CSE 421/521 - Operating Systems
Fall 2011

Lecture - X
Process Synchronization & Deadlocks

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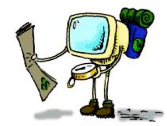
Roadmap

- Classic Problems of Synchronization
  - Readers and Writers Problem
  - Dining-Philosophers Problem
  - Sleeping Barber Problem
- Deadlocks



Readers-Writers Problem

- Multiple Readers and writers concurrently accessing the same database.
- Multiple Readers accessing at the same time --> OK
- When there is a Writer accessing, there should be no other processes accessing at the same time.

Readers-Writers Problem

- The structure of a writer process

```
do {
     wait (wrt) ;

        //    writing is performed

     signal (wrt) ;
} while (true)
```


Readers-Writers Problem (Cont.)

- The structure of a reader process

```
do {
     wait (mutex) ;
     readercount ++ ;
     if (readercount == 1)  wait (wrt) ;
     signal (mutex)

          // reading is performed

     wait (mutex) ;
     readercount  - - ;
     if readercount  == 0)  signal (wrt) ;
     signal (mutex) ;
} while (true)
```


Dining Philosophers Problem

- Five philosophers spend their time eating and thinking.
- They are sitting in front of a round table with spaghetti served.
- There are five plates at the table and five chopsticks set between the plates.
- Eating the spaghetti requires the use of two chopsticks which the philosophers pick up one at a time.
- Philosophers do not talk to each other.
- Semaphore chopstick [5] initialized to 1

Dining-Philosophers Problem (Cont.)

- The structure of Philosopher *i*:

```
Do {
     wait ( chopstick[i] );
     wait ( chopStick[ (i + 1) % 5] );

          //  eat

     signal ( chopstick[i] );
     signal (chopstick[ (i + 1) % 5] );

         //  think

} while (true) ;
```


To Prevent Deadlock

- Ensures mutual exclusion, but does not prevent deadlock
- Allow philosopher to pick up her chopsticks only if both chopsticks are available (i.e. in critical section)
- Use an asymmetric solution: an odd philosopher picks up first her left chopstick and then her right chopstick; and vice versa

Problems with Semaphores

- Wrong use of semaphore operations:
  - semaphores *A* and *B*, initialized to 1

P_0	P_1
wait (A);	*wait(B)*
wait (B);	*wait(A)*

    ➔ Deadlock

  - signal (mutex) …. wait (mutex)
    ➔ violation of mutual exclusion
  - wait (mutex) … wait (mutex)
    ➔ Deadlock
  - Omitting of wait (mutex) or signal (mutex) (or both)
    ➔ violation of mutual exclusion or deadlock

Semaphores

- inadequate in dealing with deadlocks
- do not protect the programmer from the easy mistakes of taking a semaphore that is already held by the same process, and forgetting to release a semaphore that has been taken
- mostly used in low level code, eg. operating systems
- the trend in programming language development, though, is towards more structured forms of synchronization, such as monitors

Monitors

- A high-level abstraction that provides a convenient and effective mechanism for process synchronization
- Only one process may be active within the monitor at a time

```
monitor monitor-name
{
   // shared variable declarations
   procedure P1 (…) { …. }
         …
   procedure Pn (…) {……}

    Initialization code ( ….) { … }
         …
   }
}
```

- A monitor procedure takes the lock before doing anything else, and holds it until it either finishes or waits for a condition

Monitor - Example

As a simple example, consider a monitor for performing transactions on a bank account.

```
monitor account {
    int balance := 0

  function withdraw(int amount) {
    if amount < 0 then error "Amount may not be negative"
    else if balance < amount then error "Insufficient funds"
    else balance := balance - amount
  }

  function deposit(int amount) {
    if amount < 0 then error "Amount may not be negative"
    else balance := balance + amount
  }
}
```

Condition Variables

- Provide additional synchronization mechanism
- condition x, y;

- Two operations on a condition variable:
  - x.wait () – a process invoking this operation is suspended
  - x.signal () – resumes one of processes (if any) that invoked x.wait ()

If no process suspended, x.signal() operation has no effect.

Solution to Dining Philosophers using Monitors

```
monitor DP
  {
   enum { THINKING; HUNGRY, EATING) state [5] ;
   condition self [5];       //to delay philosopher when he is
                                  hungry but unable to get chopsticks

initialization_code() {
          for (int i = 0; i < 5; i++)
                   state[i] = THINKING;
   }

void pickup (int i) {
          state[i] = HUNGRY;
          test(i);//only if both neighbors are not eating
          if (state[i] != EATING) self [i].wait;
   }
```


Solution to Dining Philosophers (cont)

```
   void test (int i) {
         if ((state[i] == HUNGRY) &&
            (state[(i + 1) % 5] != EATING) &&
            (state[(i + 4) % 5] != EATING) ) {
               state[i] = EATING ;
              self[i].signal () ;
          }
    }

void putdown (int i) {
         state[i] = THINKING;
              // test left and right neighbors
          test((i + 4) % 5);
          test((i + 1) % 5);
   }
}
```

- ➡ No two philosophers eat at the same time
- ➡ No deadlock
- ➡ But starvation can occur!

Sleeping Barber Problem

- Based upon a hypothetical barber shop with one barber, one barber chair, and a number of chairs for waiting customers
- When there are no customers, the barber sits in his chair and sleeps
- As soon as a customer arrives, he either awakens the barber or, if the barber is cutting someone else's hair, sits down in one of the vacant chairs
- If all of the chairs are occupied, the newly arrived customer simply leaves

Solution

- Use three semaphores: one for any waiting customers, one for the barber (to see if he is idle), and a mutex
- When a customer arrives, he attempts to acquire the mutex, and waits until he has succeeded.
- The customer then checks to see if there is an empty chair for him (either one in the waiting room or the barber chair), and if none of these are empty, leaves.
- Otherwise the customer takes a seat – thus reducing the number available (a critical section).
- The customer then signals the barber to awaken through his semaphore, and the mutex is released to allow other customers (or the barber) the ability to acquire it.
- If the barber is not free, the customer then waits. The barber sits in a perpetual waiting loop, being awakened by any waiting customers. Once he is awoken, he signals the waiting customers through their semaphore, allowing them to get their hair cut one at a time.

Implementation:

+ Semaphore Customers
+ Semaphore Barber
+ Semaphore accessSeats (mutex)
+ int NumberOfFreeSeats

The Barber(Thread):

```
while(true) //runs in an infinite loop
{
  Customers.wait() //tries to acquire a customer - if none is available he's going to
     sleep
  accessSeats.wait() //at this time he has been awaken -> want to modify the number
     of available seats
  NumberOfFreeSeats++ //one chair gets free
  Barber.signal() // the barber is ready to cut
  accessSeats.signal() //we don't need the lock on the chairs anymore //here the
     barber is cutting hair
}
```

The Customer(Thread):

```
while (notCut) //as long as the customer is not cut
{
 accessSeats.wait() //tries to get access to the chairs
 if (NumberOfFreeSeats>0) { //if there are any free seats
   NumberOfFreeSeats -- //sitting down on a chair
   Customers.signal() //notify the barber, who's waiting that there is
   a customer
   accessSeats.signal() // don't need to lock the chairs anymore
   Barber.wait() // now it's this customers turn, but wait if the barber
   is busy
   notCut = false
 } else // there are no free seats //tough luck
 accessSeats.signal() //but don't forget to release the lock on the
   seats }
```

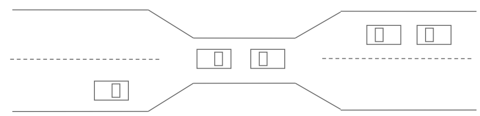

Deadlocks

The Deadlock Problem

- A set of blocked processes each holding a resource and waiting to acquire a resource held by another process in the set.
- Example
  - System has 2 disk drives.
  - P_1 and P_2 each hold one disk drive and each needs another one.
- Example
  - semaphores *A* and *B*, initialized to 1

P_0	P_1
wait (A);	*wait(B)*
wait (B);	*wait(A)*

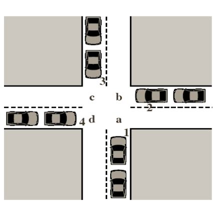
Bridge Crossing Example



- Traffic only in one direction.
- Each section of a bridge can be viewed as a resource.
- If a deadlock occurs, it can be resolved if one car backs up (preempt resources and rollback).
- Several cars may have to be backed up if a deadlock occurs.

Deadlock vs Starvation

- Deadlock - two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes



(a) Deadlock possible

- Starvation - indefinite blocking. A process may never be removed from the semaphore queue in which it is suspended.

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

1. **Mutual exclusion:** nonshared resources; only one process at a time can use a specific resource
2. **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
3. **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task

Deadlock Characterization (cont.)

Deadlock can arise if four conditions hold simultaneously.

4. Circular wait: there exists a set {P_0, P_1, …, P_0} of waiting processes such that P_0 is waiting for a resource that is held by P_1, P_1 is waiting for a resource that is held by P_2, …, P_{n-1} is waiting for a resource that is held by P_n, and P_n is waiting for a resource that is held by P_0.

Summary

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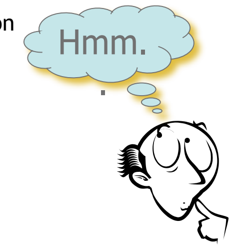

- Next Lecture: Deadlocks - II

Acknowledgements

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