Lecture 7

Process Synchronization II

Lecture Information

Ceng328 *Operating Systems* at April 06, 2010

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Contents

Peterson's Solution I

- A classic software-based solution to the critical-section problem known as Peterson's solution.

Peterson's Solution II

- The algorithm for Peterson's solution is seen in Fig. 1.

```
do {
      flag[i] = TRUE;
      turn = j;
      while (flag[j] && turn == j);

          critical section

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} while (TRUE);
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Figure: The structure of process P_i in Peterson's solution.

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- Burns CPU cycles; requires busy waiting
- It can be extended to work for *n* processes, but overhead.

Peterson's Solution III

```
#define FALSE  0
#define TRUE   1
#define N      2                          /* number of processes */

int turn;                                 /* whose turn is it? */
int interested[N];                        /* all values initially 0 (FALSE) */

void enter_region(int process);           /* process is 0 or 1 */
{
     int other;                           /* number of the other process */

     other = 1 − process;                 /* the opposite of process */
     interested[process] = TRUE;          /* show that you are interested */
     turn = process;                      /* set flag */
     while (turn == process && interested[other] == TRUE) /* null statement */ ;
}

void leave_region(int process)            /* process: who is leaving */
{
     interested[process] = FALSE;         /* indicate departure from critical region */
}
```

Figure: Peterson's solution for achieving mutual exclusion.

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  - *Sleep* is a system call that causes the caller to block, that is, be suspended until another process wakes it up.
  - The *wakeup* call has one parameter, the process to be awakened.

Semaphores I

- A synchronization tool called **semaphore**.

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  - The semaphore is initialized to the number of resources available.
  - Each process that wishes to use a resource performs a *wait*() operation on the semaphore (thereby decrementing the *count*).
  - When a process releases a resource, it performs a *signal*() operation (incrementing the *count*).
  - When the *count* for the semaphore goes to 0, all resources are being used. After that, processes that wish to use a resource will block until the count becomes greater than 0.

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- The *n* processes share a semaphore, **mutex**, initialized to 1.
- Each process P_i is organized as shown in Fig. 3.

```
do {
   waiting(mutex);

      // critical section

   signal(mutex);

      // remainder section
}while (TRUE);
```

Figure: Mutual-exclusion implementation with semaphores.

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  - Then control is transferred to the CPU scheduler, which selects another process to execute.

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- The critical aspect of semaphores is that they be executed **atomically**.
- We must guarantee that no two processes can execute *wait*() and *signal*() operations on the same semaphore at the same time.

Deadlocks and Starvation I

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- Another problem related to deadlocks is **indefinite blocking**, or **starvation**, a situation in which processes wait indefinitely within the semaphore.
- Indefinite blocking may occur if we add and remove processes from the list associated with a semaphore in LIFO (last-in, first-out) order.

Deadlocks and Starvation II

- To illustrate deadlock, we consider a system consisting of two processes, P_0 and P_1, each accessing two semaphores, S and Q, set to the value 1:

P_0	P_1
`wait(S);`	`wait(Q);`
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.	.
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  - Since these *signal*() operations cannot be executed, P_0 and P_1 are deadlocked.

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- If multiple threads are blocked on the mutex, one of them is *chosen at random* and allowed to acquire the lock.
- With threads, there is no clock that stops threads that have run too long.

Mutexes II

- Consequently, a thread that tries to acquire a lock by busy waiting will loop forever and never acquire the lock because it never allows any other thread to run and release the lock.

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Mutexes II

- Consequently, a thread that tries to acquire a lock by busy waiting will loop forever and never acquire the lock because it never allows any other thread to run and release the lock.
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- When the later fails to acquire a lock, it calls *thread_yield* to give up the CPU to another thread.

Mutexes II

- Consequently, a thread that tries to acquire a lock by busy waiting will loop forever and never acquire the lock because it never allows any other thread to run and release the lock.
- That is where the difference between *enter_region* and *mutex_lock* comes in.
- When the later fails to acquire a lock, it calls *thread_yield* to give up the CPU to another thread.
- Consequently there is no busy waiting. When the thread runs the next time, it tests the lock again.

Thread call	**Description**
Pthread_mutex_init	Create a mutex
Pthread_mutex_destroy	Destroy an existing mutex
Pthread_mutex_lock	Acquire a lock or block
Pthread_mutex_trylock	Acquire a lock or fail
Pthread_mutex_unlock	Release a lock

Figure: Some of the Pthreads calls relating to the mutexes.

Mutexes III

```c
#include <stdio.h>
#include <pthread.h>
#define MAX 1000000000                          /* how many numbers to produce */
pthread_mutex_t the_mutex;
pthread_cond_t condc, condp;
int buffer = 0;                                 /* buffer used between producer and consumer */

void *producer(void *ptr)                       /* produce data */
{       int i;

        for (i= 1; i <= MAX; i++) {
                pthread_mutex_lock(&the_mutex); /* get exclusive access to buffer */
                while (buffer != 0) pthread_cond_wait(&condp, &the_mutex);
                buffer = i;                     /* put item in buffer */
                pthread_cond_signal(&condc);    /* wake up consumer */
                pthread_mutex_unlock(&the_mutex);/* release access to buffer */
        }
        pthread_exit(0);
}

void *consumer(void *ptr)                       /* consume data */
{       int i;

        for (i = 1; i <= MAX; i++) {
                pthread_mutex_lock(&the_mutex); /* get exclusive access to buffer */
                while (buffer ==0 ) pthread_cond_wait(&condc, &the_mutex);
                buffer = 0;                     /* take item out of buffer */
                pthread_cond_signal(&condp);    /* wake up producer */
                pthread_mutex_unlock(&the_mutex);/* release access to buffer */
        }
        pthread_exit(0);
}
```

Figure: Using threads to solve the producer-consumer problem I.

Mutexes IV

```
int main(int argc, char **argv)
{
        pthread_t pro, con;
        pthread_mutex_init(&the_mutex, 0);
        pthread_cond_init(&condc, 0);
        pthread_cond_init(&condp, 0);
        pthread_create(&con, 0, consumer, 0);
        pthread_create(&pro, 0, producer, 0);
        pthread_join(pro, 0);
        pthread_join(con, 0);
        pthread_cond_destroy(&condc);
        pthread_cond_destroy(&condp);
        pthread_mutex_destroy(&the_mutex);
}
```

Figure: Using threads to solve the producer-consumer problem II.

The Bounded-Buffer Problem I

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- The *empty* (initially *n*) and *full* (initially 0) semaphores count the number of empty and full buffers.
- The code for the producer process is shown in Fig. 7;

```
do {
     . . .
   // produce an item in nextp
     . . .
   wait(empty);
   wait(mutex);
     . . .
   // add nextp to buffer
     . . .
   signal(mutex);
   signal(full);
}while (TRUE);
```

Figure: The structure of the producer process.

The Bounded-Buffer Problem II

The code for the consumer process is shown in Fig. 8;

```
do {
   wait(full);
   wait(mutex);
      . . .
   // remove an item from buffer to nextc
      . . .
   signal(mutex);
   signal(empty);
      . . .
   // consume the item in nextc
      . . .
}while (TRUE);
```

Figure: The structure of the consumer process.

The Bounded-Buffer Problem III

```
#define N 100                           /* number of slots in the buffer */
typedef int semaphore;                  /* semaphores are a special kind of int */
semaphore mutex = 1;                    /* controls access to critical region */
semaphore empty = N;                    /* counts empty buffer slots */
semaphore full = 0;                     /* counts full buffer slots */

void producer(void)
{
        int item;

        while (TRUE) {                  /* TRUE is the constant 1 */
                item = produce_item( ); /* generate something to put in buffer */
                down(&empty);           /* decrement empty count */
                down(&mutex);           /* enter critical region */
                insert_item(item);      /* put new item in buffer */
                up(&mutex);             /* leave critical region */
                up(&full);              /* increment count of full slots */
        }
}


void consumer(void)
{
        int item;

        while (TRUE) {                  /* infinite loop */
                down(&full);            /* decrement full count */
                down(&mutex);           /* enter critical region */
                item = remove_item( );  /* take item from buffer */
                up(&mutex);             /* leave critical region */
                up(&empty);             /* increment count of empty slots */
                consume_item(item);     /* do something with the item */
        }
}
```

Figure: The producer-consumer problem using semaphores.

The Readers-Writers Problem I

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- If two readers access the shared data simultaneously, no adverse affects will result.
- However, if a writer and some other thread (either a reader or a writer) access the database simultaneously, there could be some **synchronization issues**.
- To ensure that these difficulties do not arise, we require that the writers have *exclusive access* to the shared database.
- This synchronization problem is referred to as the **readers-writers** problem.

The Readers-Writers Problem II

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The Readers-Writers Problem II

- The readers-writers problem has several variations, all involving priorities.
    - The simplest one, referred to as the first readers-writers problem, requires that no reader will be kept waiting unless a writer has already obtained permission to use the shared object. In other words, no reader should wait for other readers to finish simply because a writer is waiting.
    - The second readers-writers problem requires that, once a writer is ready, that writer performs its write as soon as possible. In other words, if a writer is waiting to access the object, no new readers may start reading.

The Readers-Writers Problem III

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do {
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      . . .
   // writing is performed
      . . .
   signal(wrt);
}while (TRUE);
```

Figure: The structure of a writer process.

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      . . .
   // writing is performed
      . . .
   signal(wrt);
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Figure: The structure of a writer process.

```
do {
   wait(mutex);
   readcount++;
   if (readcount == 1)
      wait(wrt);
   signal(mutex);
      . . .
   // reading is performed
      . . .
   wait(mutex);
   readcount--;
   if (readcount == 0)
      signal(wrt);
   signal(mutex);
}while (TRUE);
```

Figure: The structure of a reader process.

The Readers-Writers Problem IV

- In the solution to the first readers-writers problem, the reader processes share the following data structures:

```
semaphore mutex, $wrt$;
int readcount;
```


The Dining-Philosophers Problem I

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- Consider five philosophers who spend their lives thinking and eating.
- The philosophers share a circular table surrounded by five chairs (see Fig. 12).

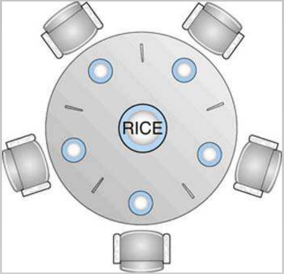

Figure: The situation of the dining philosophers.

The Dining-Philosophers Problem II

- The dining-philosophers problem is an example of a large class of concurrency-control problems.

The Dining-Philosophers Problem III

- The structure of philosopher *i* is shown in Fig. 13.

```
do {
   wait(chopstick[i]);
   wait(chopstick[(i+1) % 5]);
      . . .
   // eat
      . . .
   signal(chopstick[i]);
   signal(chopstick[(i+1) % 5]);
      . . .
   // think
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- Although this solution guarantees that no two neighbors are eating simultaneously, it could create a deadlock.
- Suppose that all five philosophers become hungry simultaneously and each grabs her left chopstick.
- When each philosopher tries to grab her right chopstick, she will be delayed forever.

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- It has a performance bug: only one philosopher can be eating at any instant.
- With five forks available, we should be able to allow two philosophers to eat at the same time.
- Any satisfactory solution to the dining-philosophers problem must guard against the possibility that one of the philosophers will starve to death.

The Dining-Philosophers Problem V

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- It uses an array, *state*, to keep track of whether a philosopher is *eating*, *thinking*, or *hungry* (trying to acquire forks).
- A philosopher may move only into eating state if neither neighbor (LEFT and RIGHT) is eating .

```
#define N           5          /* number of philosophers */
#define LEFT        (i+N-1)%N  /* number of i's left neighbor */
#define RIGHT       (i+1)%N    /* number of i's right neighbor */
#define THINKING    0          /* philosopher is thinking */
#define HUNGRY      1          /* philosopher is trying to get forks */
#define EATING      2          /* philosopher is eating */
typedef int semaphore;         /* semaphores are a special kind of int */
int state[N];                  /* array to keep track of everyone's state */
semaphore mutex = 1;           /* mutual exclusion for critical regions */
semaphore s[N];                /* one semaphore per philosopher */

void philosopher(int i)        /* i: philosopher number, from 0 to N-1 */
{
    while (TRUE) {             /* repeat forever */
        think( );              /* philosopher is thinking */
        take_forks(i);         /* acquire two forks or block */
        eat( );                /* yum-yum, spaghetti */
        put_forks(i);          /* put both forks back on table */
    }
}
```

Figure: A solution to the dining philosophers problem I.

The Dining-Philosophers Problem VI

```
void take_forks(int i)                /* i: philosopher number, from 0 to N-1 */
{
      down(&mutex);                   /* enter critical region */
      state[i] = HUNGRY;              /* record fact that philosopher i is hungry */
      test(i);                        /* try to acquire 2 forks */
      up(&mutex);                     /* exit critical region */
      down(&s[i]);                    /* block if forks were not acquired */
}

void put_forks(i)                     /* i: philosopher number, from 0 to N-1 */
{
      down(&mutex);                   /* enter critical region */
      state[i] = THINKING;            /* philosopher has finished eating */
      test(LEFT);                     /* see if left neighbor can now eat */
      test(RIGHT);                    /* see if right neighbor can now eat */
      up(&mutex);                     /* exit critical region */
}

void test(i) /* i: philosopher number, from 0 to N-1 */
{
      if (state[i] == HUNGRY && state[LEFT] != EATING && state[RIGHT] != EATING) {
            state[i] = EATING;
            up(&s[i]);
      }
}
```

Figure: A solution to the dining philosophers problem II.

The solution is deadlock–free and allows the maximum parallelism for any number of philosophers

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  - Each process must execute *wait*(*mutex*) before entering the CS and *signal*(*mutex*) afterward.
  - If this sequence is not observed,two processes may be in their CSs simultaneously.

Monitors II

- Suppose that a process interchanges the order in which the *wait*() and *signal*() operations on the semaphore mutex are executed, resulting in the following execution:

```
signal(mutex);
    ...
 critical section
    ...
wait(mutex);
```

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  - A monitor is a collection of procedures, variables, and data structures that are all grouped together in a special kind of module or package.
  - Processes may call the procedures in a monitor whenever they want to, but they cannot directly access the monitor's internal data structures from procedures declared outside the monitor.

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- Some real programming languages also support monitors. One such language is Java.
- Java is an object-oriented language that supports user-level threads and also allows methods (procedures) to be grouped together into classes (keyword **synchronized**).

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```
monitor monitor name
{
   // shared variable declarations

   procedure P1 ( . . . ) {
      . . .
   }

   procedure P2 ( . . . ) {
      . . .
   }
          .
          .
          .
   procedure Pn ( . . . ) {
      . . .
   }

   initialization code ( . . . ) {
      . . .
   }
}
```

Figure: Syntax of a monitor.

Usage II

- The monitor construct ensures that only one process at a time can be active within the monitor.

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- The monitor construct ensures that only one process at a time can be active within the monitor.
- Consequently, the programmer does not need to code this synchronization constraint explicitly (see Fig. 17).

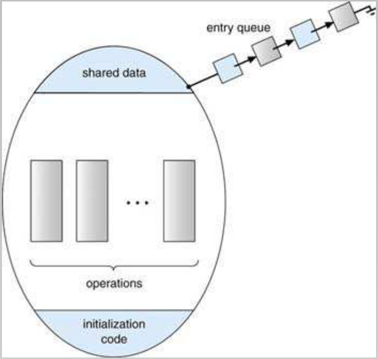

Figure: Schematic view of a monitor.