Fundamentos de los Sistemas Operativos (FSO)

Departamento de Informática de Sistemas y Computadoras (DISCA)
Universitat Politècnica de València

Part 2: Process management

Seminar 6

Synchronization: POSIX Semaphores

fSO

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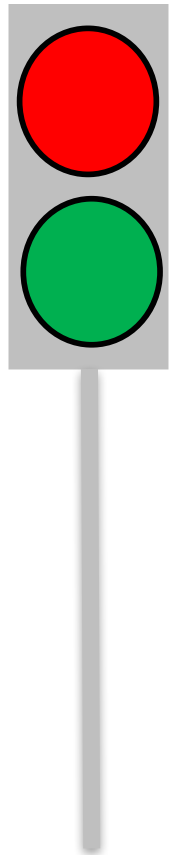
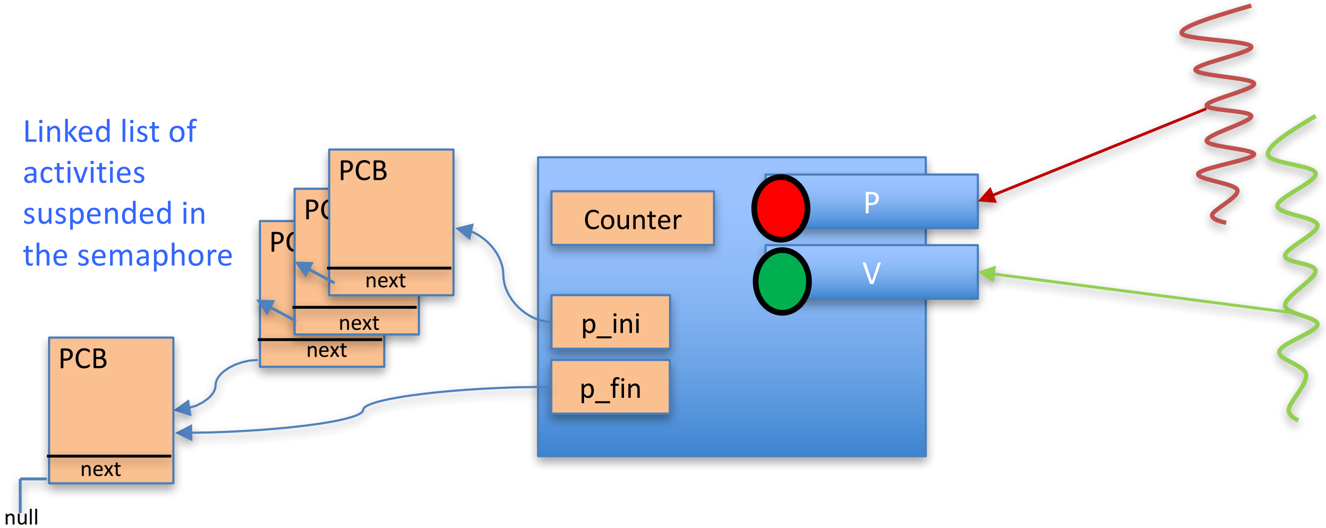
- **Goals:**
  - To get use to deal with **critical section** problems
  - To know the **synchronization** mechanisms **offered by the OS**
  - To use **semaphores** and **mutexes** to solve critical section synchronization
- **Bibliography**
  - Silberschatz 8th Ed, chapter 6
  - Robbins, chapters 13, 14

Content

- **OS level solutions**
- POSIX semaphores
- POSIX mutexes
- Exercises



- Semaphore
  - Can be seen as an integer that admits an increment by 1 and a decrement by 1 operations performed by an activity (process or thread)
    - The decrement operation can suspend the activity
    - The increment operation can awake another activity previously suspended
  - It is a synchronization object offered by the OS to user activities
    - It is declared as type “semaphore” specifying its initial value
    - The increment (V) and the decrement (P) operations are implemented as system calls



OS level solutions

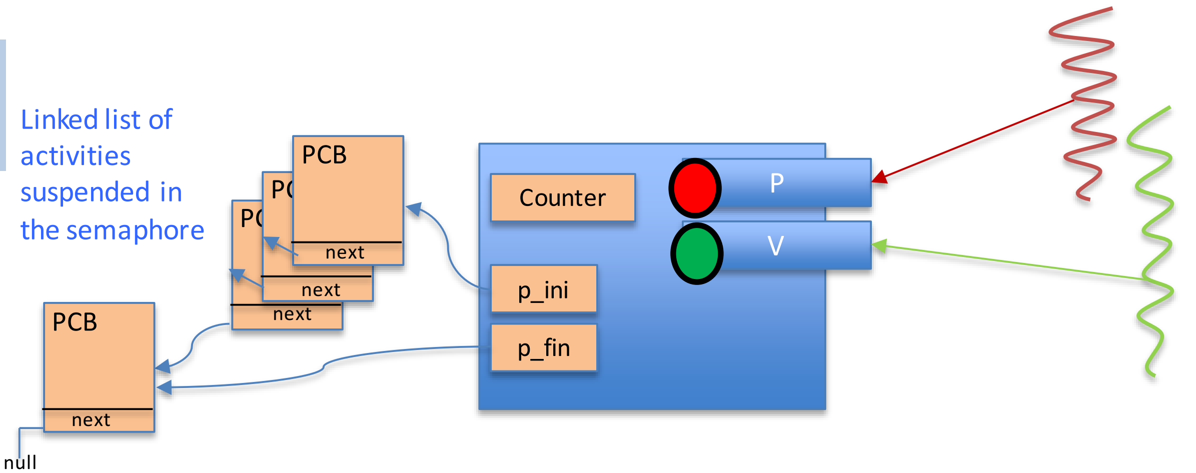
- Initialization, P and V specification
  - Declaration and initialization

    Semaphore S(N);

    - It declares a semaphore "S" with "N" as initial value
    - "N" has to be greater or equal to zero
  - Decrement

    P(S);

```
S = S - 1;
if S < 0 then suspend(S);
```



  - Increment

    V(S);

```
S = S + 1;
if S <= 0 then awake(S);
```

Notes:

- P and V are guaranteed to be atomic by the OS
- suspend(S) suspends the calling activity in a queue associated to S
- awake(S) extracts an activity from the S queue and awakes it (it goes to the scheduler ready queue)

OS level solutions

- Solving the critical section problem
  - We define as a global variable the semaphore “mutex”, **initialized to 1**

Semaphore mutex(1);

  - Code for N threads/processes

```
void *thread_i(void *p) {

  while(1) {
    P(mutex);

    /* Critical section */

    V(mutex);

    /* Remaining section */

  }
}
```

It complies with:

- Mutual exclusion
- Progress
- Limited waiting, if the semaphore queue is scheduled with FCFS policy

- Another synchronization use of semaphores: Establishing an execution order
  - We want “thread1” to execute function “F1” before “thread2” executes function “F2”
  - We define a shared semaphore between “thread1” and “thread2” named “sync”, **initialized to 0**

```
Semaphore sync(0);
```

```
void *thread1(void *p)
{
   ...

   F1;
   V(sync);
   ...
}
```

```
void *thread2(void *p)
{
    ...
    P(sync);
    F2;
    ...
}
```

- Another synchronization use of semaphores: Limiting the number of activities that can pass through a certain point in the code simultaneously
  - We have a function executed by many threads
  - We want a maximum of 5 threads call function “F” located in a certain place inside the function
  - We define a shared semaphore “max_5”, **initialized to 5**

```
Semaphore max_5(5);
```

```
…….
pthread_t th1, th2, th3, th4, th5;
 pthread_attr_t attr;

  pthread_attr_init(&attr);
  pthread_create(&th1, &attr, thread_i NULL);
  pthread_create(&th2, &attr, thread_i NULL);
  pthread_create(&th3, &attr, thread_i NULL);
  pthread_create(&th4, &attr, thread_i NULL);
…..
```

```
void *thread_i(void *p) {

   ...
   P(max_5);
   F;
   V(max_5);
   ...
}
```

OS level solutions

- **Basically a semaphore is a "resource counter"**
  - When an activity tries to use a resource, it decrements the counter (***P*** operation) and if there are not available resources then the activity is suspended
  - When an activity finishes using a resource then it increments the counter (***V*** operation). If there is any suspended activity waiting for the resource, then the ***V*** operation awakes it.
  - If the counter is greater than 0 then its value indicates the number of available resources

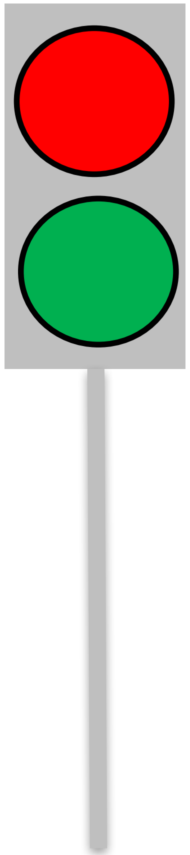
    if S >0 then |S|= number of available resources
  - When its value is less than cero its absolute value indicates the number of suspended activities in the semaphore queue

    if S <0 then |S|= number of suspended processes
  - When the counter is cero both of the former sentences are true

    if S =0 then → there are no suspended processes
    there are no available resources
- With semaphores the OS manages suspended activity queues, waiting for available resources
- Activity synchronization is one of the essential mechanisms that an OS has to provide

Content

- OS level solutions
- **POSIX semaphores**
- POSIX mutexes
- Exercises



POSIX semaphores

- POSIX.1b introduced the semaphore type `sem_t`

```
#include <semaphore.h>
sem_t sem;
```

  - A semaphore can be used by all the threads inside a process and also can be shared between processes.
    - After a fork() call semaphores in the parent can be inherited by the child depending on “pshared” paramete value in “sem_init”.

- POSIX.1b semaphore operations are:

```
– int sem_init(sem_t *sem, int pshared, unsigned int value);
– int sem_destroy(sem_t *sem);
– int sem_wait(sem_t *sem);
– int sem_trywait(sem_t *sem);
– int sem_post(sem_t *sem);
– int sem_getvalue(sem_t *sem, int *sval);
```

Operation P(sem)

Operation V(sem)

- Producer/Consumer **version 1**
  - We define a semaphore "`mutex`" initialized to **1** → **sem_init(&mutex,0,1);**

```
void *func_prod(void *p) {
  int item;

  while(1) {
    item = produce();

    sem_wait(& mutex);

    while (counter == N)
      /*empty loop*/ ;
    buffer[input] = item;
    input = (input + 1) % N;
    counter = counter + 1;

    sem_post(&mutex);
  }
}
```

```
void *func_cons(void *p) {
  int item;

  while(1) {
    sem_wait(&mutex);

    while (counter == 0)
      /*empty loop*/ ;
    item = buffer[output];
    output = (output + 1) % N;
    counter = counter - 1;

    sem_post(&mutex);

    consume(item);
  }
}
```

  - If the producer enters the critical section being the buffer full it will get into the while loop forever, the same happens with the consumer when the buffer is empty

POSIX semaphores

- Producer/Consumer **version 2**

```
#include <semaphore.h>
sem_t mutex, items, vacants;
```

```
void *func_prod(void *p) {
   int item;
   while(1) {
      item = produce();
      sem_wait(&vacants);
      sem_wait(&mutex);

      buffer[input] = item;
      input = (input + 1) % N;
      counter = counter + 1;

      sem_post(&mutex);
      sem_post(&items);
   }
}
```

```
void *func_cons(void *p) {
   int item;
   while(1) {
      sem_wait(&items);
      sem_wait(&mutex);

      item = buffer[output];
      output = (output + 1) % N;
      counter = counter - 1;

      sem_post(&mutex);
      sem_post(&vacants);
      consume(item);
   }
}
```

```
sem_init(&mutex, 0, 1);
sem_init(&vacants, 0, N);  // indicates the initial number of buffer vacants
sem_init(&items, 0, 0);  // indicates the initial number of buffer items
…
```

- OS level solutions
- POSIX semaphores
- **POSIX mutexes**
- Exercises

- **Mutex**
  - POSIX.1c defines the **mutex** object for thread synchronization
    - It can be seen as **semaphores that can only be initialized to 1**
    - It is used only to guaranty mutual exclusion
    - It works as a latch -> two operations: **lock** and **unlock**
    - A mutex has at every moment:
      - **State**: Open or closed
      - **Owner**: It is a thread that has executed a successful **lock** operation on it

- Mutex operation:
  - A mutex is created opened and without owner
  - When a thread calls to **lock**
    - If the mutex was open (without owner), the calling thread closes it and becomes its owner
    - If the mutex was closed, the calling thread is suspended
  - When an owner thread calls to **unlock**
    - The mutex gets open
    - If there were suspended threads on it, one of them is awaked, then the mutex gets closed an the awoken thread is the new owner

- **Mutex operation**

A **mutex is created opened** and without owner

When a thread **calls to lock** and ....

mutex is open?

NO

YES

the calling thread **closes it and** becomes its owner

the calling thread is **suspended**

when the **owner** thread calls to **unlock** and …

there are suspended threads?

NO

YES

one of them is awaked, then the mutex gets closed an the awoken thread is the **new owner**

The mutex gets **opened**

POSIX mutexes

- **POSIX calls for mutexes**
  - Creation and destruction
    - pthread_mutex_init
    - pthread_mutex_destroy
  - Attribute initialization
    - pthread_mutexattr_init
    - pthread_mutexattr_destroy
    - Changing/Checking attribute values
  - Lock and unlock
    - pthread_mutex_lock
    - pthread_mutex_trylock
    - pthread_mutex_unlock

Equivalent to P(sem)

Equivalent to V(sem)

POSIX mutexes

- **Example**: concurrent access to a shared variable by two threads
  - Main function code:

```
pthread_mutex_t m = PTHREAD_MUTEX_INITIALIZER;

int V = 100;

// Threads code (next slide)

int main ( ) {
   pthread_t        thread1, thread2;
   pthread_attr_t   attributes;
   pthread_attr_init(&attributes);
   pthread_create(&thread1, &attributes, func_thread1, NULL);
   pthread_create(&thread2, &attributes, func_thread2, NULL);

   pthread_join(thread1,NULL);
   pthread_join(thread2,NULL);
}
```

- Example (cont)
  - Thread functions:

```
void *func_thread1(void *p) {
   int c;

   for(c=0; c<1000; c++) {
      pthread_mutex_lock(&m);

      V = V + 1;

      pthread_mutex_unlock(&m);
   }
   pthread_exit(0);
}
```

```
void *func_thread2(void *p) {
   int c;

   for(c=0; c<1000; c++) {
      pthread_mutex_lock(&m);

      V = V - 1;

      pthread_mutex_unlock(&m);
   }
   pthread_exit(0);
}
```

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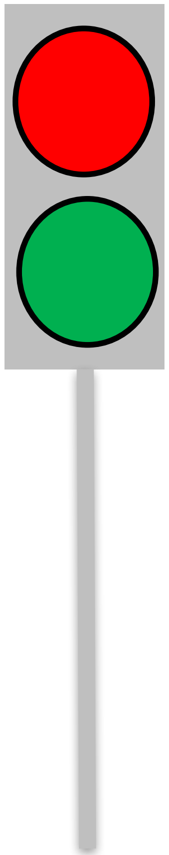
- OS level solutions
- POSIX semaphores
- POSIX mutexes
- **Exercises**



- **Exercise S06.1** What possible values will take **x** as a result of the concurrent execution of the following threads?

```
#include <semaphore.h>
#include <pthread.h>
#include <stdlib.h>
#include <stdio.h>
sem_t s1,s2,s3;
int x;
```

```
void *func_thread1(void *a)
{
 sem_wait(&s1);
 sem_wait(&s2);
 x=x+1;
 sem_post(&s3);
 sem_post(&s1);
 sem_post(&s2);
}
void *func_thread2(void *b)
{
 sem_wait(&s2);
 sem_wait(&s1);
 sem_wait(&s3);
 x=10*x;
 sem_post(&s2);
 sem_post(&s1);
}
```

```
int main()
{
  pthread_t h1,h2 ;
  x = 1;
  sem_init(&s1,0,1); /*Inicializa a 1*/
  sem_init(&s2,0,1); /*Inicializa a 1*/
  sem_init(&s3,0,0); /*Inicializa a 0*/

  pthread_create(&h1,NULL,func_thread1,NULL);
  pthread_create(&h2,NULL,func_thread2,NULL);
  pthread_join(h1,NULL);
  pthread_join(h2,NULL);
}
```

Exercise S06.2 What possible values will take shared variables **x** and **y** at the end of the following concurrent threads. The initial values are: x=1, y=4, S1=1, S2=0 y S3=1.

Thread A	Thread B	Thread C
P(S2);	P(S1);	P(S1);
P(S3);	P(S3);	P(S3);
x = y * 2;	x = x + 1;	x = y + 2;
y = y + 1;	y = 8 + x;	y = x * 4;
V(S3);	V(S2);	V(S3);
	V(S3);	V(S1);