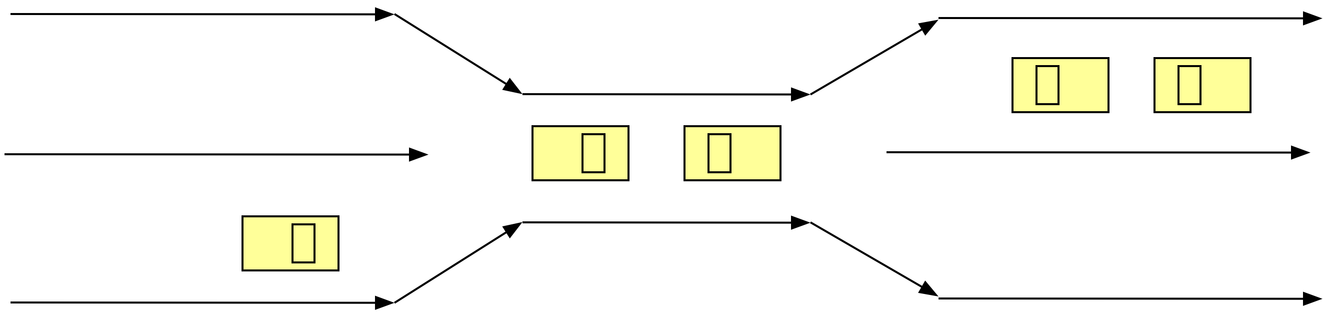
Deadlocks

The Deadlock Problem

- A deadlock consists of a set of blocked processes, each holding a resource and waiting to acquire a resource held by another process in the set
- Example #1
  - A system has 2 disk drives
  - P_1 and P_2 each hold one disk drive and each needs the other one
- Example #2
  - 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
- The resource is a one-lane bridge
- 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

System Model

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

  CPU cycles, memory space, I/O devices
- Each resource type R_i has *1 or more* instances
- Each process utilizes a resource as follows:
  - request
  - use
  - release

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

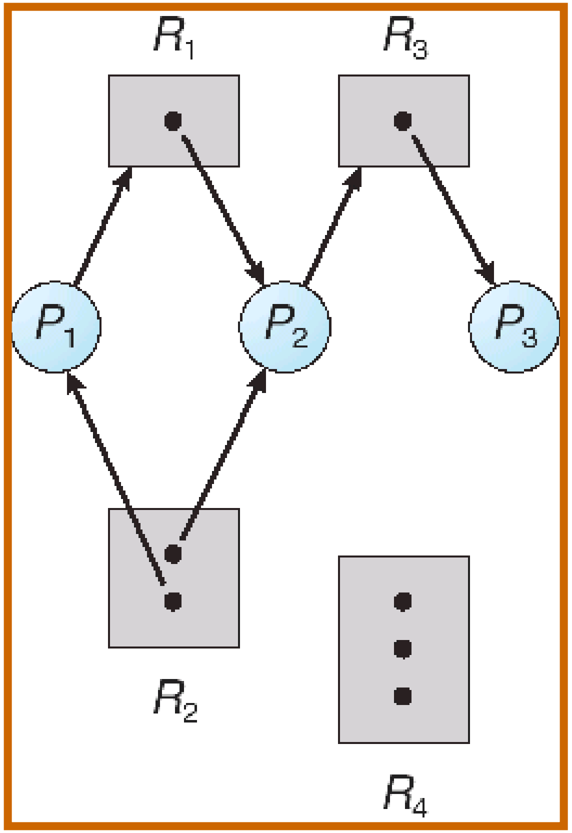
- **Mutual exclusion:** only one process at a time can use a resource
- **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption:** a resource can be released only voluntarily by the process holding it after that process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

  $P_2, \ldots, P_{n-1}$ 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

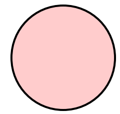
A set of vertices V and a set of edges E.

- 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 $P_1 \rightarrow R_j$
- assignment edge – directed edge $R_j \rightarrow P_i$

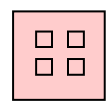


Resource-Allocation Graph (Cont.)

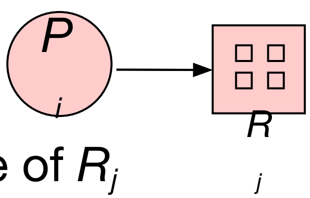
- Process



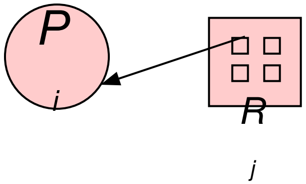
- Resource Type with 4 instances



- P_i requests instance of R_j

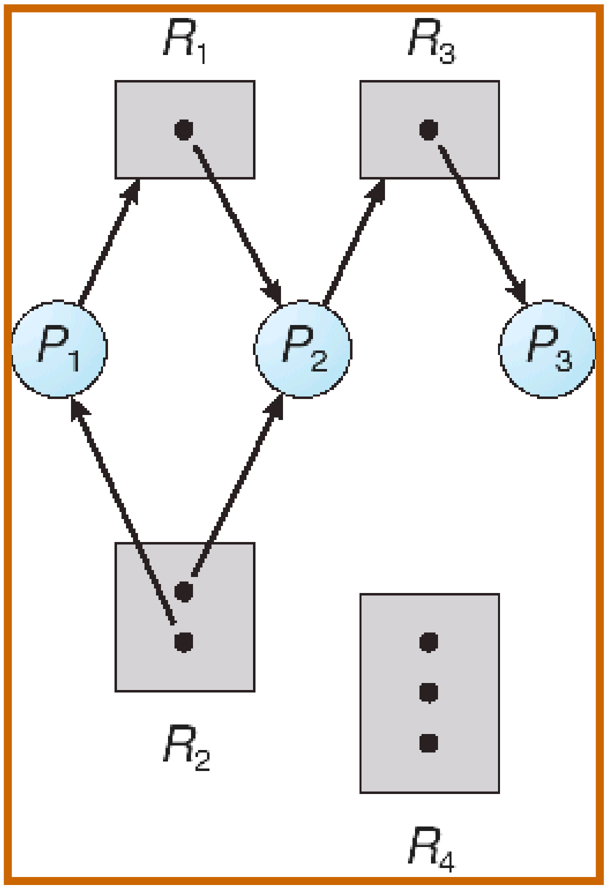


- P_i is holding an instance of R_j

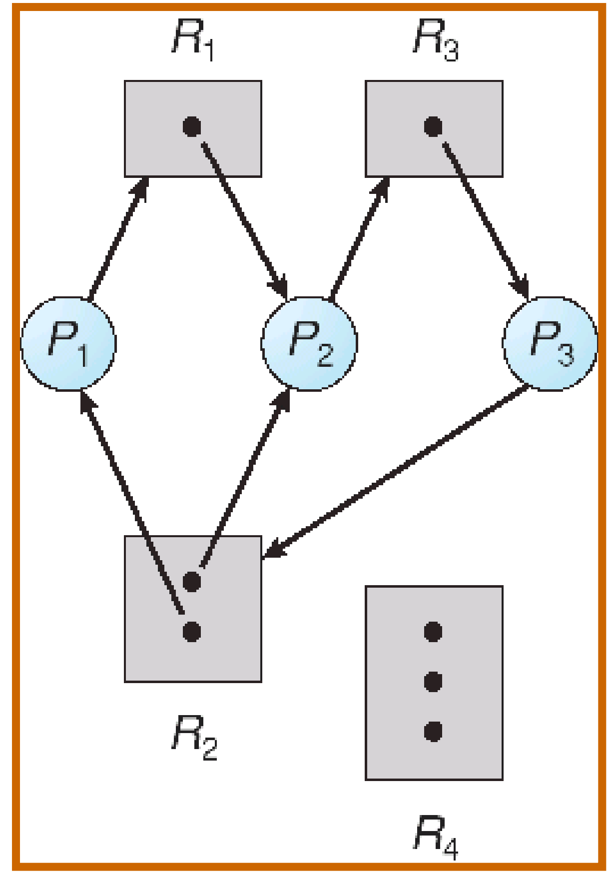


Resource Allocation Graph With A Deadlock

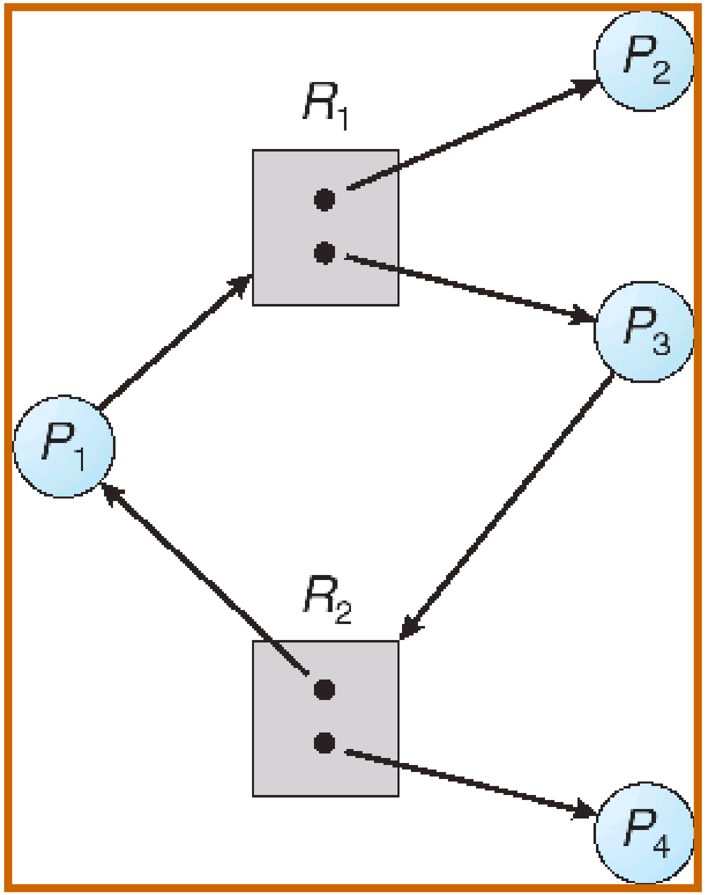
Before P_3 requested an instance of R_2



After P_3 requested an instance of R_2



Graph With A Cycle But No Deadlock



Process P_4 may release its instance of resource type R_2. That resource can then be allocated to P3, thereby breaking the cycle.

Relationship of cycles to deadlocks

- If a resource allocation graph contains <u>no</u> cycles ⇒ no deadlock
- If a resource allocation graph contains a cycle and if <u>only one</u> instance exists per resource type ⇒ deadlock
- If a resource allocation graph contains a cycle and and if <u>several</u> instances exists per resource type ⇒ possibility of deadlock

Methods for Handling Deadlocks

- **Prevention**
  - Ensure that the system will *never* enter a <u>deadlock</u> state

- **Avoidance**
  - Ensure that the system will *never* enter an <u>unsafe</u> state
- **Detection**
  - Allow the system to enter a deadlock state and then recover

- **Do Nothing**
  - Ignore the problem and let the user or system administrator respond to the problem; used by most operating systems, including Windows and UNIX

Deadlock Prevention

To prevent deadlock, we can restrain the ways that a request can be made

- **Mutual Exclusion** – The mutual-exclusion condition must hold for non-sharable resources

- **Hold and Wait** – we must guarantee that whenever a process requests a resource, it <u>does not</u> hold any other resources
  - Require a process to request and be allocated all its resources <u>before</u> it begins execution, or allow a process to request resources <u>only</u> when the process has none
  - Result: 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
  - A 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 <u>total ordering</u> of all resource types, and require that each process requests resources in an increasing order of enumeration. For example:

  F(tape drive) = 1
  F(disk drive) = 5
  F(printer) = 12

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

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

a priori: formed or conceived beforehand

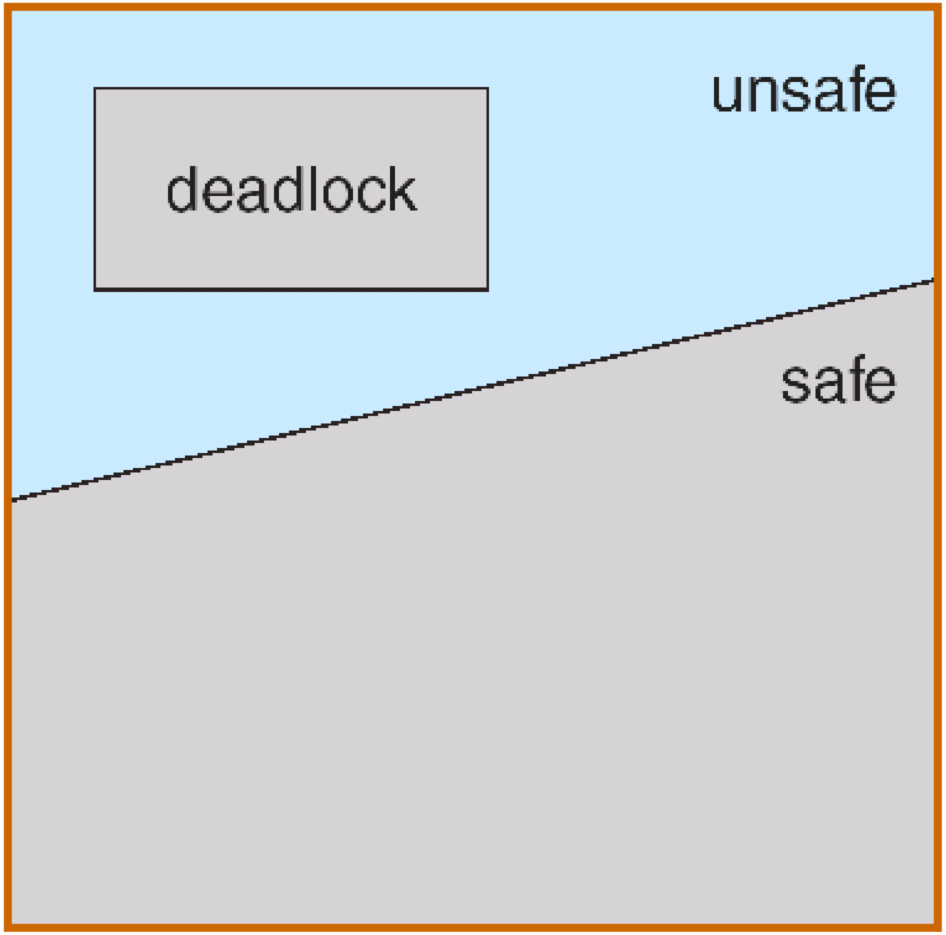
Safe State

- When a process requests an available resource, the system must decide if immediate allocation leaves the system in a safe state
- A system is in a safe state only if there exists a safe sequence
- A sequence of processes $<P_1, P_2, \ldots, P_n>$ is a safe sequence for the current allocation state if, for each P_i, the resource requests that P_i can still make, can be satisfied by currently available resources plus resources held by all P_j, with $j < i$.
- That is:
  - If the 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 (continued)

- If a system is in safe state ⇒ no deadlocks
- If a system is in unsafe state ⇒ possibility of deadlock
- Avoidance ⇒ ensure that a system will never enter an unsafe state

Safe, Unsafe , Deadlock State



Avoidance algorithms

- For a single instance of a resource type, use a resource-allocation graph
- For multiple instances of a resource type, use the banker's algorithm

Resource-Allocation Graph Scheme

- Introduce a new kind of edge called a <u>claim edge</u>

- *Claim edge* $P_i \longrightarrow R_j$ indicates that process P_j may request resource R_j; which is represented by a dashed line

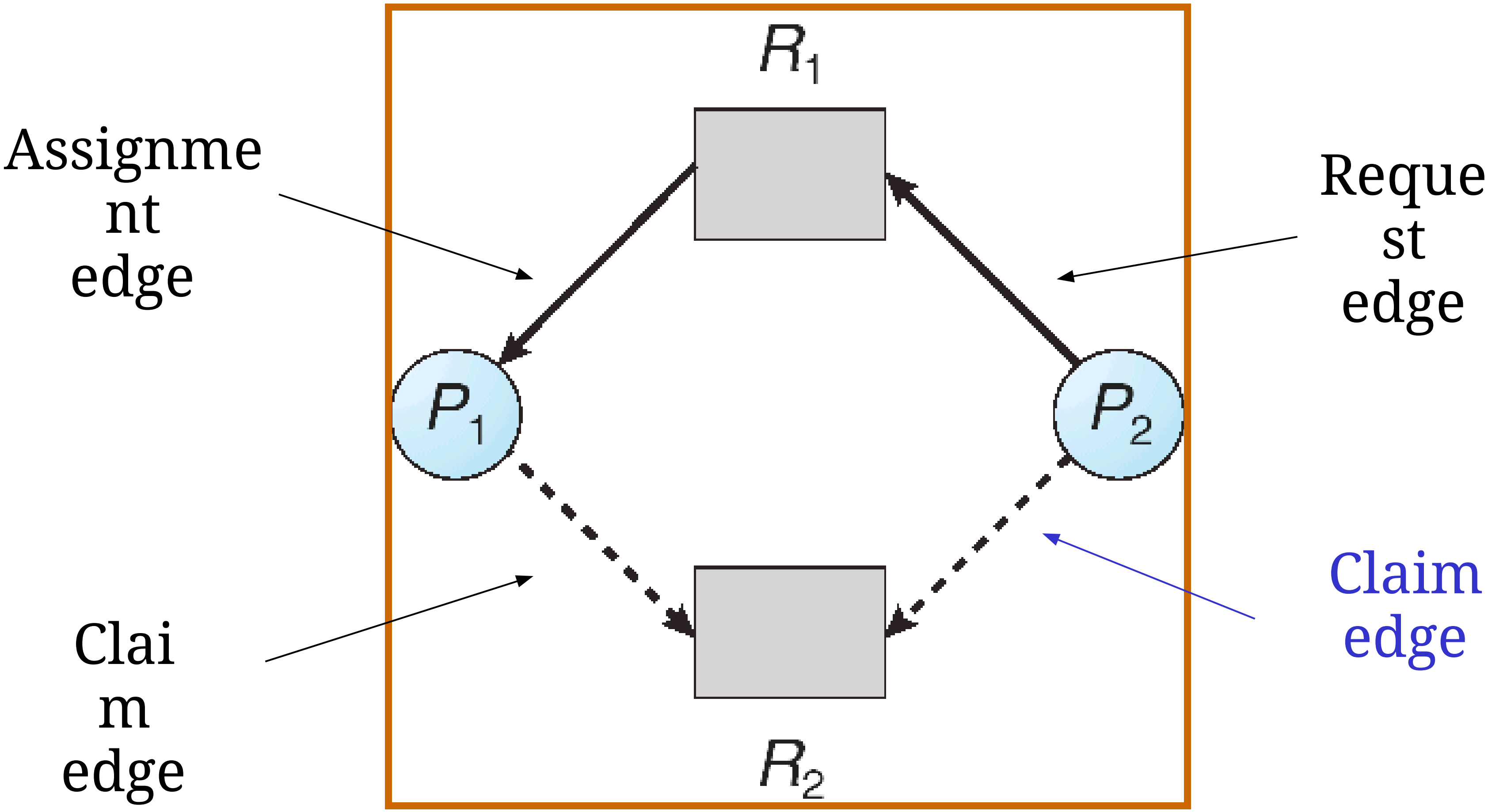
- A <u>claim edge</u> converts to a <u>request edge</u> when a process **requests** a resource

- A <u>request edge</u> converts to an <u>assignment edge</u> when the resource is **allocated** to the process

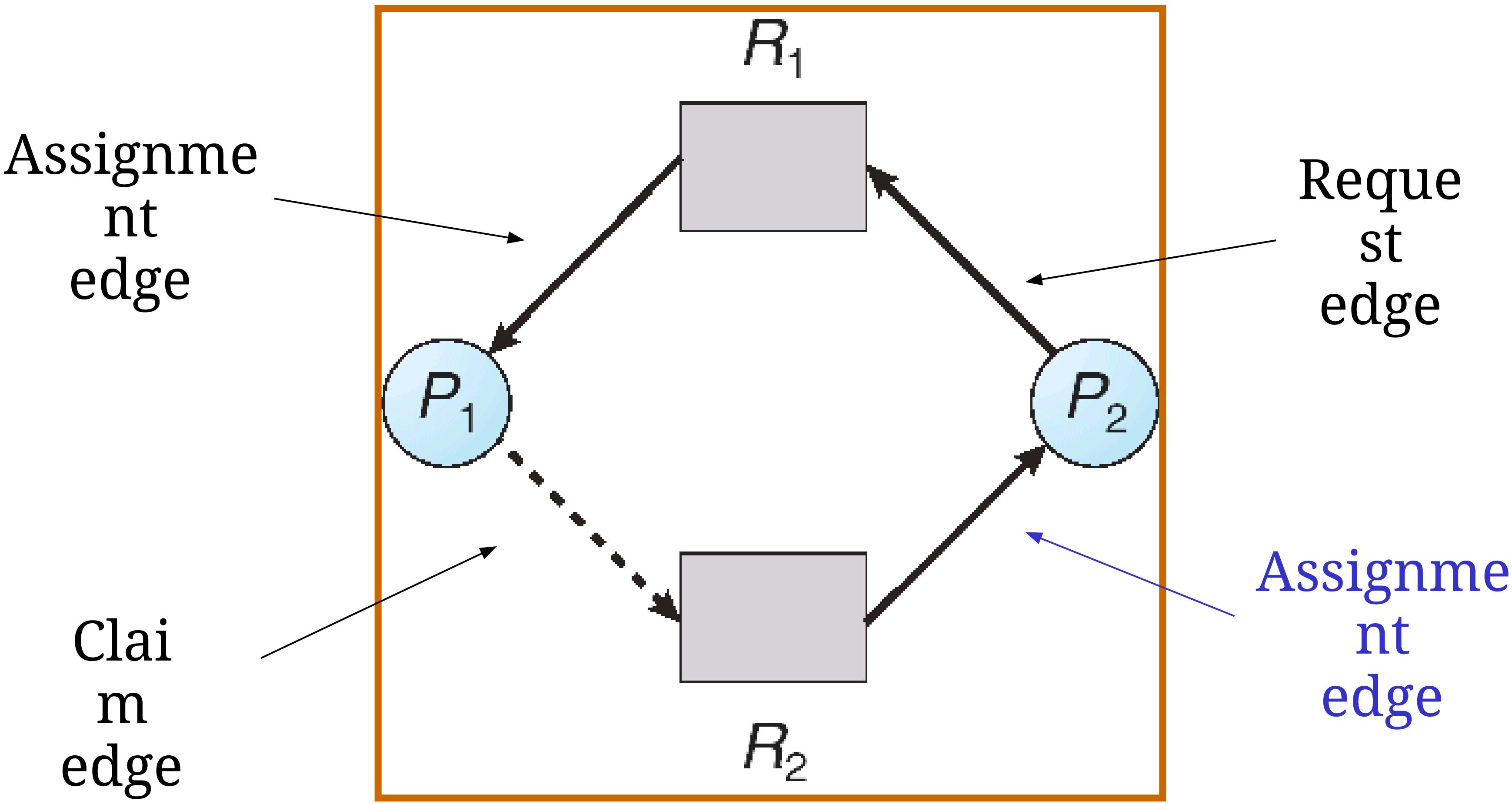
- When a resource is **released** by a process, an <u>assignment edge</u> reconverts to a <u>claim edge</u>

- Resources must be **claimed *a priori*** in the system

Resource-Allocation Graph with Claim Edges



Unsafe State In Resource-Allocation Graph



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

- Used when there exists **multiple** instances of a resource type
- Each process must **a priori** 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.

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

Safety Algorithm

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

   Work := *Available*

   Finish [*i*] = *false* for *i* - 1,3, …, *n.*

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

$Request_i$ = 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*

7.6 Deadlock Detection

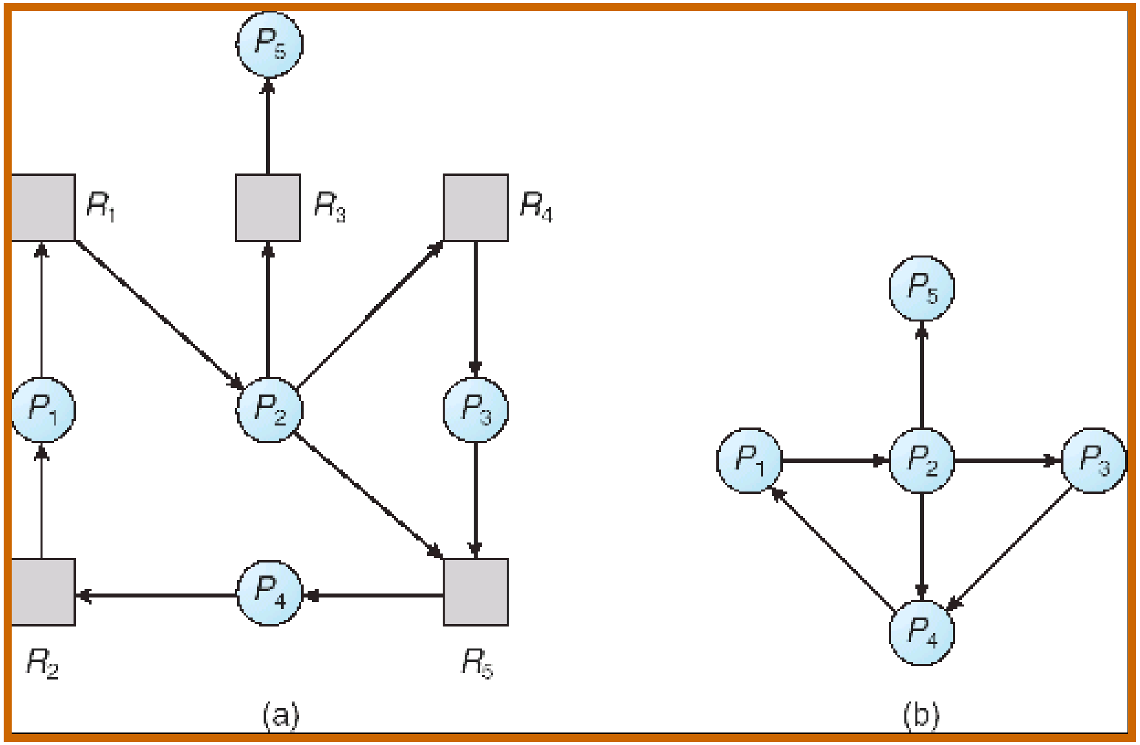
Deadlock Detection

- For deadlock detection, the system must provide
  - An algorithm that examines the state of the system to detect whether a deadlock has occurred
  - And an algorithm to recover from the deadlock
- A detection-and-recovery scheme requires various kinds of overhead
  - Run-time costs of maintaining necessary information and executing the detection algorithm
  - Potential losses inherent in recovering from a deadlock

Single Instance of Each Resource Type

- Requires the creation and maintenance of a *wait-for* graph
  - Consists of a variant of the resource-allocation graph
  - The graph is obtained by **removing** the resource nodes from a resource-allocation graph and **collapsing** the appropriate edges
  - Consequently; all 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



Resource-Allocation Graph

Corresponding wait-for graph

Multiple Instances of a Resource Type

Required 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.

Detection-Algorithm Usage

- When, and how often, to invoke the detection algorithm depends on:
  - How often is a deadlock likely to occur?
  - How many processes will be affected by deadlock when it happens?

- If the detection algorithm is invoked arbitrarily, there may be **many** cycles in the resource graph and so we would not be able to tell **which one** of the many deadlocked processes "caused" the deadlock
- If the detection algorithm is invoked for every resource request, such an action will incur a considerable **overhead** in computation time
- A less expensive alternative is to invoke the algorithm when CPU utilization drops **below 40%**, for example
  - This is based on the observation that a deadlock eventually cripples system throughput and causes CPU utilization to drop

7.7 Recovery From Deadlock

Recovery from Deadlock

- Two Approaches
  - Process termination
  - Resource preemption

Recovery from Deadlock: <u>Process Termination</u>

- **Abort all deadlocked processes**
  - This approach will break the deadlock, but at great expense

- **Abort one process at a time until the deadlock cycle is eliminated**
  - This approach incurs considerable overhead, since, after each process is aborted, a deadlock-detection algorithm must be re-invoked to determine whether any processes are still deadlocked

- **Many factors may affect which process is chosen for termination**
  - What is the priority of the process?
  - How long has the process run so far and how much longer will the process need to run before completing its task?
  - How many and what type of resources has the process used?
  - How many more resources does the process need in order to finish its task?
  - How many processes will need to be terminated?
  - Is the process interactive or batch?

Recovery from Deadlock: Resource Preemption

- With this approach, we successively preempt some resources from processes and give these resources to other processes until the deadlock cycle is broken
- When preemption is required to deal with deadlocks, then three issues need to be addressed:
  - **Selecting a victim** – Which resources and which processes are to be preempted?
  - **Rollback** – If we preempt a resource from a process, what should be done with that process?
  - **Starvation** – How do we ensure that starvation will not occur? That is, how can we guarantee that resources will not always be preempted from the same process?

Summary

- Four necessary conditions must hold in the system for a deadlock to occur
  - Mutual exclusion
  - Hold and wait
  - No preemption
  - Circular wait
- Four principal methods for dealing with deadlocks
  - Use some protocol to (1) **prevent** or (2) **avoid** deadlocks, ensuring that the system will never enter a deadlock state
  - Allow the system to enter a deadlock state, (3) **detect** it, **and** then **recover**

    Recover by **process termination** or **resource preemption**
  - **(4) Do nothing;** ignore the problem altogether and pretend that deadlocks never occur in the system (used by Windows and Unix)
- To prevent deadlocks, we can ensure that **at least one** of the four necessary conditions **never holds**

End of Chapter 7