
sem_t mutex;       /* controls access to data*/

void main(void) {
  pthread_t th1, th2, th3, th4;

  sem_init(&mutex, 0, 1);
  sem_init(&sem_rd, 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);
```

Readers-writers with semaphores

```
  pthread_join(th1, NULL);
  pthread_join(th2, NULL);
  pthread_join(th3, NULL);
  pthread_join(th4, NULL);

  /* cerrar todos los semaforos */
  sem_destroy(&mutex);
  sem_destroy(&sem_rd);

  exit(0);
}
```

Readers-writers: reader thread

```
void reader() { /* reader code */
  sem_wait(&sem_rd);
  nreaders = nreaders + 1;
  if (nreaders == 1) sem_wait(&mutex);
  sem_post(&sem_rd);

  printf(``%d\n'', data);  /* read data and print it*/

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

Readers-writers: writer thread

```
void writer() {   /* writer code */
   sem_wait(&mutex);
   data = data + 2;     /* modify resource */
   sem_post(&mutex);

   pthread_exit(0);
}
```

Content

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- **Mutex and condition variables.**

Mutex and condition variables

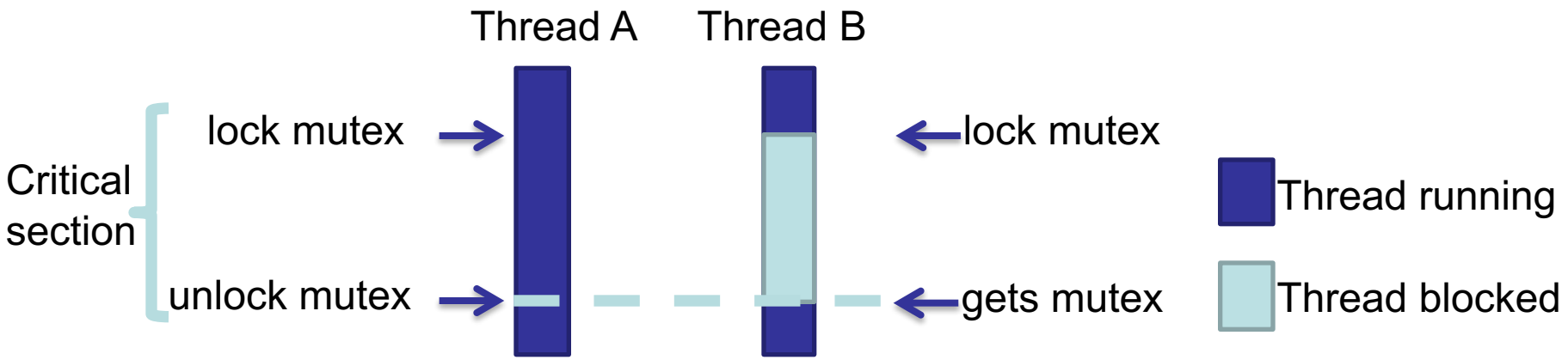
- A **mutex** is a synchronization mechanism for threads.

- It is a binary semaphore with to **atomic** operations.
  - **lock(m)** Try to block the mutex. If the mutex is already blocked the calling thread is suspended.
  - **unlock(m)** Unblocks the mutex. If there are processes blocked in the mutex one is unblocked.

Critical sections with mutexes

```
lock(m);     /* entry into critical section */
 <critical section>
 unlock(s);  /* exit from critical section */
```

- **unlock** operation must be performed by the thread that performed **lock**



Condition variables

- Synchronization variables associated to a mutex.
- Two **atomic** operations:
  - **wait** Blocks running thread and releases mutex.
  - **signal** Unblocks one or more threads suspended in the condition variable. Unblocked threads contend for acquiring the mutex again.

- They have to be in a **lock/unlock** block.

Using mutexes and condition variables

Thread A

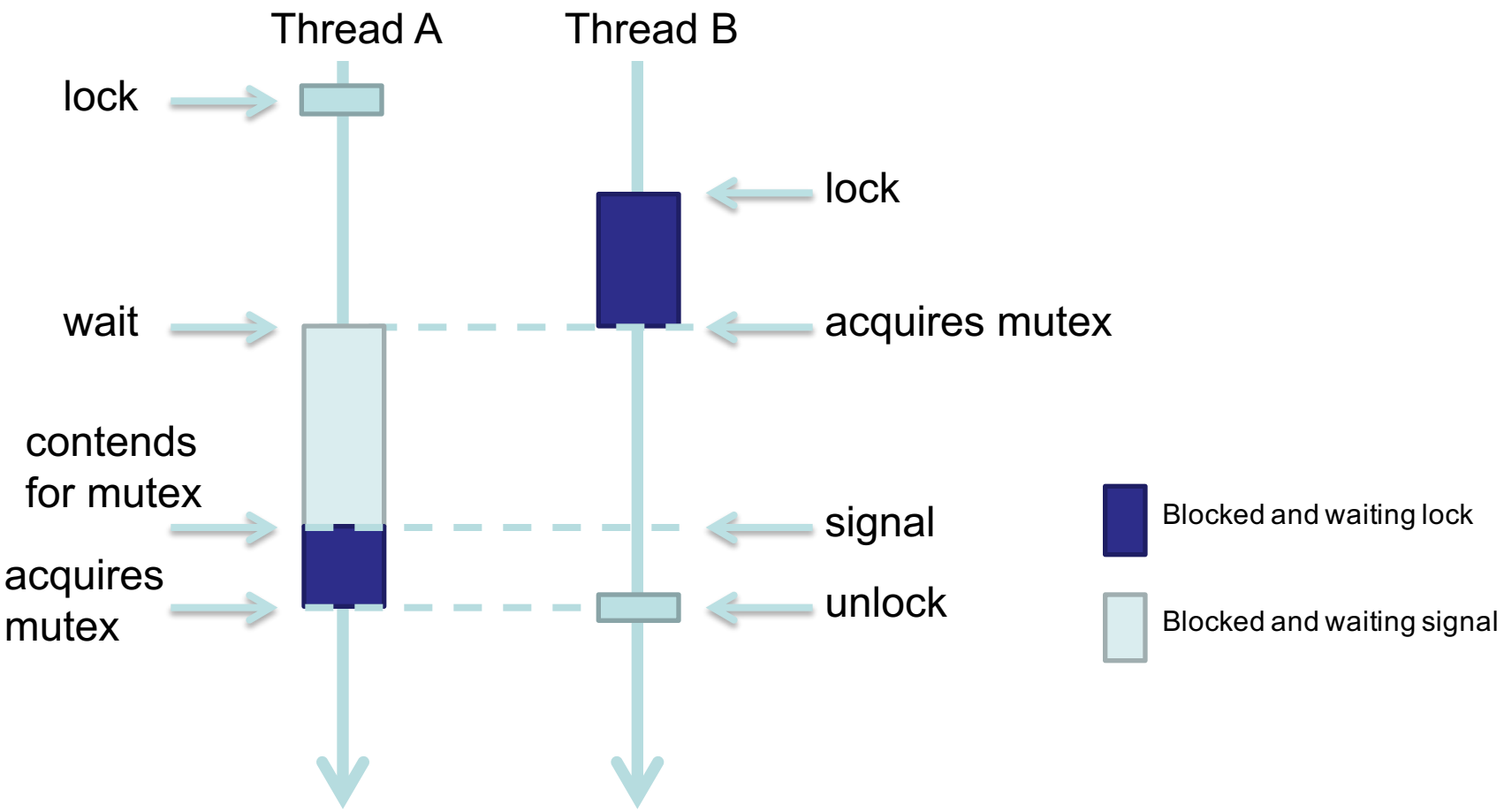
```
lock(mutex);  /* access to resource */
<check data structures>
while (resource is busy) {
   wait (condition, mutex);
}
<mark resource as busy>
unlock (mutex);
```

Thread B

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

Important to use while

Condition variables



POSIX services

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

- Initialize mutex.

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

- Destroy mutex.

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

- Try to get access to mutex.
- Blocks thread if mutex is already acquired by other thread.

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

- Unblock mutex.

POSIX services

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

- Initialize a condition variable.

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

- Destroy a condition variable.

POSIX services

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

- Unblocks one or more threads that are suspended in the condition variable **cond**.
- Has no effect if there is no thread waiting (difference with semaphores).

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

- All blocked threads in condition variable **cond** are unblocked.
- Has no effect if there is no thread waiting.

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

- Suspend thread until another thread signals condition variable **cond**.
- Automatically releases the **mutex**. When thread is unblocked it contends again for the **mutex**.

Producer-Consumer with mutexes

```
#define MAX_BUFFER       1024     /* size of buffer*/
#define DATA_SIZE   100000    /* number of data items to be produced*/

pthread_mutex_t mutex; /* mutex to access shared buffer */
pthread_cond_t non_full;   /* can we add more elements? */
pthread_cond_t non_empty;   /* can we remove elements? */
int n_elements;          /* number of elements in buffer */
int buffer[MAX_BUFFER];    /* common buffer */

int main() {
   pthread_t th1, th2;

   pthread_mutex_init(&mutex, NULL);
   pthread_cond_init(&non_full, NULL);
   pthread_cond_init(&non_empty, NULL);
```

Producer-Consumer with mutexes

```
    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(&non_full);
    pthread_cond_destroy(&non_empty);

    exit(0);
}
```

Producer

```
void producer()  {   /* Producer code */
  int data, i ,pos = 0;
  for(i=0; i < DATA_SIZE; i++ )  {
    data= i;       /* generate data */
    pthread_mutex_lock(&mutex);       /* access to buffer*/
    while (n_elements == MAX_BUFFER)  /* when buffer is full*/
      pthread_cond_wait(&non_full, &mutex);
    buffer[pos] = data;
    pos = (pos + 1) % MAX_BUFFER;
    n_elements ++;
    pthread_cond_signal(&non_empty);   /* buffer is not empty */
    pthread_mutex_unlock(&mutex);
  }
  pthread_exit(0);
}
```

Consumer

```
void consumer() {   /* consumer code */
  int dato, i ,pos = 0;
  for(i=0; i < DATA_SIZE; i++ ) {
    pthread_mutex_lock(&mutex);    /* access to buffer */
    while (n_elements == 0)       /* when buffer empty */
      pthread_cond_wait(&non_empty, &mutex);
    dato = buffer[pos];
    pos = (pos + 1) % MAX_BUFFER;
    n_elements --;
    pthread_cond_signal(&non_full);   /* buffer is not full */
    pthread_mutex_unlock(&mutex);
    printf("Consumed %d \n", data);     /* Use data*/
  }
  pthread_exit(0);
}
```

Readers writers with mutex

```
int data= 5;                /* resource*/
int nreaders = 0;           /* number of readers */
pthread_mutex_t data_mutex;       /* Control access to data*/
pthread_mutex_t mutex_rd; /* Controls access to nreaders */

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

   pthread_mutex_init(&data_mutex, NULL);
   pthread_mutex_init(&mutex_rd, NULL);

   pthread_create(&th1, NULL, Lector, NULL);
   pthread_create(&th2, NULL, Escritor, NULL);
   pthread_create(&th3, NULL, Lector, NULL);
   pthread_create(&th4, NULL, Escritor, NULL);
```

Readers writers with mutex

```
  pthread_join(th1, NULL);
  pthread_join(th2, NULL);
  pthread_join(th3, NULL);
  pthread_join(th4, NULL);

  pthread_mutex_destroy(&data_mutex);
  pthread_mutex_destroy(&mutex_rd);

  exit(0);
}
```

Writer

```
void writer() {   /* writer code*/
   pthread_mutex_lock(&data_mutex);
   dato = dato + 2;     /* modify resource*/
   pthread_mutex_unlock(&data_mutex);
   pthread_exit(0);
}
```

Reader

```
void reader() { /* codigo del lector */
  pthread_mutex_lock(&mutex_rd);
  nreaders++;
  if (nreaders == 1) pthread_mutex_lock(&data_mutex);
  pthread_mutex_unlock(&mutex_rd);

  printf("%d\n", data);  /* read data and print it*/

  pthread_mutex_lock(&mutex_rd);
  nreaders--;
  if (nreaders == 0) pthread_mutex_unlock(&data_mutex);
  pthread_mutex_unlock(&mutex_rd);

  pthread_exit(0);
}
```

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