

CSE 421/521 - Operating Systems
Fall 2011

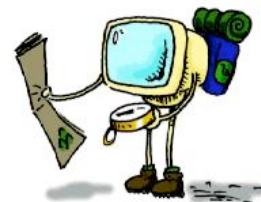
LECTURE - XI
DEADLOCKS - II

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Roadmap

- Deadlocks
 - Resource Allocation Graphs
 - Deadlock Prevention
 - Deadlock Detection



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

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Deadlock Characterization (cont.)

Deadlock can arise if four conditions hold simultaneously.

4. **Circular wait:** there exists a set $\{P_0, P_1, \dots, P_n\}$ 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 .

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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:
 - $P = \{P_1, P_2, \dots, P_n\}$, the set consisting of all the processes in the system.
 - $R = \{R_1, R_2, \dots, R_m\}$, the set consisting of all resource types in the system.
- **P requests R** - directed edge $P_i \rightarrow R_j$
- **R is assigned to P** - directed edge $R_j \rightarrow P_i$

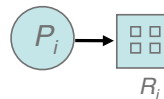
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Resource-Allocation Graph (Cont.)

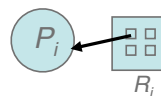
- Process
- Resource Type with 4 instances



- P_i requests instance of R_j

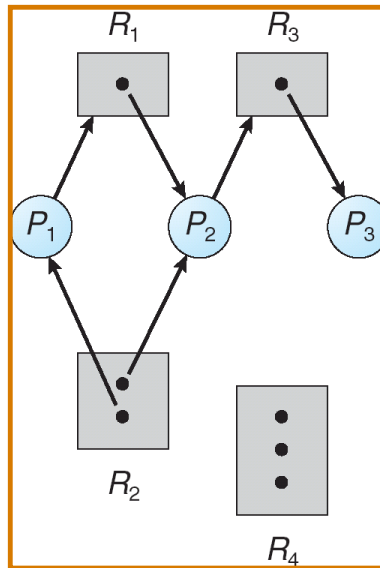


- P_i is holding an instance of R_j



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Example of a Resource Allocation Graph



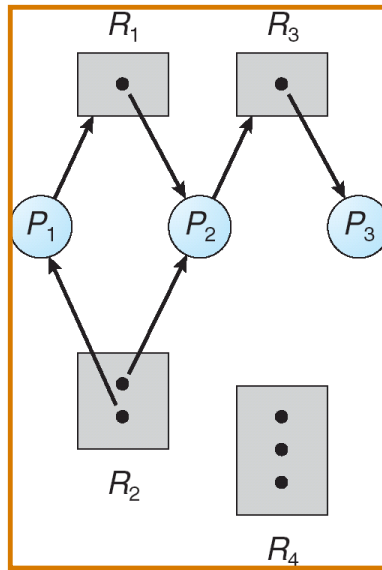
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Basic Facts

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

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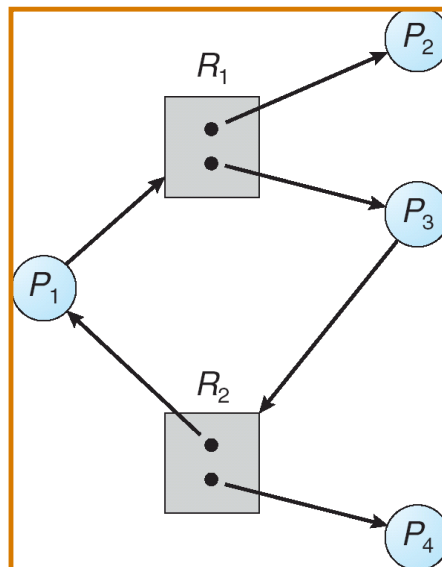
Resource Allocation Graph - Example 1



→ No Cycle, no Deadlock

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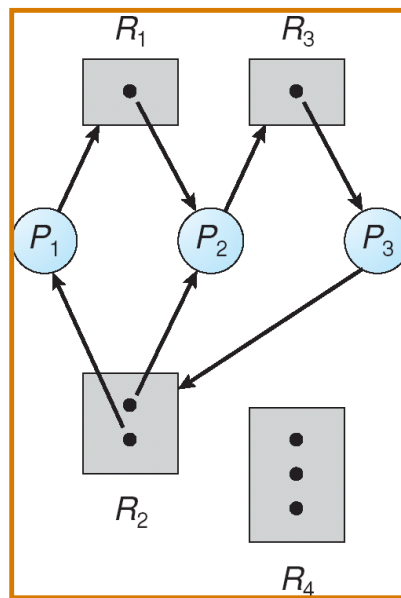
Resource Allocation Graph - Example 2



→ Cycle, but no Deadlock

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Resource Allocation Graph - example 3



→ **Deadlock**

Which Processes
deadlocked?

→ **P1 & P2 & P3**

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Exercise

In the code below, three processes are competing for six resources labeled A to F.

- a. Using a resource allocation graph (Silberschatz pp.249-251) show the possibility of a deadlock in this implementation.

```
void P0()
{
  while (true) {
    get(A);
    get(B);
    get(C);
    // critical region:
    // use A, B, C
    release(A);
    release(B);
    release(C);
  }
}
```

```
void P1()
{
  while (true) {
    get(D);
    get(E);
    get(B);
    // critical region:
    // use D, E, B
    release(D);
    release(E);
    release(B);
  }
}
```

```
void P2()
{
  while (true) {
    get(C);
    get(F);
    get(D);
    // critical region:
    // use C, F, D
    release(C);
    release(F);
    release(D);
  }
}
```

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```

void P0()
{
  while (true) {
    get(A);
    get(B);
    get(C);
    // critical region:
    // use A, B, C
    release(A);
    release(B);
    release(C);
  }
}

```

```

void P1()
{
  while (true) {
    get(D);
    get(E);
    get(B);
    // critical region:
    // use D, E, B
    release(D);
    release(E);
    release(B);
  }
}

```

```

void P2()
{
  while (true) {
    get(C);
    get(F);
    get(D);
    // critical region:
    // use C, F, D
    release(C);
    release(F);
    release(D);
  }
}

```

Rule of Thumb

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

Methods for Handling Deadlocks

- Ensure that the system will *never* enter a deadlock state.
 - deadlock prevention or avoidance
- Allow the system to enter a deadlock state and then recover.
 - deadlock detection
- Ignore the problem and pretend that deadlocks never occur in the system
 - Programmers should handle deadlocks (UNIX, Windows)

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Deadlock Prevention

→ Ensure one of the deadlock conditions cannot hold

→ Restrain the ways request can be made.

- **Mutual Exclusion** - not required for sharable resources; must hold for nonsharable resources.
 - Eg. read-only files
- **Hold and Wait** - must guarantee that whenever a process requests a resource, it does not hold any other resources.
 1. Require process to request and be allocated all its resources before it begins execution
 2. or allow process to request resources only when the process has none.

Example: Read from DVD to memory, then print.

 1. holds printer unnecessarily for the entire execution
 - Low resource utilization
 2. may never get the printer later
 - starvation possible

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Deadlock Prevention (Cont.)

- **No Preemption** -
 - If a process that is holding some resources requests another resource that cannot be immediately allocated to it, then all resources currently being held are released.
 - Preempted resources are added to the list of resources for which the process is waiting.
 - Process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting.
- **Circular Wait** - impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration.

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Exercise

In the code below, three processes are competing for six resources labeled A to F.

- Using a resource allocation graph (Silberschatz pp.249-251) show the possibility of a deadlock in this implementation.
- Modify the order of some of the `get` requests to prevent the possibility of any deadlock. You cannot move requests across procedures, only change the order inside each procedure. Use a resource allocation graph to justify your answer.

```
void P0()  
{  
  while (true) {  
    get(A);  
    get(B);  
    get(C);  
    // critical region:  
    // use A, B, C  
    release(A);  
    release(B);  
    release(C);  
  }  
}
```

```
void P1()  
{  
  while (true) {  
    get(D);  
    get(E);  
    get(B);  
    // critical region:  
    // use D, E, B  
    release(D);  
    release(E);  
    release(B);  
  }  
}
```

```
void P2()  
{  
  while (true) {  
    get(C);  
    get(F);  
    get(D);  
    // critical region:  
    // use C, F, D  
    release(C);  
    release(F);  
    release(D);  
  }  
}
```

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```

void P0()
{
  while (true) {
    get(A);
    get(B);
    get(C);
    // critical region:
    // use A, B, C
    release(A);
    release(B);
    release(C);
  }
}

```

```

void P1()
{
  while (true) {
    get(D);
    get(E);
    get(B);
    // critical region:
    // use D, E, B
    release(D);
    release(E);
    release(B);
  }
}

```

```

void P2()
{
  while (true) {
    get(C);
    get(F);
    get(D);
    // critical region:
    // use C, F, D
    release(C);
    release(F);
    release(D);
  }
}

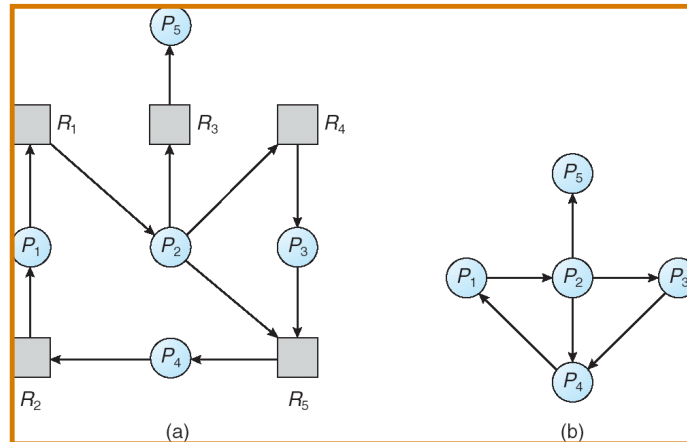
```

Deadlock Detection

- Allow system to enter deadlock state
- Detection algorithm
- Recovery scheme

Single Instance of Each Resource Type

- Maintain *wait-for* graph
 - Nodes are processes.
 - $P_i \rightarrow P_j$ if P_i is waiting for P_j .



Resource-Allocation Graph

Corresponding wait-for graph

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Single Instance of Each Resource Type

- Periodically invoke an algorithm that searches for a cycle in the graph.
- An algorithm to detect a cycle in a graph requires an order of n^2 operations, where n is the number of vertices in the graph.
- Only good for single-instance resource allocation systems.

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Several Instances of a Resource Type

- *Available*: A vector of length m indicates the number of available resources of each type.
- *Allocation*: An $n \times m$ matrix defines the number of resources of each type currently allocated to each process.
- *Request*: An $n \times m$ matrix indicates the current request of each process. If $Request [i,j] = k$, then process P_i is requesting k more instances of resource type R_j .

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Detection Algorithm

1. Let *Work* and *Finish* be vectors of length m and n , respectively Initialize:
 - (a) $Work = Available$
 - (b) For $i = 0, 2, \dots, n-1$, if $Allocation_i \neq 0$, then $Finish[i] = false$; otherwise, $Finish[i] = true$.
2. Find an index i such that both:
 - (a) $Finish[i] == false$
 - (b) $Request_i \leq Work$

If no such i exists, go to step 4.

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Detection Algorithm (Cont.)

3. $Work = Work + Allocation_i$
 $Finish[i] = true$
go to step 2.
4. If $Finish[i] == false$, for some i , $0 \leq i \leq n-1$, then the system is in deadlock state. Moreover, if $Finish[i] == false$, then P_i is deadlocked.

Algorithm requires an order of $O(m \times n^2)$ operations to detect whether the system is in deadlocked state.

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Example of Detection Algorithm

- Five processes P_0 through P_4 ; three resource types A (7 instances), B (2 instances), and C (6 instances).
- Snapshot at time T_0 :

	<u>Allocation</u>			<u>Request</u>			<u>Available</u>		
	A	B	C	A	B	C	A	B	C
P_0	0	1	0	0	0	0	0	0	0
P_1	2	0	0	2	0	2			
P_2	3	0	3	0	0	0			
P_3	2	1	1	1	0	0			
P_4	0	0	2	0	0	2			

- Sequence $\langle P_0, P_2, P_3, P_1, P_4 \rangle$ will result in $Finish[i] = true$ for all i .

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Example (Cont.)

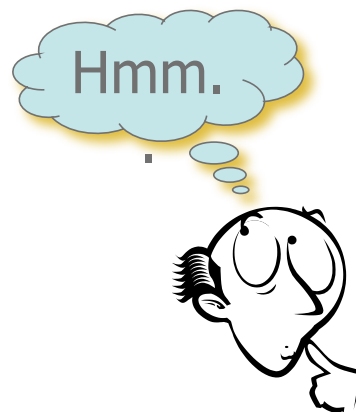
- P_2 requests an additional instance of type C.

	<u>Request</u>		
	A	B	C
P_0	0	0	0
P_1	2	0	1
P_2	0	0	1
P_3	1	0	0
P_4	0	0	2

- State of system?
 - Can reclaim resources held by process P_0 , but insufficient resources to fulfill other processes; requests.
 - Deadlock exists, consisting of processes P_1 , P_2 , P_3 , and P_4 .

Summary

- Deadlocks
 - Resource Allocation Graphs
 - Deadlock Prevention
 - Deadlock Detection



- Next Lecture: Deadlocks -III & Main Memory
- HW-2 due next Tuesday!

Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
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