Lecture 8: Deadlocks

Instructor: Mitch Neilsen

Office: N219D

Outline

- Reading:
  - Ch. 4 - Threads
  - Ch. 5 - CPU Scheduling
  - Ch. 6 - Synchronization
  - Ch. 7 - Deadlocks
- Project 1: Scheduling and Synchronization
  - Alarm Clock
  - Priority-based Scheduler
  - Synchronization and Priority Inheritance
  - [Extra Credit] MLFQ Scheduler

Quote of the Day

"Man's greatest asset is the unsettled mind. "

- Isaac Asimov

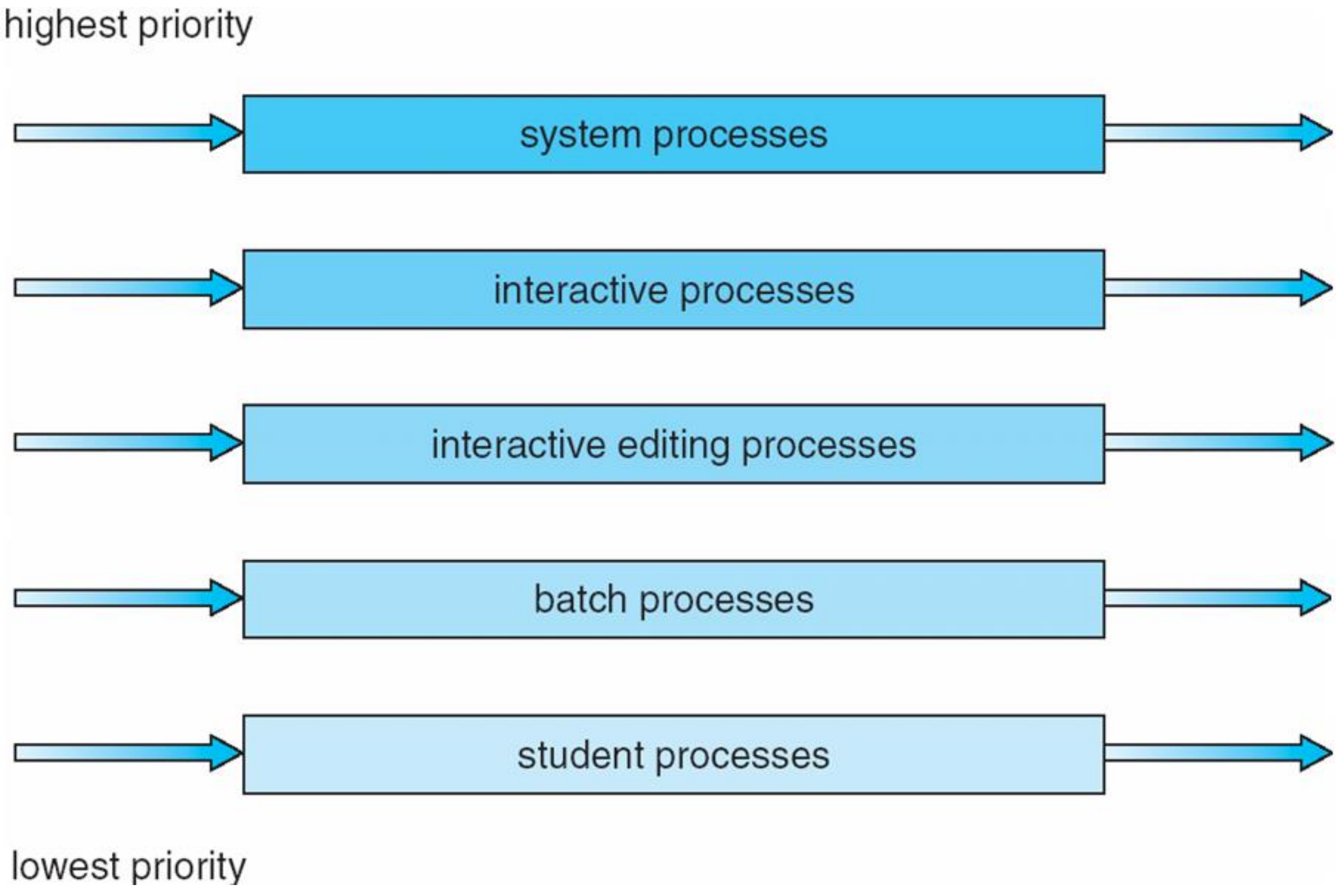
Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – # of processes that complete their execution per time unit
- **Turnaround time** – amount of time to execute a particular process
- **Waiting time** – amount of time a process has been waiting in the ready queue
- **Response time** – amount of time it takes from when a request was submitted until the first response is produced, not output (for time-sharing environment)

Multilevel Queue

- Ready queue is partitioned into separate queues:
  foreground (interactive)
  background (batch)
- Each queue has its own scheduling algorithm
  - foreground – RR
  - background – FCFS
- Scheduling must be done between the queues
  - Fixed priority scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., 80% to foreground in RR, and 20% to background in FCFS

Multilevel Queue Scheduling



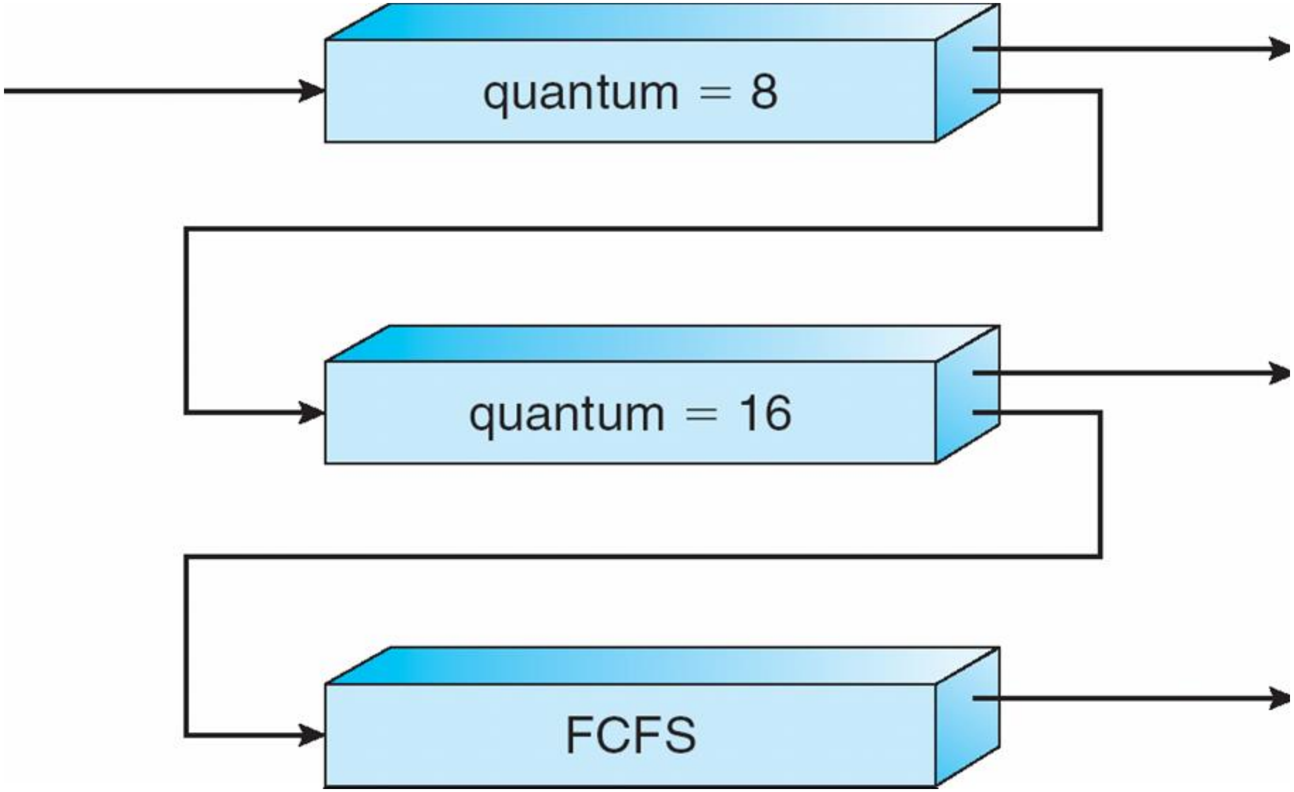
Multilevel Feedback Queue

- A process can move between the various queues; aging can be implemented this way
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when that process needs service

Example of Multilevel Feedback Queue

- Three queues:
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS
- Scheduling
  - A new job enters queue Q_0 which is served RR. When it gains CPU, job receives 8 milliseconds. If it does not finish in 8 milliseconds, job is moved to queue Q_1.
  - At Q_1 job is again served RR and receives 16 additional milliseconds. If it still does not complete, it is preempted and moved to queue Q_2.

Multilevel Feedback Queues

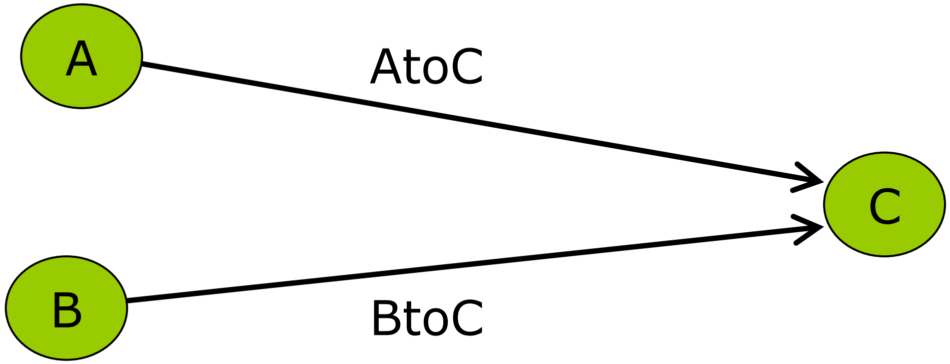


Synchronization

- Processes A and B complete before C?

```
semaphore AtoC = 0;
semaphore BtoC = 0;
```

Process A:	Process B:	Process C:
`- do work`	`- do work`	`sem_wait(AtoC);`
`sem_signal(AtoC);`	`sem_signal(BtoC);`	`sem_wait(BtoC);`
		`- do work`



Chapter 7: Deadlocks

- The Deadlock Problem
- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Recovery from Deadlock

The Deadlock Problem

- A set of blocked processes each holds a resource and waits to acquire a resource held by another process in the set.
- The following program can fail to make progress – how?

```
mutex_t m1, m2;

void p1 (void *ignored) {
  lock (m1);
  lock (m2);
  /* critical section */
  unlock (m2);
  unlock (m1);
}

void p2 (void *ignored) {
  lock (m2);
  lock (m1);
  /* critical section */
  unlock (m1);
  unlock (m2);
}
```

- Do all deadlocks involve semaphores?

More Deadlocks

- **Same problem with condition variables**

  - Suppose resource 1 managed by *c*1, resource 2 by *c*2

  - A has resource 1, waits on *c*2, B has resource 2, waits on *c*1

- **Or have combined mutex/condition variable deadlock:**

  - lock (a); lock (b); while (!ready) wait (b, c);

  unlock (b); unlock (a);

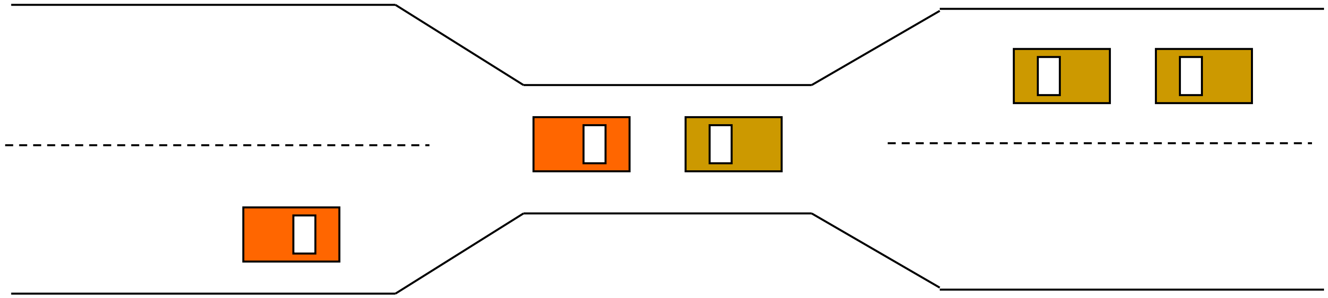
  - lock (a); lock (b); ready = true; signal (c);

  unlock (b); unlock (a);

- **One lesson: Dangerous to hold locks when crossing abstraction barriers!**

  - i.e., lock (a) then call function that uses condition variable

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
- Note – Most OSes do not prevent or deal with deadlocks

System Model

- Resource types R_1, R_2, . . ., R_m

  CPU cycles, memory space, I/O devices
- Each resource type R_i has W_i instances.
- Each process utilizes a resource as follows:
  - **request**
  - **use**
  - **release**

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

- **Mutual exclusion:** only one process at a time can use a resource
- **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task
- **Circular wait:** there exists a set $\{P_0, P_1, \ldots, P_n\}$ 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.

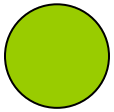
Resource-Allocation Graph

A set of vertices V and a set of edges E.

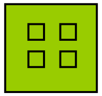
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system
- **request edge** – directed edge $P_i \rightarrow R_j$
- **assignment edge** – directed edge $R_j \rightarrow P_k$

Resource-Allocation Graph (Cont.)

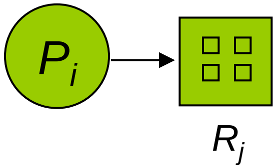
- Process



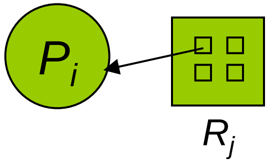
- Resource Type with 4 instances



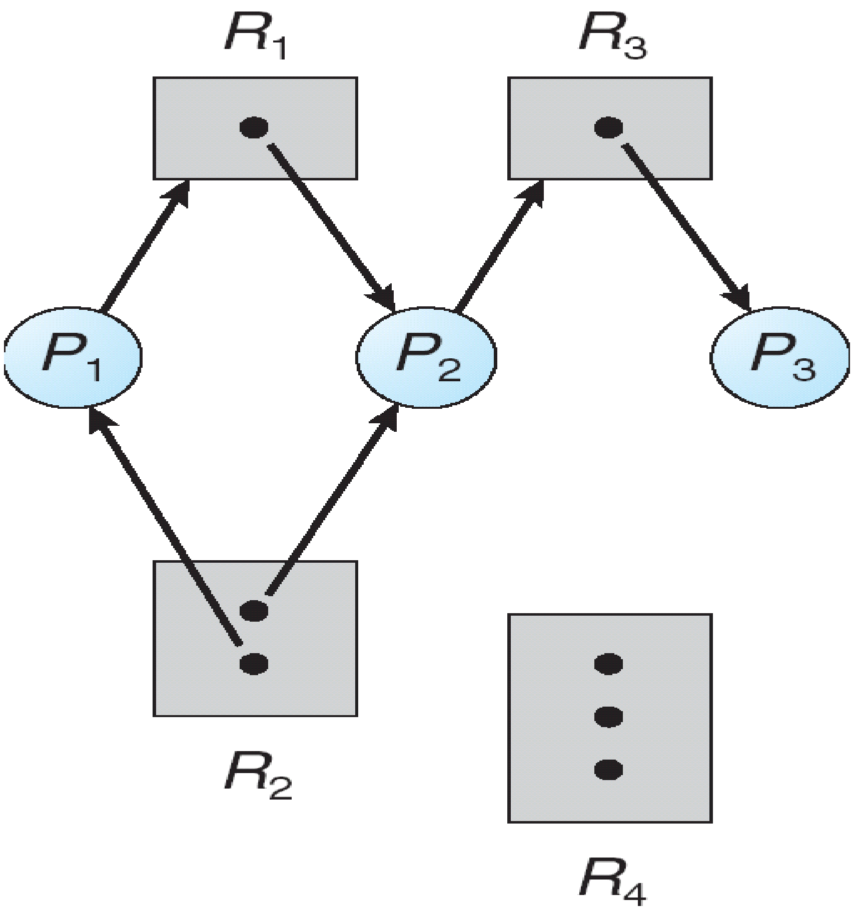
- P_i requests instance of R_j



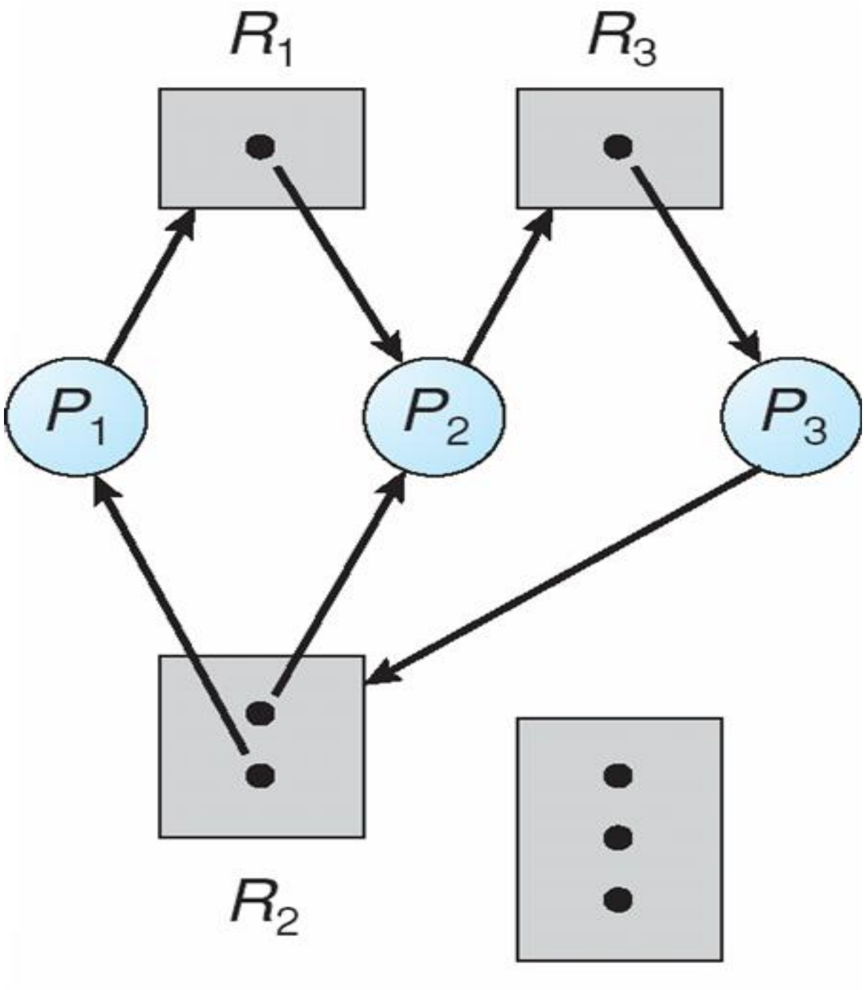
- P_i is holding an instance of R_j



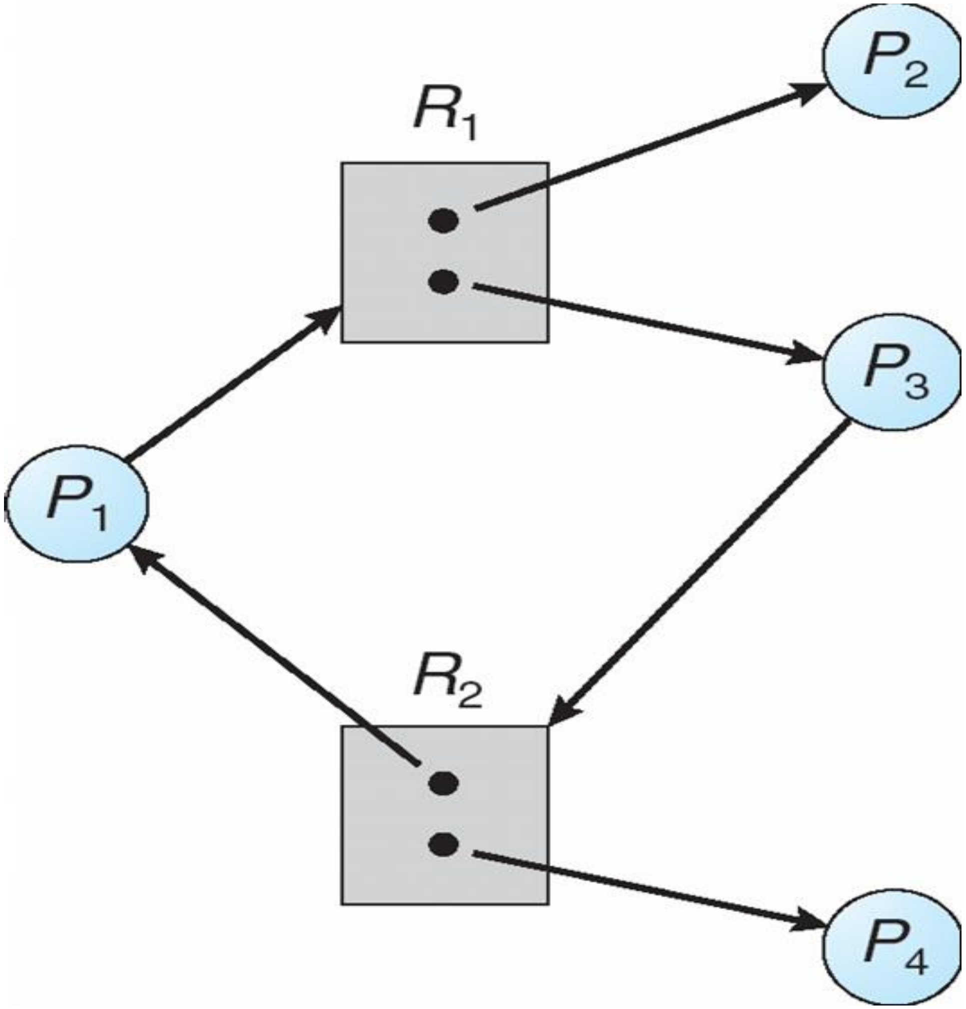
Example of a Resource Allocation Graph



Resource Allocation Graph With A Deadlock



Is This Deadlock?



Basic Facts

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

Methods for Handling Deadlocks

- Ensure that the system will ***never*** enter a deadlock state
- Allow the system to enter a deadlock state and then recover
- Ignore the problem and pretend that deadlocks never occur in the system; used by most operating systems, including UNIX

Deadlock Prevention

Restrain the ways request can be made

- **Mutual Exclusion** – not required for sharable resources; must hold for non-sharable resources
- **Hold and Wait** – must guarantee that whenever a process requests a resource, it does not hold any other resources
  - Require process to request and be allocated all its resources before it begins execution, or allow process to request resources only when the process has none
  - Low resource utilization; starvation possible

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

Deadlock Avoidance

Requires that the system has some additional ***a priori*** information available

- Simplest and most useful model requires that each process declare the ***maximum number*** of resources of each type that it may need

- The deadlock-avoidance algorithm dynamically examines the resource-allocation state to ensure that there can never be a circular-wait condition

- Resource-allocation ***state*** is defined by the number of available and allocated resources, and the maximum demands of the processes

Safe State

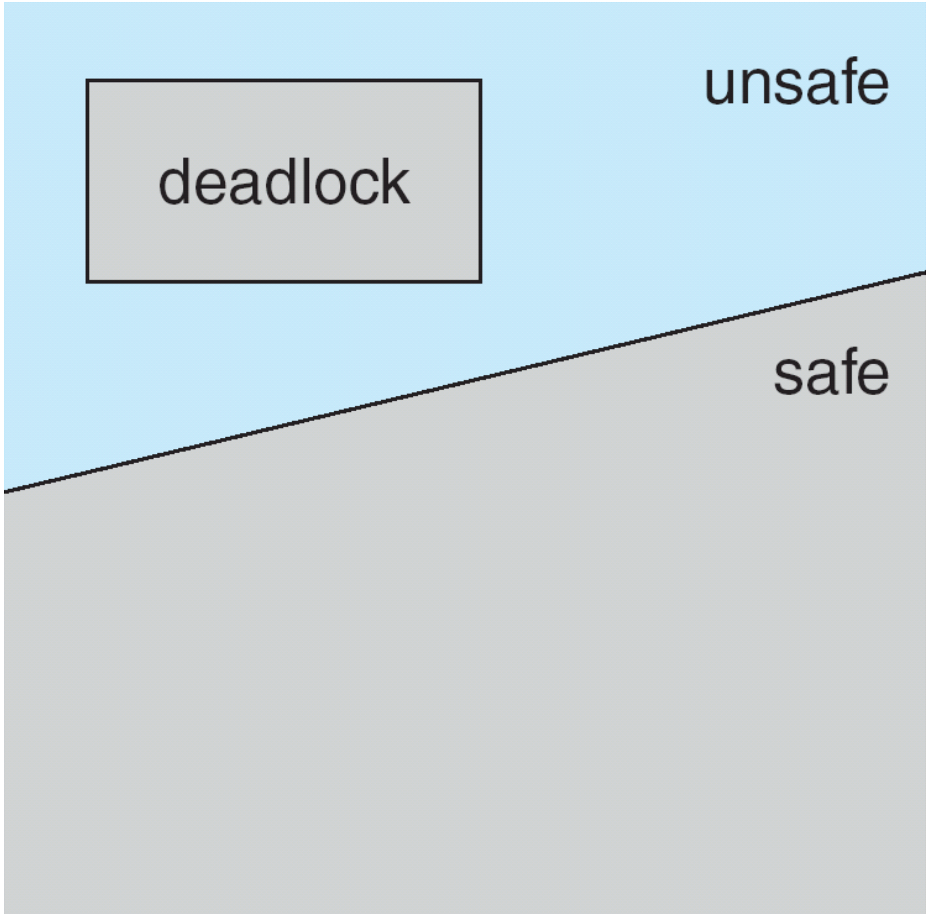
- When a process requests an available resource, system must decide if immediate allocation leaves the system in a safe state

- System is **in** **safe state** if there exists a sequence $<P_1, P_2, \ldots, P_n>$ of ALL the processes in the systems such that for each P_i, the resources that P_i can still request can be satisfied by currently available resources + resources held by all the P_j, with $j < i$
- That is:
  - If P_i resource needs are not immediately available, then P_i can wait until all P_j have finished
  - When P_j is finished, P_i can obtain needed resources, execute, return allocated resources, and terminate
  - When P_i terminates, P_{i+1} can obtain its needed resources, and so on

Basic Facts

- If a system is in safe state $\Rightarrow$ no deadlocks
- If a system is in unsafe state $\Rightarrow$ possibility of deadlock
- Deadlock Avoidance $\Rightarrow$ ensure that a system will never enter an unsafe state; i.e., conservatively prohibit system from entering a state that may lead to deadlock.

Safe, Unsafe , Deadlock State



Deadlock Avoidance Algorithms

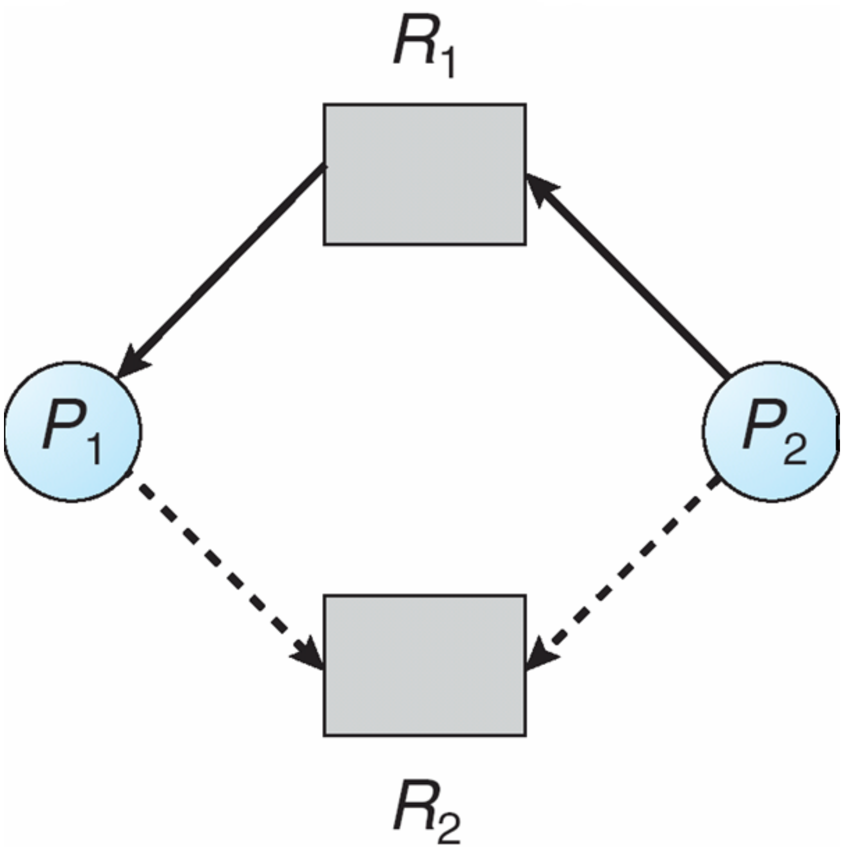
- Single instance of a resource type
  - Use a resource-allocation graph
  - Check for cycles

- Multiple instances of a resource type
  - Use the Banker’s Algorithm

Resource-Allocation Graph Scheme

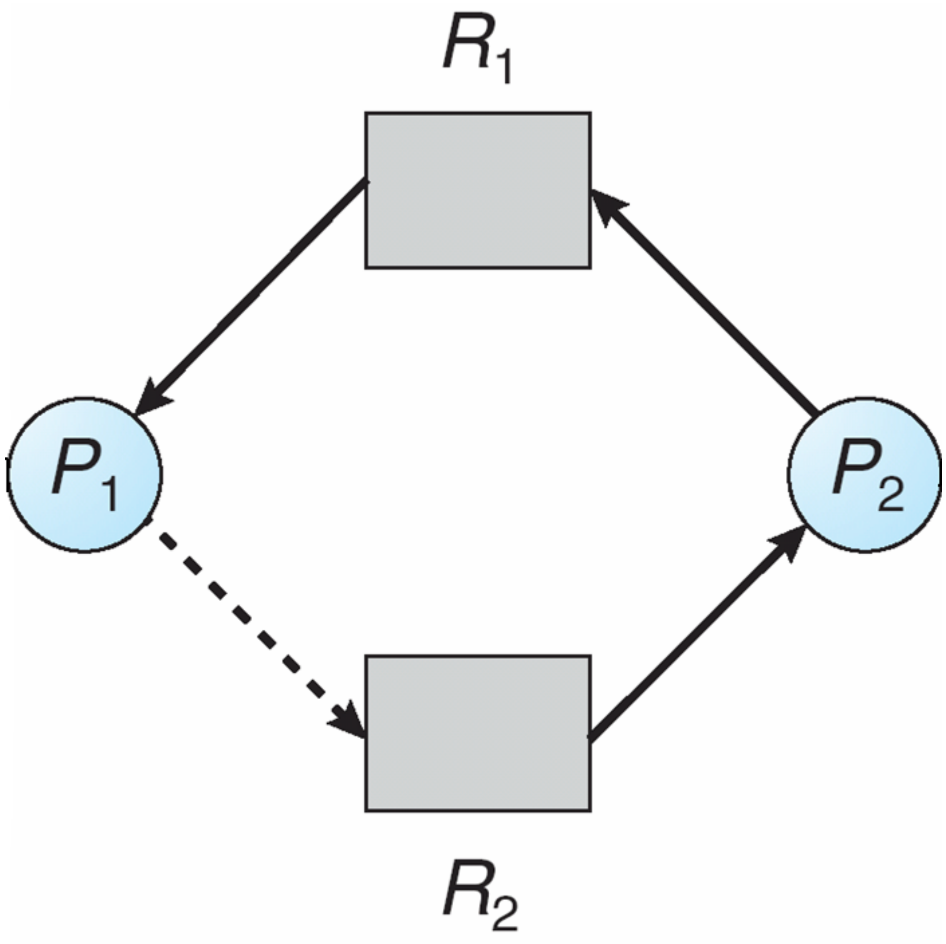
- **Claim edge** $P_i \dashrightarrow R_j$ indicates that process P_j may request resource R_j; represented by a dashed line
- Claim edge converts to request edge when a process requests a resource
- Request edge converted to an assignment edge when the resource is allocated to the process
- When a resource is released by a process, assignment edge reconverts to a claim edge
- Resources must be claimed *a priori* in the system

Resource-Allocation Graph



Dashed line is a *claim edge,* the processes may request R_2

Unsafe State In Resource-Allocation Graph



Note cycle in graph
- *P*1 might request *R*2 before relinquishing *R*1
- Would cause deadlock

Resource-Allocation Graph Algorithm

- Suppose that process P_i requests a resource R_j
- The request can be granted only if converting the request edge to an assignment edge does not result in the formation of a cycle in the resource allocation graph

Banker's Algorithm

- Multiple instances
- Each process must *a priori* report maximum possible resource use for each resource type
- When a process requests a resource it may have to wait even if the resource is available
- When a process gets all its resources it must return them in a finite amount of time

Data Structures for Banker's Algorithm

Let n = number of processes, and m = number of resources types.

- **Available**: Vector of length m. If available $[j] = k$, there are k instances of resource type R_j available
- **Max**: n x m matrix. If $Max\,[i,j] = k$, then process P_i may request at most k instances of resource type R_j
- **Allocation**: n x m matrix. If Allocation$[i,j] = k$ then P_i is currently allocated k instances of R_j
- **Need**: n x m matrix. If $Need[i,j] = k$, then P_i may need k more instances of R_j to complete its task

$$Need\,[i,j] = Max[i,j] - Allocation\,[i,j]$$

Safety Algorithm

1. Let *Work* and *Finish* be vectors of length m and n, respectively. Initialize:

   Work = *Available*

   Finish [*i*] = *false* for $i = 0, 1, \ldots, n- 1$

2. Find and *i* such that both:

   (a) *Finish* [*i*] = *false*

   (b) $Need_i \leq Work$

   If no such *i* exists, go to step 4

3. $Work = Work + Allocation_i$
   Finish[*i*] = *true*
   go to step 2

4. If *Finish* [*i*] == true for all *i*, then the system is in a safe state

Resource-Request Algorithm for Process P_i

Request = request vector for process P_i.

If $Request_i[j] = k$ then process P_i wants k instances of resource type R_j

1. If $Request_i \leq Need_i$ go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim
2. If $Request_i \leq Available$, go to step 3. Otherwise P_i must wait, since resources are not available
3. Pretend to allocate requested resources to P_i by modifying the state as follows:

$$Available = Available - Request_i;$$

$$Allocation_i = Allocation_i + Request_i;$$

$$Need_i = Need_i - Request_i;$$

- *If safe* $\Rightarrow$ *the resources are allocated to* P_i
- *If unsafe* $\Rightarrow$ P_i *must wait, and the old resource-allocation state is restored*

Example of Banker's Algorithm

- 5 processes P_0 through P_4; 3 resource types: *A, B,* and *C* *A* (10 instances), *B* (5 instances), and *C* (7 instances)

Snapshot at time T_0:

	Allocation	*Max*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 5 3	3 3 2
P_1	2 0 0	3 2 2	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

Example (Cont.)

- The content of the matrix *Need* is defined to be *Need = Max – Allocation*

	Need
	A B C
P_0	7 4 3
P_1	1 2 2
P_2	6 0 0
P_3	0 1 1
P_4	4 3 1

- The system is in a safe state since the sequence $< P_1, P_3, P_4, P_2, P_0>$ satisfies safety criteria

Example: P_1 Request (1,0,2)

- Check that Request $\leq$ Available (that is, $(1,0,2) \leq (3,3,2) \Rightarrow$ true, after the request remaining available is (2,3,0)

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	2 3 0
P_1	3 0 2	0 2 0	
P_2	3 0 1	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence $< P_1, P_3, P_4, P_0, P_2>$ satisfies safety requirement
- Can a request for (3,3,0) by P_4 be granted safely?
- Can a request for (0,2,0) by P_0 be granted safely?

Example: P_1 Request (1,0,2)

- Check that Request ≤ Available (that is, (1,0,2) ≤ (3,3,2) ⇒ true, after the request remaining available is (2,3,0)

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	**2 3 0**
$\boldsymbol{P_1}$	**3 0 2**	**0 2 0**	
P_2	3 0 1	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence < $\boldsymbol{P_1}$, P_3, P_4, P_0, P_2> satisfies safety requirement
- Can a request for (3,3,0) by P_4 be granted safely?
- Can a request for (0,2,0) by P_0 be granted safely?

Example: P_1 Request (1,0,2)

- Check that Request $\leq$ Available (that is, $(1,0,2) \leq (3,3,2) \Rightarrow$ true, after the request remaining available is (2,3,0)

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	**5 3 2**
$\boldsymbol{P_1}$	**0 0 0**	**3 2 2**	
P_2	3 0 1	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence < $\boldsymbol{P_1}$, P_3, P_4, P_0, P_2> satisfies safety requirement
- Can a request for (3,3,0) by P_4 be granted safely?
- Can a request for (0,2,0) by P_0 be granted safely?

Example: P_1 Request (1,0,2)

- Check that Request $\le$ Available (that is, $(1,0,2) \le (3,3,2) \Rightarrow$ true, after the request remaining available is (2,3,0)

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	**5 3 2**
$\boldsymbol{P_1}$	**0 0 0**	**3 2 2**	
P_2	3 0 1	6 0 0	
$\boldsymbol{P_3}$	**2 1 1**	**0 1 1**	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence < $\boldsymbol{P_1}$, $\boldsymbol{P_3}$, P_4, P_0, P_2> satisfies safety requirement
- Can a request for (3,3,0) by P_4 be granted safely?
- Can a request for (0,2,0) by P_0 be granted safely?

Example: P_1 Request (1,0,2)

- Check that Request ≤ Available (that is, (1,0,2) ≤ (3,3,2) ⇒ true, after the request remaining available is (2,3,0)

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	**7 4 3**
$\boldsymbol{P_1}$	**0 0 0**	**3 2 2**	
P_2	3 0 1	6 0 0	
$\boldsymbol{P_3}$	**0 0 0**	**2 2 2**	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence < $\boldsymbol{P_1}$, $\boldsymbol{P_3}$, P_4, P_0, P_2> satisfies safety requirement
- Can a request for (3,3,0) by P_4 be granted safely?
- Can a request for (0,2,0) by P_0 be granted safely?

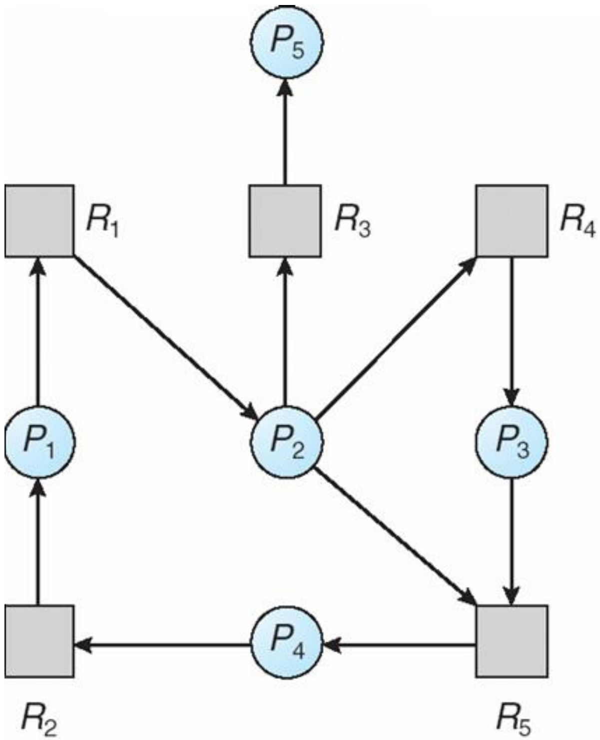
Deadlock Detection

- Allow system to enter a deadlock state
- Apply a Deadlock Detection Algorithm to find it
- Then, apply a Recovery Scheme to recover from it

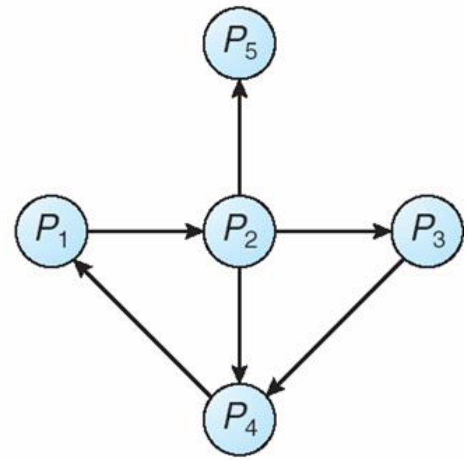
Single instance of each Resource Type

- Maintain *wait-for* graph
  - Nodes are processes
  - $P_i \rightarrow P_j$ if P_i is waiting for P_j
- Periodically invoke an algorithm that searches for a cycle in the graph. If there is a cycle, there exists a deadlock
- 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

Resource-Allocation Graph and Wait-for Graph



(a)



(b)

Resource-Allocation Graph   Corresponding Wait-for Graph

Several Instances of a Resource Type

- **Available***:* A vector of length *m* indicates the number of available resources of each type.

- **Allocation***:* An *n* x *m* matrix defines the number of resources of each type currently allocated to each process.

- **Request***:* An *n* x *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.

Detection Algorithm

1. Let *Work* and *Finish* be vectors of length *m* and *n*, respectively Initialize:

   (a) *Work* = *Available*

   (b) For i = 1,2, …, n, 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

Detection Algorithm (Cont.)

3. *Work* = *Work* + $Allocation_i$
   Finish[*i*] = *true*
   go to step 2

4. If *Finish*[*i*] == false, for some *i*, $1 \leq i \leq n$, then the system is in deadlock state. Moreover, if *Finish*[*i*] == *false*, then P_i is deadlocked

Algorithm requires on the order of O(m x n^2) operations to detect whether the system is in deadlocked state

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:

	Allocation	*Request*	*Available*
	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 <P_0, P_2, P_3, P_1, P_4> will result in *Finish*[*i*] = true for all *i*

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:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
$\boldsymbol{P_0}$	**0 0 0**	**0 0 0**	**0 1 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 <$\boldsymbol{P_0}$, P_2, P_3, P_1, P_4> will result in *Finish*[*i*] = true for all *i*

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:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 0 0	0 0 0	**3 1 3**
P_1	2 0 0	2 0 2	
$\boldsymbol{P_2}$	**0 0 0**	**0 0 0**	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

- Sequence <P_0, $\boldsymbol{P_2}$, P_3, P_1, P_4> will result in *Finish*[*i*] = true for all *i*

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:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 0 0	0 0 0	**5 2 4**
P_1	2 0 0	2 0 2	
P_2	0 0 0	0 0 0	
$\boldsymbol{P_3}$	**0 0 0**	**0 0 0**	
P_4	0 0 2	0 0 2	

- Sequence <P_0, P_2, $\boldsymbol{P_3}$, P_1, P_4> will result in *Finish*[*i*] = true for all *i*

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:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 0 0	0 0 0	**7 2 4**
$\boldsymbol{P_1}$	**0 0 0**	**0 0 0**	
P_2	0 0 0	0 0 0	
P_3	0 0 0	0 0 0	
P_4	0 0 2	0 0 2	

- Sequence <P_0, P_2, P_3, $\boldsymbol{P_1}$, P_4> will result in *Finish*[*i*] = true for all *i*

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:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 0 0	0 0 0	**7 2 6**
P_1	0 0 0	0 0 0	
P_2	0 0 0	0 0 0	
P_3	0 0 0	0 0 0	
$\boldsymbol{P_4}$	**0 0 0**	**0 0 0**	

- Sequence <P_0, P_2, P_3, P_1, $\boldsymbol{P_4}$> will result in *Finish*[*i*] = true for all *i*

Example (Cont.)

- P_2 requests an additional instance of type C

	Request		
	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

Example (cont.)

- 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:

	Allocation	*Request*	*Available*
	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 **1**	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

- Sequence <P_0> will result in *Finish*[*i*] = false for all *i=1,2,3,4*

Example (cont.)

- 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:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
$\boldsymbol{P_0}$	**0 0 0**	**0 0 0**	**0 1 0**
P_1	2 0 0	2 0 2	
P_2	3 0 3	0 0 **1**	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

- Sequence <P_0> will result in *Finish*[*i*] = false for all *i=1,2,3,4*

Detection-Algorithm Usage

- When, and how often, to invoke depends on:
  - How often a deadlock is likely to occur?
  - How many processes will need to be rolled back?
    - one for each disjoint cycle

- If detection algorithm is invoked arbitrarily, there may be many cycles in the resource graph and so we would not be able to tell which of the many deadlocked processes "caused" the deadlock

Recovery from Deadlock: Process Termination

- Abort all deadlocked processes
- Abort one process at a time until the deadlock cycle is eliminated
- In which order should we choose to abort?
  - Priority of the process
  - How long process has computed, and how much longer to completion
  - Resources the process has used
  - Resources process needs to complete
  - How many processes will need to be terminated
  - Is process interactive or batch?

Recovery from Deadlock: Resource Preemption

- Selecting a victim(s) – minimize cost
- Rollback – return to some safe state, restart process for that state
- Starvation – same process may always be picked as victim, include number of rollbacks in cost factor

Summary

- Read Ch. 1-6
- Processes and Threads (Ch. 4)
- Process Scheduling (Ch. 5)
- Synchronization (Ch. 6)
- Project 1 – Scheduling and Synchronization