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	P_j
…	…
A	*wait* (flag) ;
signal (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

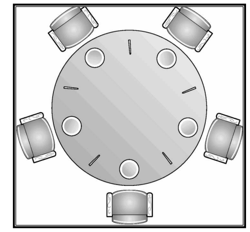
```
…
wait(wrt);
…
writing is performed
…
signal(wrt);
…
```

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 */
};
```