



# Deadlocks

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- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention





# System Model

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- System consists of resources
- Resource types  $R_1, R_2, \dots, R_m$ 
  - 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**

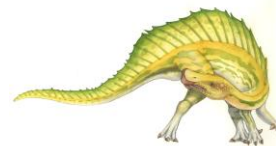




# Deadlock Characterization

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  $\{P_0, P_1, \dots, P_n\}$  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  $P_0$ .





# Resource-Allocation Graph

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

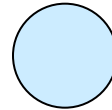
- $V$  is partitioned into two types:
  - $P = \{P_1, P_2, \dots, P_n\}$ , the set consisting of all the processes in the system
  - $R = \{R_1, R_2, \dots, R_m\}$ , the set consisting of all resource types in the system
- **request edge** – directed edge  $P_i \rightarrow R_j$
- **assignment edge**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





# Resource-Allocation Graph (Cont.)

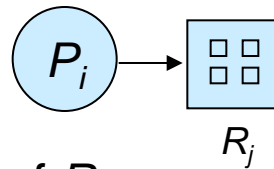
- Process



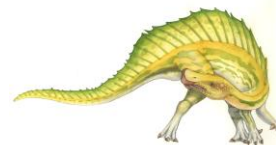
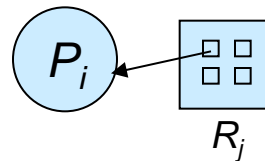
- Resource Type with 4 instances



- $P_i$  requests instance of  $R_j$

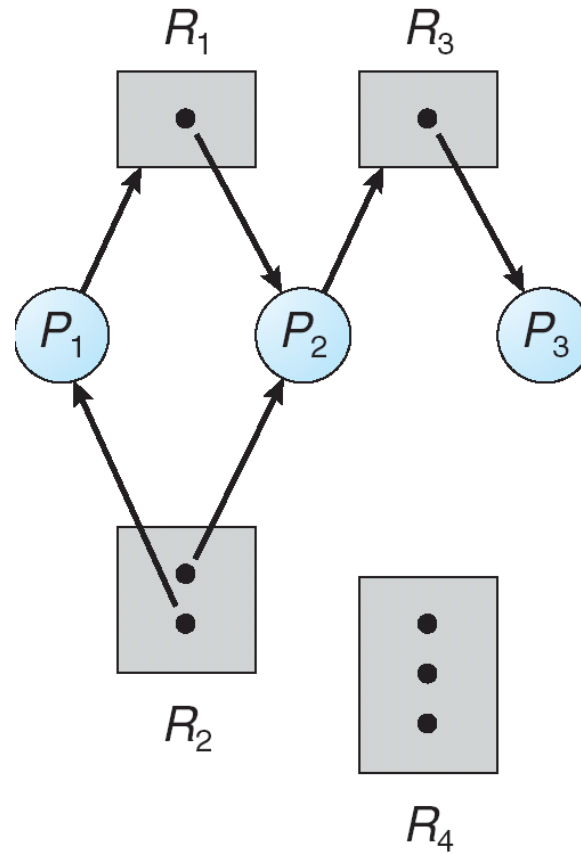


- $P_i$  is holding an instance of  $R_j$



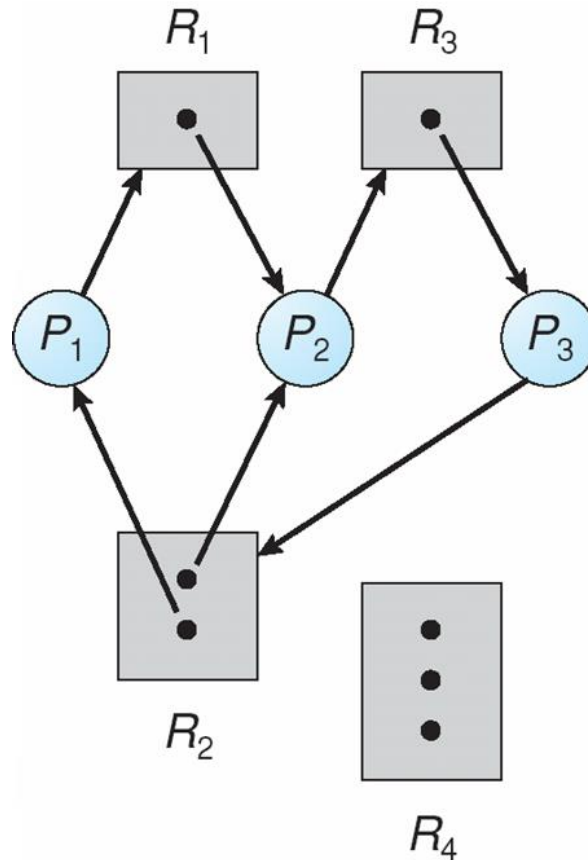


# Example of a Resource Allocation Graph



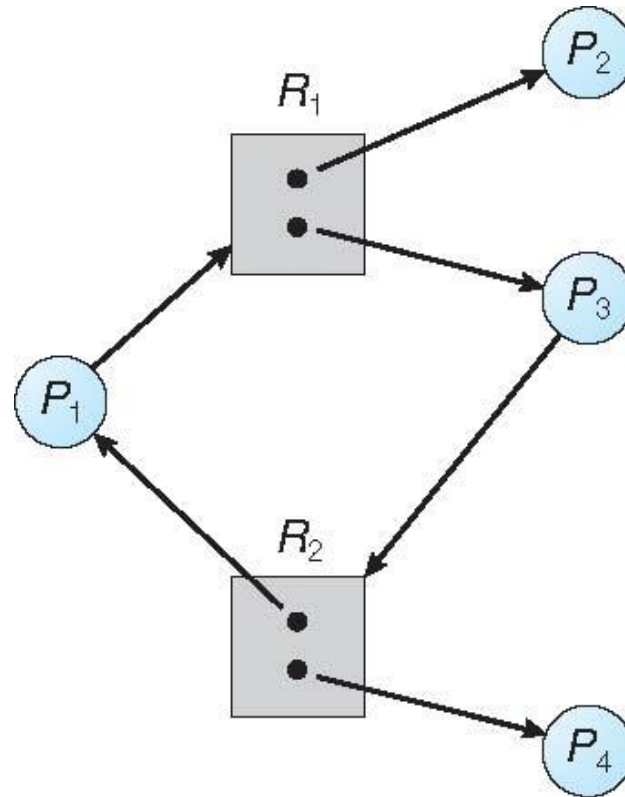


# Resource Allocation Graph With A Deadlock





# Graph With A Cycle But No Deadlock







# Basic Facts

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- 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

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- Ensure that the system will *never* enter a deadlock state:
  - Deadlock prevention
  - Deadlock avoidance
- 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



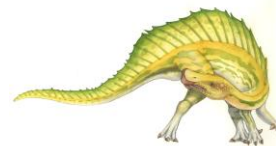


# Deadlock Prevention

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Restrain the ways request can be made

- **Mutual Exclusion** – not required for sharable resources (e.g., read-only files); 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 allocated to it.
  - Low resource utilization; starvation possible





# Deadlock Prevention (Cont.)

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- **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

