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.
  - P1 and P2 each hold one disk drive and each needs another one.
- Example
  - semaphores A and B, initialized to 1

P0	P1
wait (A);	wait(B)
wait (B);	wait(A)

System Model

- Resource types $R_1, R_2, \ldots, R_m$.
  - 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.

Necessary Conditions for Deadlock

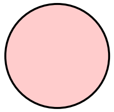
- **Mutual exclusion**: only one process at a time can use a resource.
- **Hold and wait**: a process holding at least one resource is waiting to acquire additional resources held by other processes.
- **No preemption**: a resource can be released only voluntarily by the process holding it.
- **Circular 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

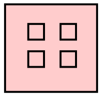
- A set of vertices V and a set of edges E.
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set of processes.
  - $R = \{R_1, R_2, \ldots, R_m\}$, a set consisting of all resource *types*.
- Request edge – directed edge $P_i \rightarrow R_j$.
- Assignment edge – directed edge $R_j \rightarrow P_i$.

Resource Allocation Graph

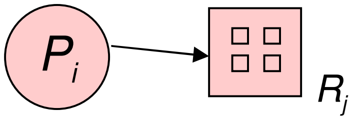
- Process.



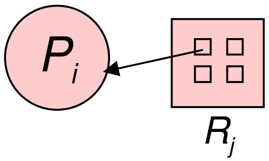
- Resource Type with 4 instances.



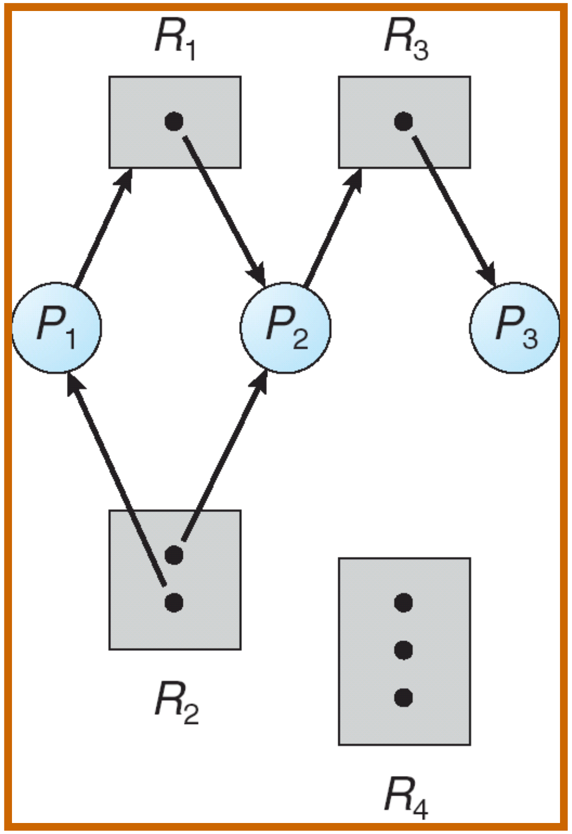
- P_i requests instance of R_j.



- P_i is holding an instance of R_j.



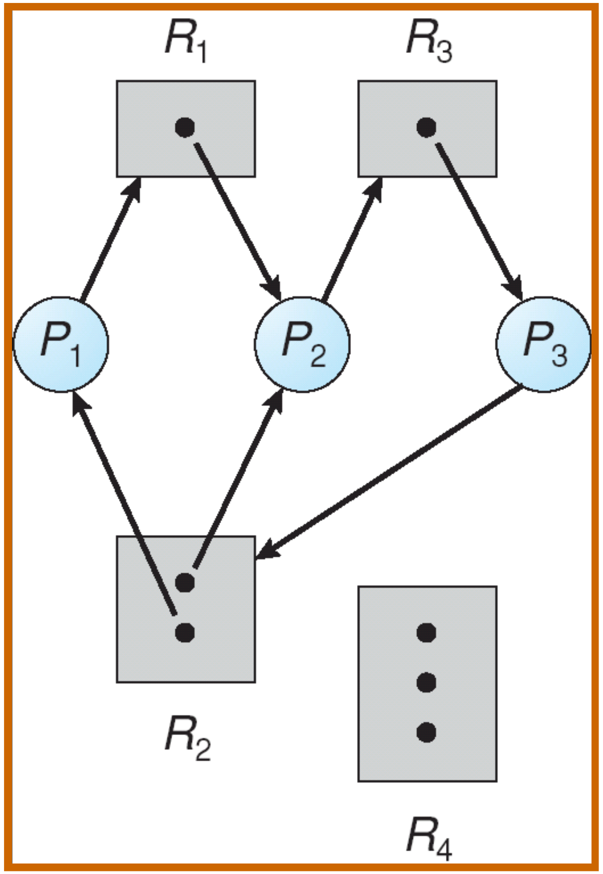
Example Graph



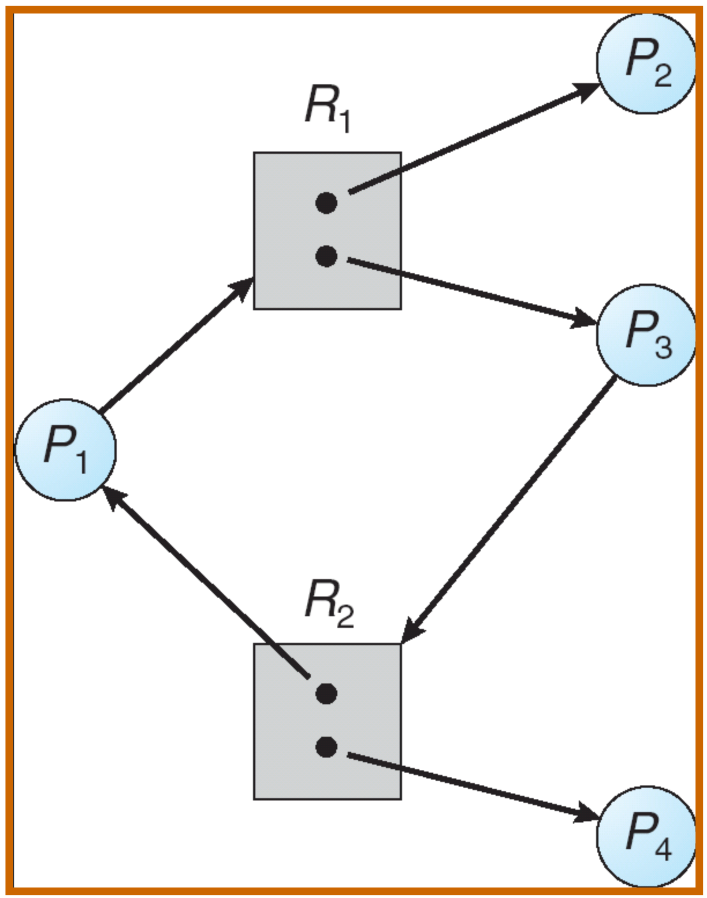
Deadlock Rules

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

Resource Allocation Graph (Deadlock?)



Graph With Cycle (Deadlock?)



Handling Deadlocks

- Ensure that the system will <u>never</u> enter a deadlock state.
  - Deadlock prevention.
- 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.
  - Used by most operating systems, including Linux.
  - “The Ostrich Algorithm”.
  - Why might this make sense?

Deadlock Prevention

- Recall our preconditions for deadlock:
  - Mutual exclusion.
  - Hold and wait.
  - No preemption.
  - Circular wait.
- If we can exclude any one, we can prevent deadlock.
- Mutual Exclusion?

Hold and Wait

- Require processes to request all resources at startup (atomically).
- Require processes to release all resources before requesting new ones.
- Drawbacks?

No Preemption 1

- If a process that is holding some resources requests another resource that cannot be allocated to it, then all resources 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.

No Preemption 2

- If a process requests resources that are held, check to see if the holding process is waiting.
- If it *is* waiting, preempt its resources.
- If resources are held by a non-waiting process, requesting process must wait.
- Any drawbacks to the two preemption schemes?

Circular Wait

- Impose a total ordering of all resource types, and require that each process requests resources in increasing order of enumeration.
- Why this works:
  - It is not possible to have a set of processes such that every process is waiting for a resource with a higher number than the number of a currently held resource.
- Any drawbacks to this algorithm?

Deadlock Avoidance

- Our deadlock prevention methods put restrictions on how processes could request resources.
- Deadlock avoidance mechanisms require the OS to keep track of requests and resources to make sure that no deadlock can occur.
- This will require the system to have some a-priori information about the requests that a process could make.

Deadlock Avoidance

- Each process declares the max number of resources of each type it may need.
- System examines the resource-allocation state to ensure that there can never be a circular-wait condition.
  - If a request could lead to a circular wait, the process must wait until the state changes.
- Resource-allocation state is defined by the number of available and allocated resources, and the maximum demands of the processes.

Safe States

- System is in safe state if there exists a sequence <P_1, P_2, ..., P_n> of ALL the processes is 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 $j < i$.

- I.e. There remains some way to grant everyone's maximum request.
- (Assumption is that all processes terminate eventually.)

Safe State Example

- Example from the book:
  - Assume that a system has 12 tape drives.
  - This is a safe state:

	MAX	ALLOC
P0	10	5
P1	4	2
P2	9	2

  - The sequence (P1, P0, P2) works.

	MAX	ALLOC
P0	10	5
P1	4	2
P2	9	2

Safe State Example

– This is *not* a safe state:

	MAX	ALLOC
P0	10	5
P1	4	2
P2	9	3

– P1 is the only process who's max request could still be granted.

– When it exits, only 4 free drives.

– If both P0 and P2 then request their max drives, deadlock occurs.

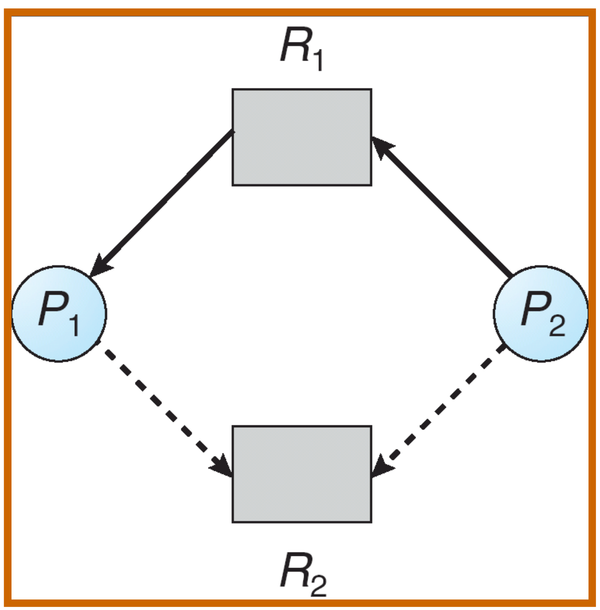
- An unsafe state does not guarantee deadlock.

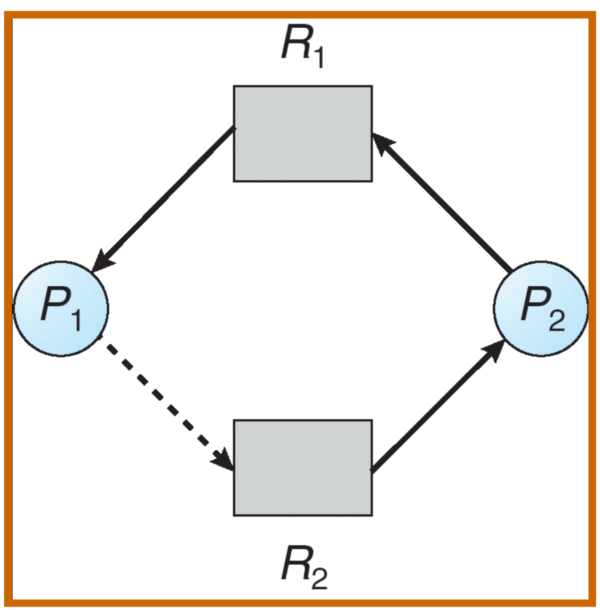
Resource Allocation Graph Algorithm

- Only works if there is at most one resource of each type.
- Claim edge P_i -> 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 Algorithm

- Suppose that process P_i requests a resource R_j.
- Grant request only if converting the request edge to an assignment edge does not result in the formation of a cycle.





Banker's Algorithm

- Multiple resource instances.
- Each process must declare maximum use.
- Any process that makes a request that would lead to an unsafe state must wait.
- When a process gets all its resources it must return them in a finite amount of time.

Banker's Algorithm Data Structures

- *n* processes, *m* resource types.
- ***Available***: Vector of length *m*. Available[*j*] = number of available resources of type R_j .
- ***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.

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

Banker's Algorithm: Checking For Safety

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

   Work = *Available*

   Finish [*i*] = *false* for *i* = 0, 1, …, *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.

Banker's Algorithm: Requesting Resources

$Request_i$ = request vector for process P_i.

1. If $Request_i \leq Need_i$ go to step 2. Otherwise, raise error condition.
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.*

Banker's Algorithm Analysis

- Thoughts on running time of safety check?
- An drawbacks to the bankers algorithm?

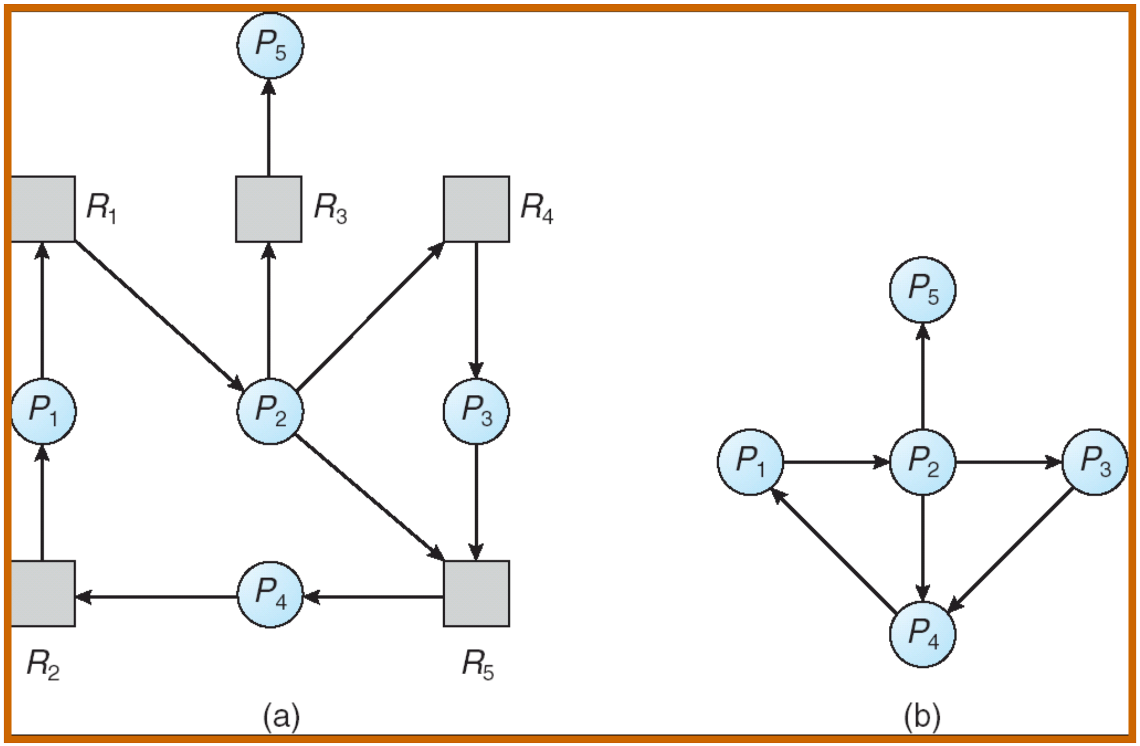
Deadlock Detection: Single Instance of Each Resource

- 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.

Wait-for Graph



- Why bother collapsing the graph?

Deadlock Detection With Multiple Resource Instances

- Big picture:
  - Periodically we check the system for deadlocks.
  - The deadlock check algorithm is very similar to the safety check algorithm we saw before.
  - Instead of looking for unsafe states, we look for deadlocked states.

Deadlock Detection Data Structures

- ***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.

Deadlock Detection Algorithm

1. Let *Work* and *Finish* be vectors of length m and n, respectively Initialize:
   (a) *Work* = *Available*
   (b) For $i = 1,2, \ldots, n$, 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.

Deadlock Detection Algorithm

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.

Deadlock Recovery: 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?

Deadlock Recovery: Resource Preemption

- Selecting a victim – minimize some cost measure.
- Rollback – return to some safe state, restart process for that state.
  - Can be tricky.
- Starvation – same process may always be picked as victim
  - Include number of rollbacks in cost factor.

Acknowledgments

- Portions of these slides are taken from Power Point presentations made available along with:
  - Silberschatz, Galvin, and Gagne. Operating System Concepts, Seventh Edition.
- Original versions of those presentations can be found at:
  - http://os-book.com/