CSC 4103 - Operating Systems
Spring 2008

LECTURE - IX

DEADLOCKS - I

Tevfik Koşar

Louisiana State University

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Roadmap

- Synchronization
  - Dining Philosophers Problem
  - Monitors
- Deadlocks
  - Deadlock Characterization
  - Resource Allocation Graphs

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 and channels

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!

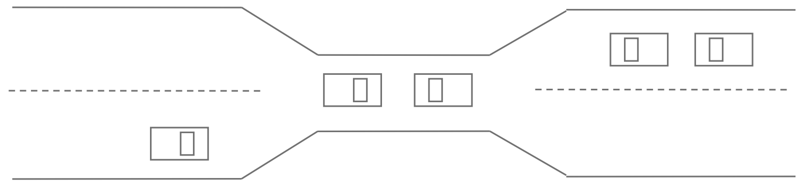
Deadlocks

The Deadlock Problem - *revisiting*

- 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.
- Starvation is possible.

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.)

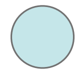
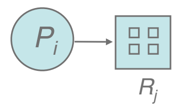
Deadlock can arise if four conditions hold simultaneously.

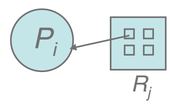
4. **Circular wait:** there exists a set $\{P_0, P_1, \ldots, P_0\}$ of waiting processes such that P_0 is waiting for a resource that is held by P_1, P_1 is waiting for a resource that is held by P_2, …, P_{n-1} is waiting for a resource that is held by P_n, and P_n is waiting for a resource that is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

Resource-Allocation Graph

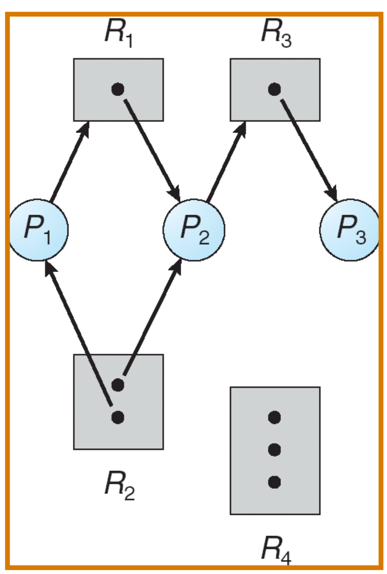
- Used to describe deadlocks
- Consists of a set of vertices *V* and a set of edges *E*.
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system.
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system.
- P requests R – directed edge $P_1 \rightarrow R_j$
- R is assigned to P – directed edge $R_j \rightarrow P_i$

Resource-Allocation Graph (Cont.)

- Process 
- Resource Type with 4 instances 
- P_i requests instance of R_j 

- P_i is holding an instance of R_j 

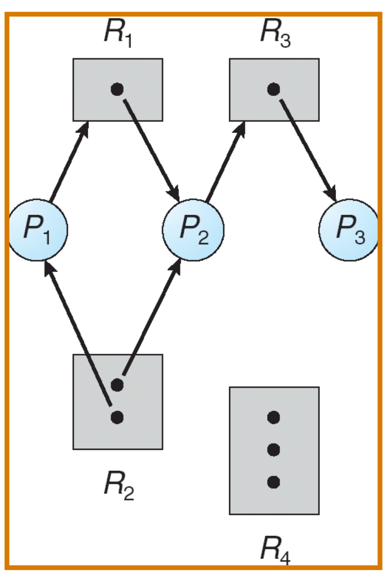
Example of a Resource Allocation Graph



Basic Facts

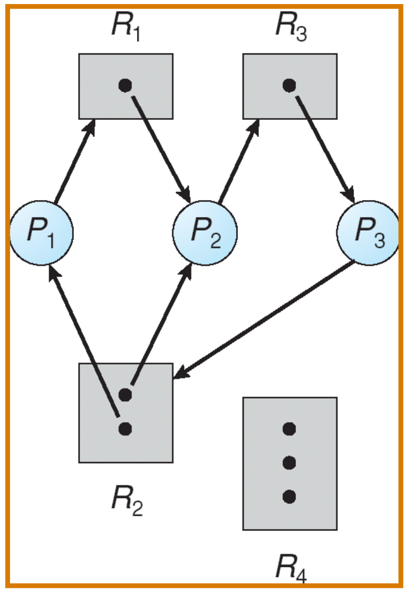
- If graph contains no cycles ⇒ no deadlock.
- If graph contains a cycle ⇒ there may be a deadlock
  - if only one instance per resource type, then deadlock.
  - if several instances per resource type, possibility of deadlock.

Resource Allocation Graph – Example 1



➔ No Cycle, no Deadlock

Resource Allocation Graph – example 2

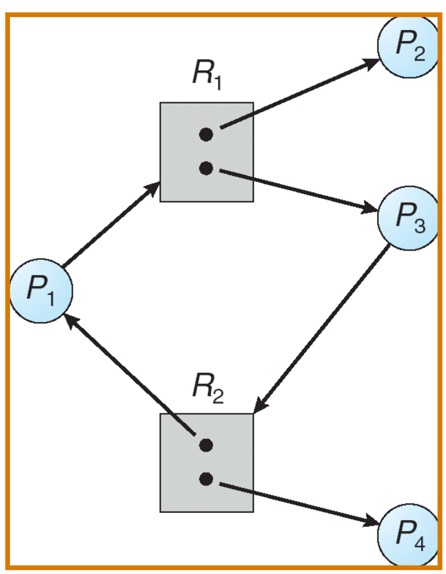


➔ Deadlock

Which Processes deadlocked?

➔ P1 & P2 & P3

Resource Allocation Graph – Example 3



➔ Cycle, but no Deadlock

Rule of Thumb

- A cycle in the resource allocation graph
  - Is a necessary condition for a deadlock
  - But not a sufficient condition

Summary

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  - Dining Philosophers Problem
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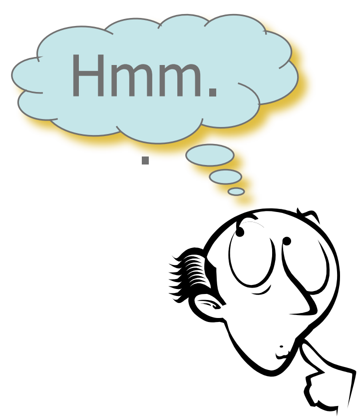
  - Resource Allocation Graphs



- Next Lecture: Deadlocks - II
- Reading Assignment: Chapter 7 from Silberschatz.

Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne

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