CSE 3221.3
Operating System Fundamentals

No.6

Process Synchronization(2)

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Semaphores

- **Problems with the software solutions.**
  - **Not easy to generalize to more complex synchronization problems.**
  - **Complicated programming, not flexible to use.**
- **Semaphore: an easy-to-use synchronization tool**
  - **An integer variable *S***
  - ***wait(S)* {**

```
    while (S<=0) ;
    S-- ;
  }
```

  - ***signal(S)* {**

```
    S++ ;
  }
```

Semaphore usage (1):
the n-process critical-section problem

- **The n processes share a semaphore,**
  Semaphore *mutex ;* *// mutex* **is initialized to 1.**

Process P_i

```
do {

    wait(mutex);

        critical section of Pi

    signal(mutex);

        remainder section of Pi

} while (1);
```

Semaphore usage (2):
as a General Synchronization Tool

- **Execute *B* in P_j only after *A* executed in P_i**
- **Use semaphore *flag* initialized to 0**

P_i

```
…
A
signal (flag) ;
…
```

P_j

```
…
wait (flag) ;
B
…
```

Semaphore without busy-waiting

- **Previous definition of semaphore requires busy waiting**
  - **It is called** *spinlock.*
  - *spinlock* **does not need context switch, but waste CPU cycles in a continuous loop.**
  - *spinlock* **is OK only for lock waiting is very short.**
- **Semaphore without busy-waiting:**
  - **In defining *wait()*, rather than busy-waiting, the process makes system calls to block itself and switch back to waiting state, and put the process to a waiting queue associated with the semaphore. The control is transferred to CPU scheduler.**
  - **In defining *signal()*, the process makes system calls to pick a process in the waiting queue of the semaphore, wake it up by moving it to the ready queue to wait for CPU scheduling.**

Semaphore without busy-waiting

- **Define a semaphore as a record:**

```
typedef struct {
  int value;   // Initialized to 1
  struct process *L;
} semaphore;
```

- **Assume two system calls:**
  - *block()* **suspends the process that invokes it.**
  - *wakeup(P)* **resumes the execution of a blocked process** P.
- **Normally this type of semaphore is implemented in kernel.**

Semaphore without busy-waiting

- Semaphore operations now defined as:

```
wait(S):
        S.value--;
        if (S.value < 0) {
                add this process to S.L;
                block();
        }

signal(S):
        S.value++;
        if (S.value <= 0) {
                remove a process P from S.L;
                wakeup(P);
        }
```

Semaphore Implementation(1)

- In uni-processor machine, disabling interrupt before modifying semaphore.

```
wait(S) {

  do {
     Disable_Interrupt;
     if(S>0) {
        S-- ;
       Enable_Interrupt ;
       return ;
      } else {
       Enable_Interrupt ;
      }
   }  while(1) ;
}
```

```
signal(S) {

   Disable_Interrupt ;
   S++ ;
   Enable_Interrupt ;
   return ;

}
```

Semaphore Implementation(2)

- In multi-processor machine, inhibiting interrupt of all processors is not easy and efficient.
- Use software solution to critical-section problems
  - e.g., bakery algorithm.
  - Treat *wait()* and *signal()* as critical sections.
- Example: implement spinlock between two processes.
  - Use Peterson's solution for process synchronization.
  - Shared data:

```
Semaphore S ;  Initially S=1

boolean flag[2]; initially flag [0] = flag [1] = false.
int turn;   initially turn = 0 or 1.
```

Semaphore Implementation(3)

```
wait(S) {
    int i=process_ID(); //0→P0, 1→P1
    int j=(i+1)%2 ;
 do {
  flag [ i ]:= true; //request to enter
  turn = j;
  while (flag [ j ] and turn = j) ;
  if (S >0) {  //critical section
       S--;
      flag [ i ] = false;
      return ;
    } else {
     flag [ i ] = false;
   }
 } while (1);
}
```

```
signal(S) {
    int i=process_ID(); //0→P0, 1→P1
    int j=(i+1)%2 ;

  flag [ i ]:= true; //request to enter
  turn = j;
  while (flag [ j ] and turn = j) ;

   S++; //critical section

  flag [ i ] = false;

  return ;
}
```

Two Types of Semaphores

- ***Counting*** semaphore – integer value can range over an unrestricted domain.
- ***Binary*** semaphore – integer value can range only between 0 and 1; simpler to implement by hardware.
- We can implement a counting semaphore *S* by using two binary semaphore.

Implementing counting semaphore with two Binary Semaphores

- Data structures:

  binary-semaphore S1, S2;
  int C:

- Initialization:

  S1 = 1
  S2 = 0
  C = initial value of semaphore *S*

Implementing *S*

- ***wait(S)*** **operation:**

```
wait(S1);
C--;
if (C < 0) {
    signal(S1);
    wait(S2);
}
signal(S1);
```

- ***signal(S)*** **operation:**

```
wait(S1);
C ++;
if (C <= 0)
    signal(S2);
else
    signal(S1);
```

Classical Synchronization Problems

- **The Bounded-Buffer Problem**
- **The Readers-Writers Problem**
- **The Dining-Philosophers Problem**

Bounded-Buffer Problem

- **A producer produces some data for a consumer to consume. They share a bounded-buffer for data transferring.**
- **Shared memory:**

  A buffer to hold at most *n* items
- **Shared data (three semaphores)**

  Semaphore filled, empty, mutex;

  Initially:

  filled = 0, empty = n, mutex = 1

Bounded-Buffer Problem: Producer Process

```
do {
        …
    produce an item in nextp
        …
    wait(empty);
    wait(mutex);
        …
    add nextp to buffer
        …
    signal(mutex);
    signal(filled);

} while (1);
```

Bounded-Buffer Problem: Consumer Process

```
do {
    wait(filled)
    wait(mutex);
      …
    remove an item from buffer to nextc
      …
    signal(mutex);
    signal(empty);
      …
    consume the item in nextc
      …
} while (1);
```

The Readers-Writers Problem

- **Many processes concurrently access a data object**
  - **Readers: only read the data.**
  - **Writers: update and may write the data object.**
- **Only writer needs exclusive access of the data.**
- **The first readers-writers problem:**
  - **Unless a writer has already obtained permission to use the shared data, readers are always allowed to access data.**
  - **May starve a writer.**
- **The second readers-writer problem:**
  - **Once a writer is ready, the writer performs its write as soon as possible.**
  - **May starve a reader.**

The 1st Readers-Writers Problem

- **Use semaphore to implement 1st readers-writer problem**
- **Shared data:**

```
int readcount = 0 ;   // keep track the number of readers
                      //  accessing the data object

Semaphore mutex = 1 ;  // mutually exclusive access to
                       // readcount among readers

Semaphore wrt = 1 ;   // mutual exclusion to the data object
                      // used by every writer
                      //also set by the 1st reader to read the data
                      // and clear by the last reader to finish reading
```

The 1st Readers-Writers Problem

Writer Process

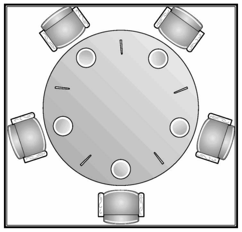
```
  …
wait(wrt);
  …
writing is performed
  …
signal(wrt);
  …
```

Reader Process

```
…
wait(mutex);
readcount++;
if (readcount == 1)   wait(wrt);
signal(mutex);
  …
reading is performed
…
wait(mutex);
readcount--;
if (readcount == 0)   signal(wrt);
signal(mutex);
…
```

The Dining-Philosophers Problem

- **Five philosophers are thinking or eating**
- **Using only five chopsticks**
- **When thinking, no need for chopsticks.**
- **When eating, need two closest chopsticks.**
- **Can pick up only one chopsticks**
- **Can not get the one already in the hand of a neighbor.**



The Dining-Philosophers Problem: Semaphore Solution

- **Represent each chopstick with a semaphore**

  Semaphore *chopstick[5]*; **// Initialized to** *1*

Philosopher i (i=0,1,2,3,4)

```
do {
    wait(chopstick[i]) ;
    wait(chopstick[(i+1) % 5]) ;
      …
      eat
      …
    signal(chopstick[i]);
    signal(chopstick[(i+1) % 5]);
      …
      think
      …
} while (1);
```

Incorrect Semaphore Usage

Mistake 1:

```
…
signal(mutex) ;
…
Critical
Section
…
wait(mutex) ;
```

Mistake 2:

```
…
wait(mutex) ;
…
Critical
Section
…
wait(mutex) ;
```

Mistake 3:

```
…
wait(mutex) ;
…
Critical
Section
…
```

Mistake 4:

```
…
Critical
Section
…
signal(mutex) ;
```

Starvation and Deadlock

- *Starvation* **– infinite blocking. A process may never be removed from the semaphore queue in which it is suspended.**
- *Deadlock* **– two or more processes are waiting infinitely for an event that can be caused by only one of the waiting processes.**
- **Let *S* and *Q* be two semaphores initialized to 1**

P_0	P_1
***wait*(*S*);**	***wait*(*Q*);**
***wait*(*Q*);**	***wait*(*S*);**
⋮	⋮
***signal*(*S*);**	***signal*(*Q*);**
***signal*(*Q*)**	***signal*(*S*);**

Pthread Semaphore

- Pthread semaphores for multi-process and multi-thread programming in Unix/Linux:
  - Pthread Mutex Lock
    (binary semaphore)
  - Pthread Semaphore
    (general counting semaphore)

Pthread Mutex Lock

```
#include <pthread.h>
/*declare a mutex variable*/
pthread_mutex_t  mutex ;

/* create a mutex lock */
pthread_mutex_init (&mutex, NULL) ;

/* acquire the mutex lock  */
pthread_mutex_lock(&mutex) ;

/* release the mutex lock  */
pthread_mutex_unlock(&mutex) ;
```

Using Pthread Mutex Locks

- Use mutex locks to solve critical section problems:

```
#include <pthread.h>
pthread_mutex_t  mutex ;
…
pthread_mutex_init(&mutex, NULL) ;
…
pthread_mutex_lock(&mutex) ;

/*** critical section ***/

pthread_mutex_unlock(&mutex) ;
```

Pthread Semaphores

```
#include <semaphore.h>
/*declare a pthread semaphore*/
sem_t sem ;

/* create and initialize a semaphore */
sem_init (&sem, flag, initial_value) ;

/* wait() operation  */
sem_wait(&sem) ;

/* signal() operation  */
sem_post(&sem) ;
```

Using Pthread semaphore

- Using Pthread semaphores for counters shared by multiple threads:

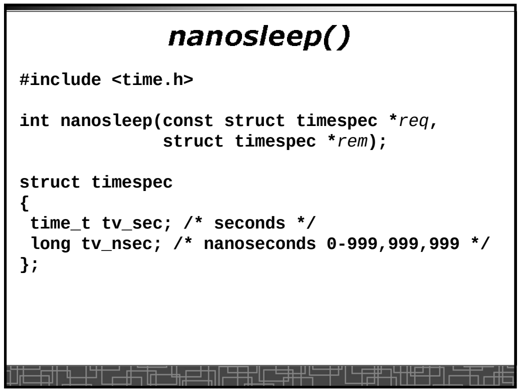
```
#include <semaphore.h>
sem_t  counter ;
…
sem_init(&counter, 0, 0) ;  /* initially 0 */
…
sem_post(&counter) ;    /* increment */
…
sem_wait(&counter) ;    /* decrement */
```

volatile in multithread program

- In multithread programming, a shared global variable must be declared as volatile to avoid compiler's optimization which may cause conflicts:

```
volatile int data ;

volatile char buffer[100] ;
```



nanosleep()

```
#include <time.h>

int nanosleep(const struct timespec *req,
              struct timespec *rem);

struct timespec
{
 time_t tv_sec; /* seconds */
 long tv_nsec; /* nanoseconds 0-999,999,999 */
};
```