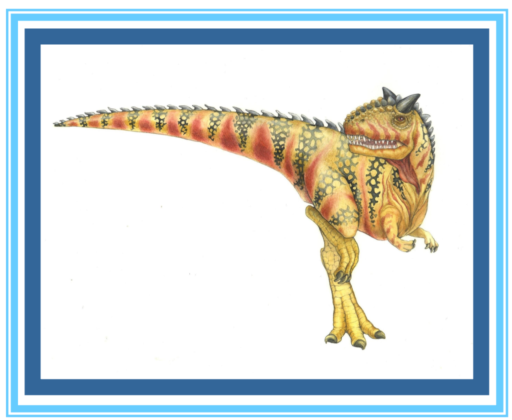
Chapter 7: Deadlocks



Chapter 7: Deadlocks

- a process may utilize a resource in only the following sequence:
- **Request:** The process requests the resource. If the request cannot be granted immediately (for example, if the resource is being used by another process), then the requesting process must wait until it can acquire the resource.
- **Use:** The process can operate on the resource (for example, if the resource is a printer, the process can print on the printer).
- **Release:** The process releases the resource.
- The resources are partitioned into several types, each consisting of some number of identical instances.
- Memory space, CPU cycles, files, and I/0 devices (such as printers and DVD drives) are examples of resource types. If a system has two CPUs, then the resource type *CPU* has two instances. Similarly, the resource type *printer* may have five instances.
- Ie,. Each resource type R_i has W_i instances.
- The resources may be either physical resources (for example, printers, tape drives, memory space, and CPU cycles) or logical resources (for example, semaphores, mutex locks, and files).

Chapter 7: Deadlocks

- Processes may compete for a finite number of resources.
- A process requests resources; if the resources are not available at that time, the process enters a waiting state.
- Sometimes, a waiting process is never again able to change state, because the resources it has requested are held by other waiting processes. This situation is called a deadlock.

- The request and release of resources are system calls.
- Examples are the request() and release() device, open() and close() file, and allocate() and free() memory system calls. Request and release of resources can be accomplished through the wait() and signal() operations on semaphores or through acquisition and release of a mutex lock.

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

- **Mutual exclusion:** At least one resource must be held in a nonsharable mode; that is, only one process at a time can use the resource. If another process requests that resource, the requesting process must be delayed until the resource has been released.(Only one process can use a resource at any given time [Non-sharable resources cause deadlock]); If resources were fully sharable (e.g., read-only files), then processes could use them simultaneously → no blocking → no deadlock.
- **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption:** Resources cannot be preempted; that is, 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.

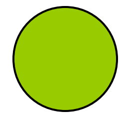
Resource-Allocation Graph

A set of vertices and a set of edges.

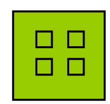
- vertices is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system
- **request edge** – directed edge $P_i \rightarrow R_j$
- **assignment edge**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

Resource-Allocation Graph (Cont.)

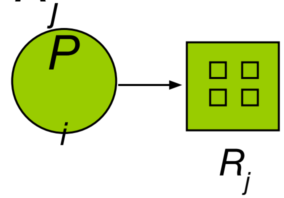
- Process



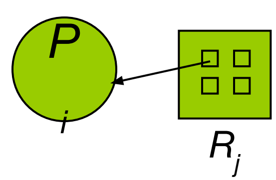
- Resource Type with 4 instances



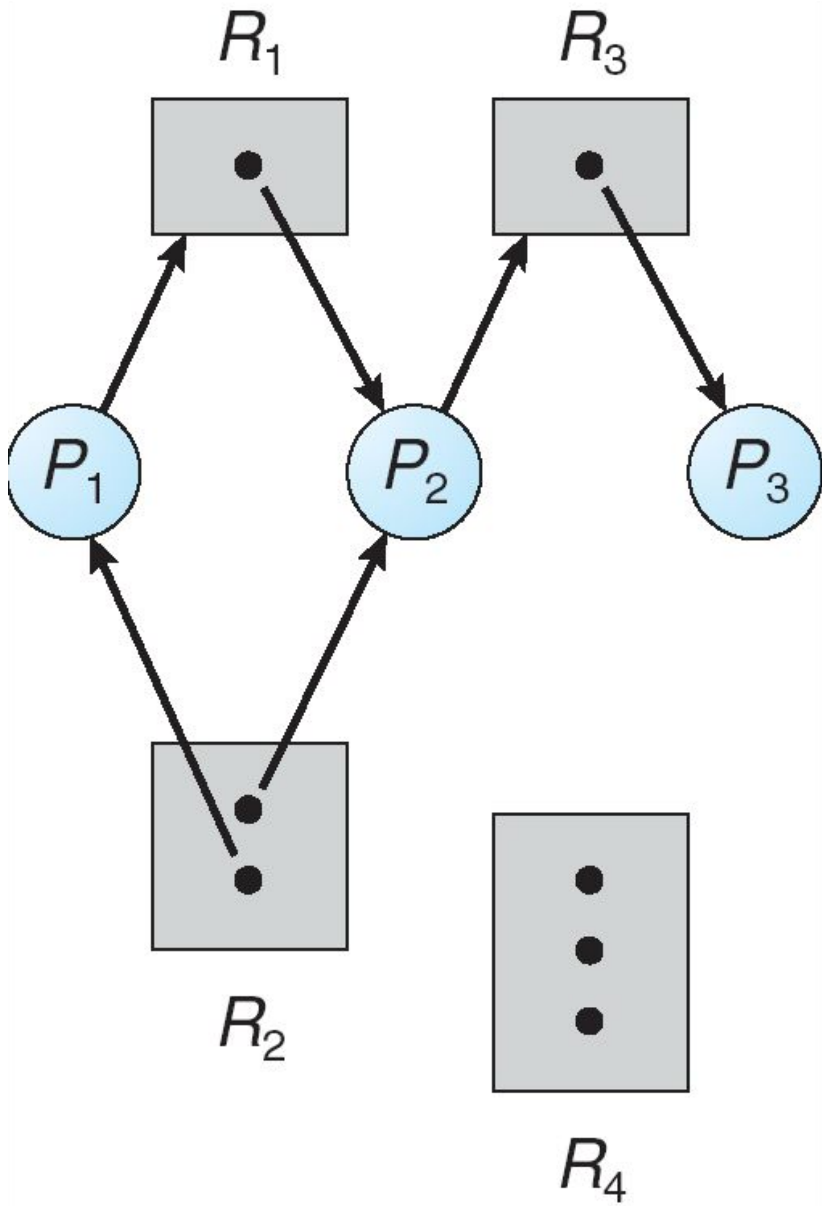
- P_i requests instance of R_j



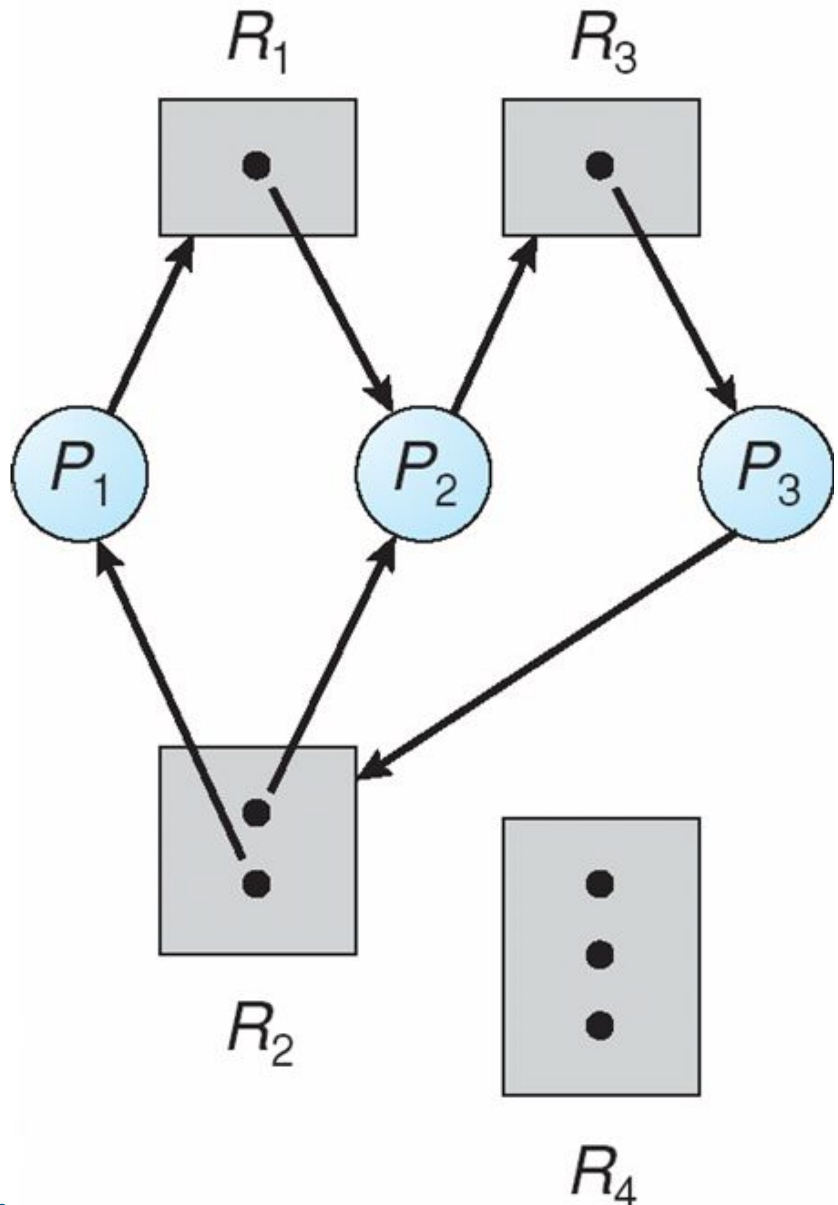
- P_i is holding an instance of R_j



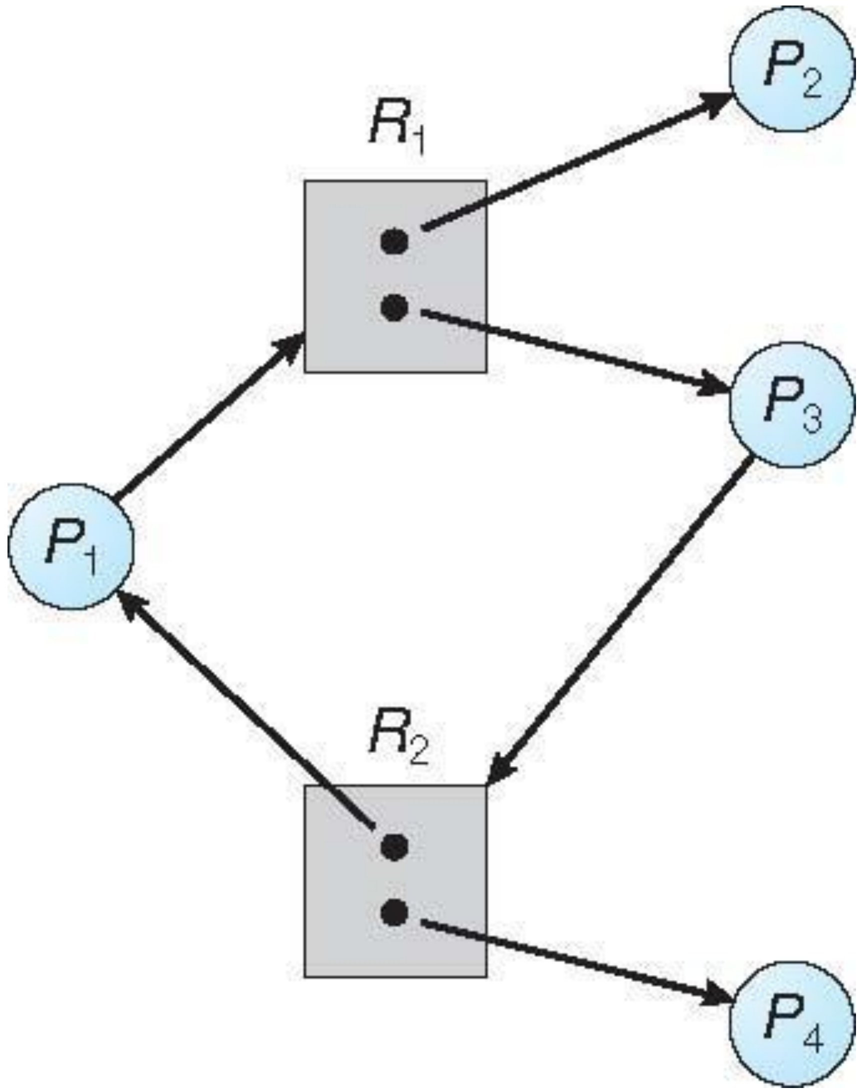
Example of a Resource Allocation Graph



Resource Allocation Graph With A Deadlock



Graph With A Cycle But No Deadlock



Basic Facts

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

- we can deal with the deadlock problem in one of three ways:
- We can use a protocol to prevent or avoid deadlocks, ensuring that the system will never enter a deadlocked state.
- We can allow the system to enter a deadlocked state, detect it, and recover.

- To ensure that deadlocks never occur, the prevention or a deadlock-avoidance scheme.
- Deadlock prevention provides a set of methods for ensuring that at least one of the necessary conditions cannot hold.

- Deadlock-avoidance requires that the operating system be given in advance additional information concerning which resources a process will request and use during its lifetime.(avoid the entry to an unsafe state)

Deadlock Prevention

Restrain the ways request can be made

- **Mutual Exclusion** –The mutual-exclusion condition must hold for nonsharable resources. we cannot prevent deadlocks by denying the mutual-exclusion condition, because some resources are intrinsically nonsharable.
- **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.
  - two main disadvantages:
    - Low resource utilization (A process may request printer + scanner + CPU at once, but may use CPU immediately while printer and scanner stay idle until later.)
    - starvation possible (Processes with **larger resource requests** may have to wait indefinitely until all required resources are simultaneously available.)

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
- Formally, we define a one-to-one F:R□ *N,* where *N* is the

set of natural numbers. For example, if the set of resource types *R* includes tape drives, disk drives, and printers, then the function *F* might be defined as follows:

- For example, suppose we have three resources A, B, and C, and a total ordering of resources such that A < B < C. If process P1 currently holds resource A and wants to acquire resource B, it must first release resource A before requesting resource B. Similarly, if process P2 currently holds resource B and wants to acquire resource C, it must first release resource B before requesting resource C. This ensures that no circular wait can occur.

- F (A:tape drive) = 1
- F (B:disk drive) = 5
- F (C:printer) = 12
- We can now consider the following protocol to prevent deadlocks: Each

process can request resources only in an increasing order of enumeration. That is, a process can initially request any number of instances of a resource type -say, Ri. After that, the process can request instances of resource type Rj if and only if F(Rj) > F(Ri).

F-function that assigns a unique integer value (a rank or ordering number)

This numbering enforces a **global ordering** of resources in the system.

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
- A sequence of processes <P1, P2, ... , Pn> is a safe sequence for the current allocation state if, for each Pi, the resource requests that Pi can still make can be satisfied by the currently available resources plus the resources held by all Pj,
- 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

Safe State

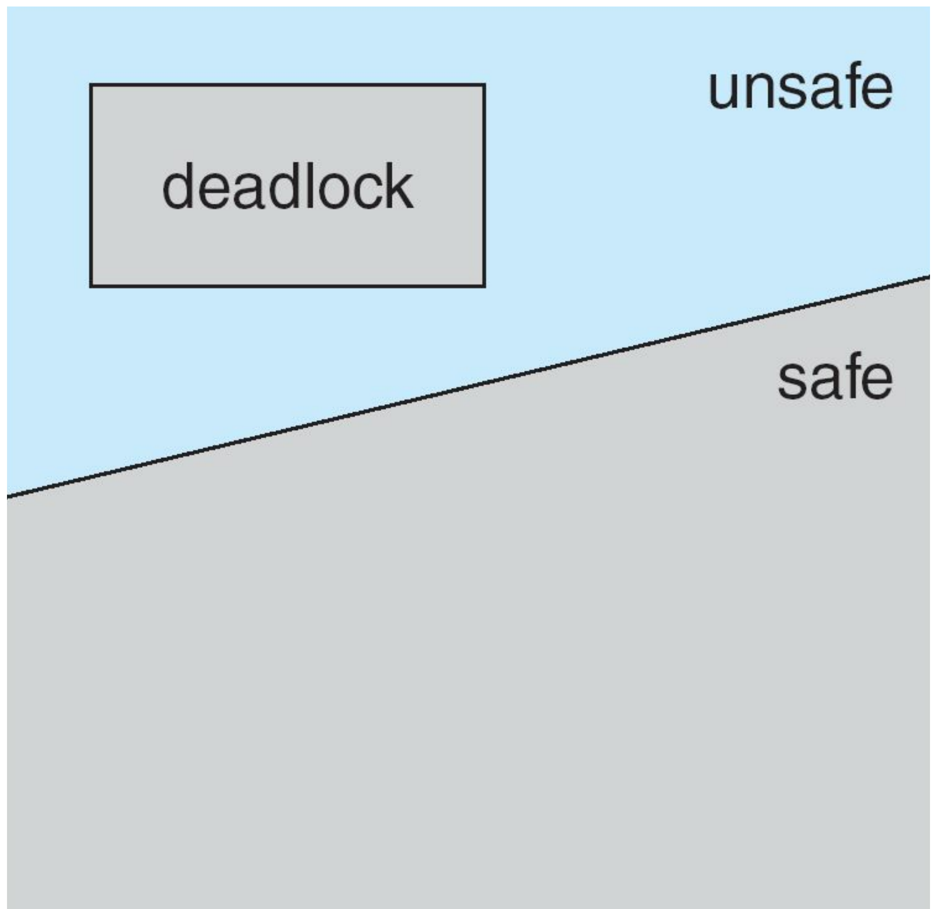
consider a system with **twelve** magnetic tape drives and three processes: P0, P1, and P2

	Maximum Needs	Current Needs
P_0	10	5
P_1	4	2
P_2	9	2

At time t0, the system is in a safe state. The sequence satisfies the safety condition.<P1,P0,P2>

A system can go from a safe state to an unsafe state. Suppose that, at time t1, process P2 requests and is allocated one more tape drive. The system is no longer in a safe state.

Safe, Unsafe, Deadlock State



Basic Facts

- If a system is in safe state ⇒ no deadlocks
- If a system is in unsafe state ⇒ possibility of deadlock

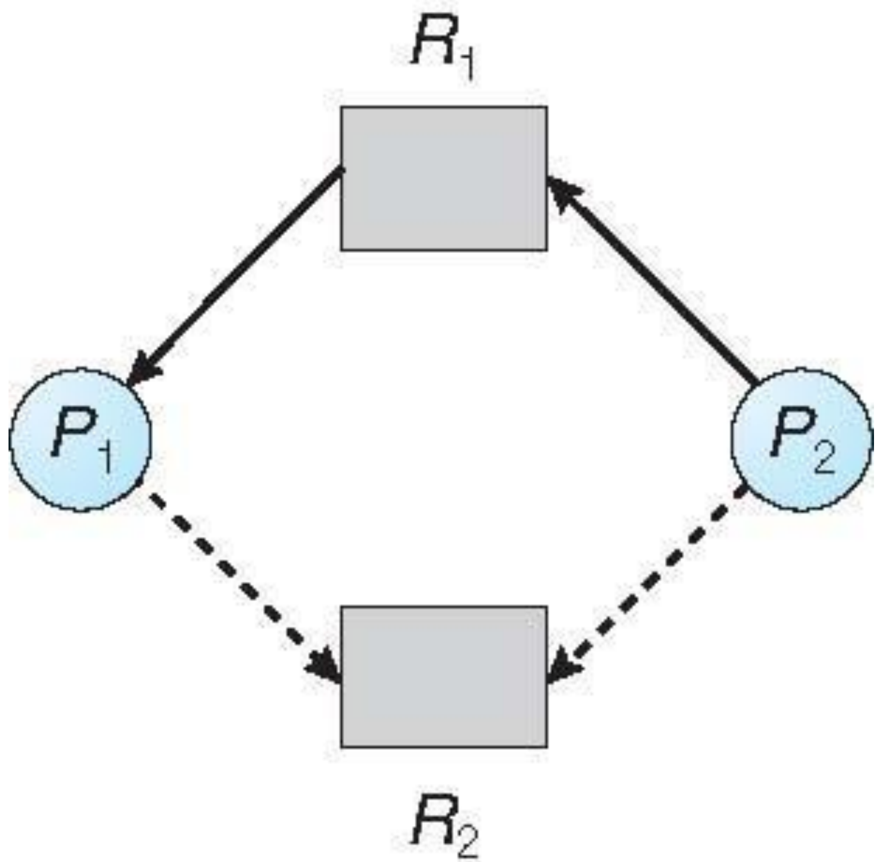
Avoidance algorithms

- Single instance of a resource type
  - Use a resource-allocation graph
- Multiple instances of a resource type
  - Use the banker's algorithm

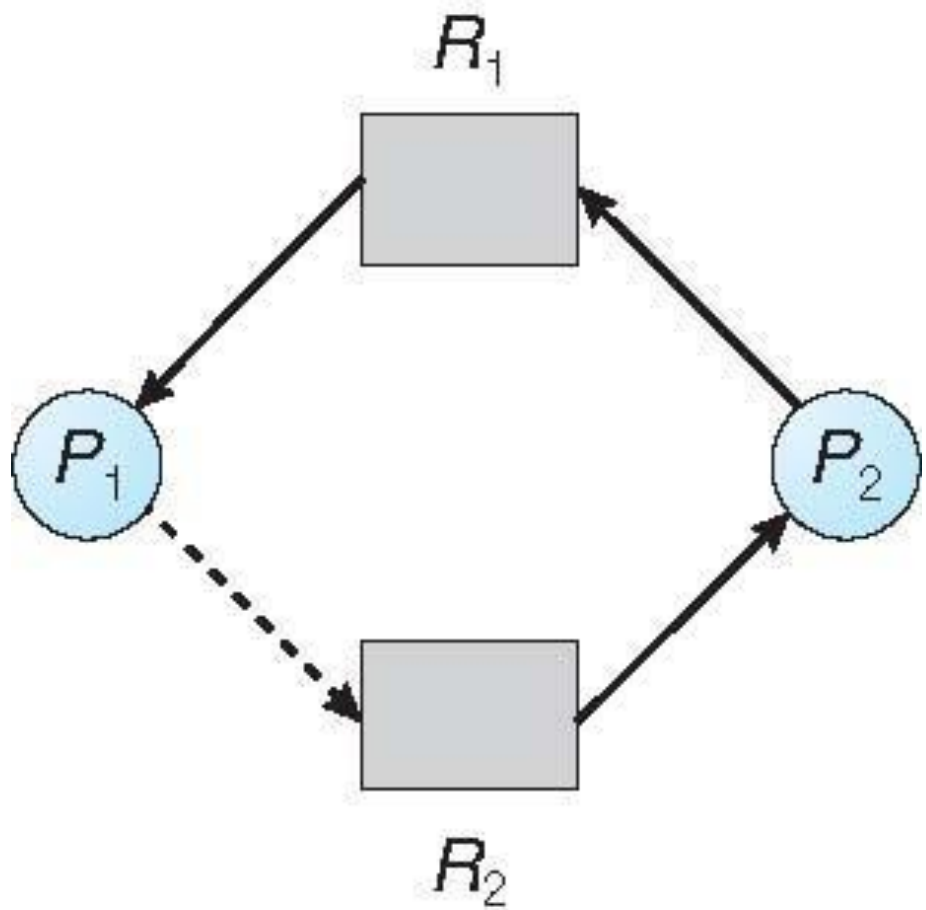
Resource-Allocation Graph Scheme

- **Claim edge** $P_i \rightarrow R_j$ indicated that process P_i 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



Unsafe State In Resource-Allocation Graph



Resource-Allocation Graph Algorithm

- Suppose 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 declare apriori claim maximum use
- When a process requests a resource it may have to wait
- When a process gets all its resources it must return them in a finite amount of time

Data Structures for the 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**: $n \times m$ matrix. If $Max[i,j] = k$, then process P_i may request at most k instances of resource type R_j
- **Allocation**: $n \times m$ matrix. If Allocation$[i,j] = k$ then P_i is currently allocated k instances of R_j
- **Need**: $n \times m$ matrix. If $Need[i,j] = k$, then P_i may need k more instances of R_j to complete its task

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

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:

$$Available = Available - Request;$$

$$Allocation_i = Allocation_i + Request_i;$$

$$Need_i = Need_i - Request_i;$$

- *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*

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 an 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

Example of Banker's Algorithm

- 5 processes P_0 through P_4;

  3 resource types:

  A (10 instances), *B* (5instances), 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 *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 ≤ Available (that is, (1,0,2) ≤ (3,3,2) ⇒ true

	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 2	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 request for (3,3,0) by P_4 be granted?
- Can request for (0,2,0) by P_0 be granted?

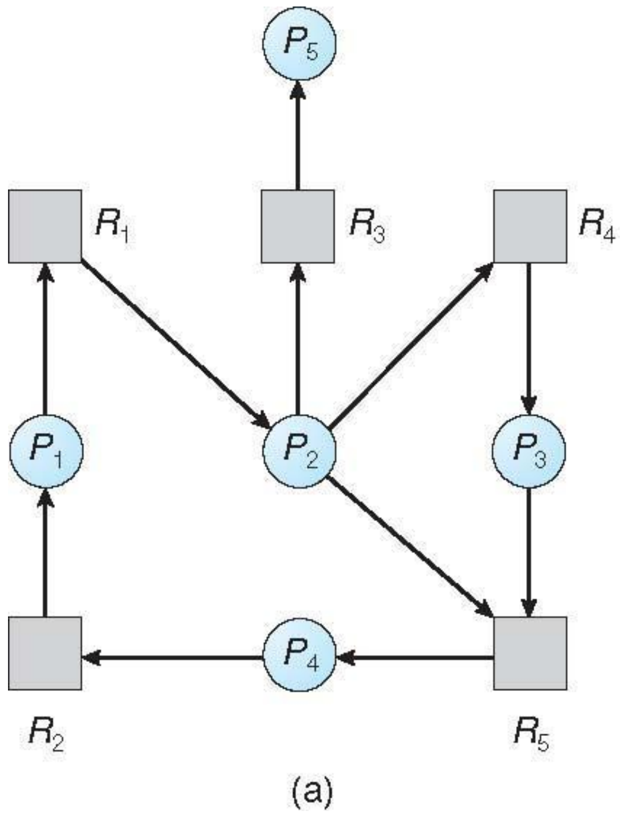
Deadlock Detection

- Detection algorithm
- Recovery scheme

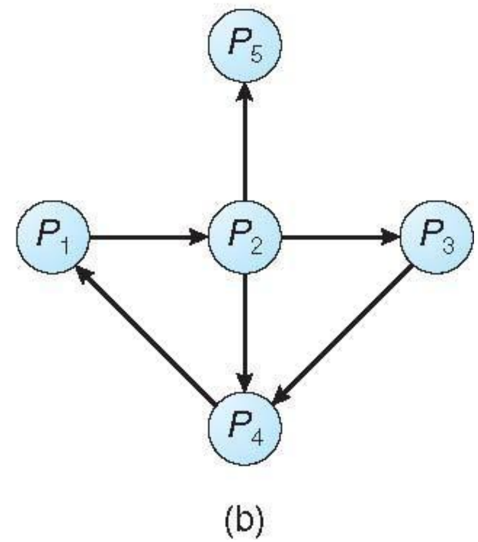
Single Instance of Each Resource Type

- Maintain *wait-for* graph(variant of resource allocation graph)
  - Nodes are processes(no resource node)
  - $P_i \rightarrow P_j$ 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

Resource-Allocation Graph and Wait-for Graph



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

Example of Detection Algorithm

- Five processes P_0 through P_4; three resource types A (7 instances), *B* (2 instances), and *C* (6 instances)
- 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 $\langle P_0, P_2, P_3, P_1, P_4\rangle$ or $\langle P_0, P_2, P_3, P_4, P_1\rangle$ 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 2
P_2	0 0 1
P_3	1 0 0
P_4	0 0 2

- State of system?
  - Deadlock exists, consisting of processes P_1, P_2, P_3, and P_4

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
  - How many resources the process has used?
  - How many more resources process needs to complete?
  - Is process interactive or batch?

Recovery from Deadlock: Resource Preemption

- Selecting a victim – minimize cost
- Rollback – return to some safe state, restart process for that state
- Problem: starvation – same process may always be picked as victim.

End of Chapter 7