Operating Systems Principles

cosc1112/cosc1114

School of Science

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Lecture 06 - Deadlocks

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Outline

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

Objectives

- To develop a description of deadlocks, which prevent sets of concurrent processes from completing their tasks
- To present a number of different methods for preventing or avoiding deadlocks in a computer system

Solution to Critical-Section Problem

1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections
2. **Progress** - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section next cannot be postponed indefinitely
3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted

System Model

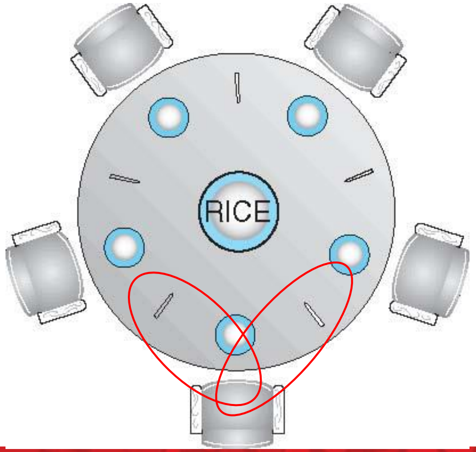
- System consists of resources
- Resource types $R_1, R_2, \ldots, R_m$

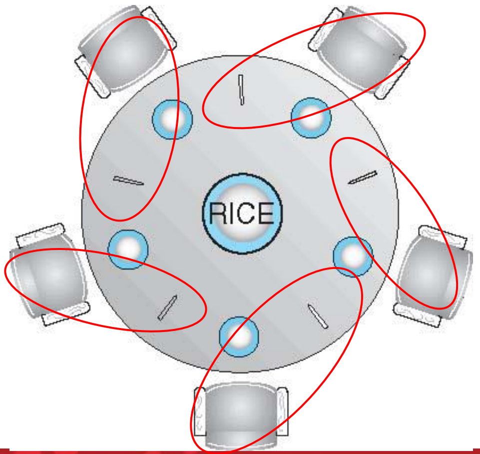
  CPU cycles, memory space, I/O devices
- Each resource type R_i has W_i instances.
- Each process utilizes a resource as follows:
  - **request**
  - **use**
  - **release**

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.





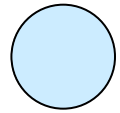
Resource-Allocation Graph

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

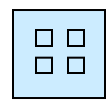
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system
- **request edge** – directed edge $P_i \rightarrow R_j$
- **assignment edge** – directed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

Resource-Allocation Graph (Cont.)

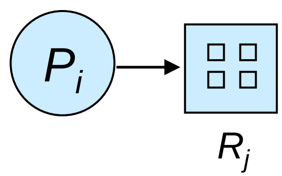
- Process



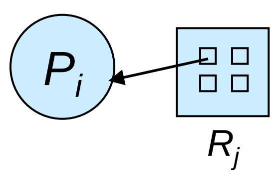
- Resource Type with 4 instances



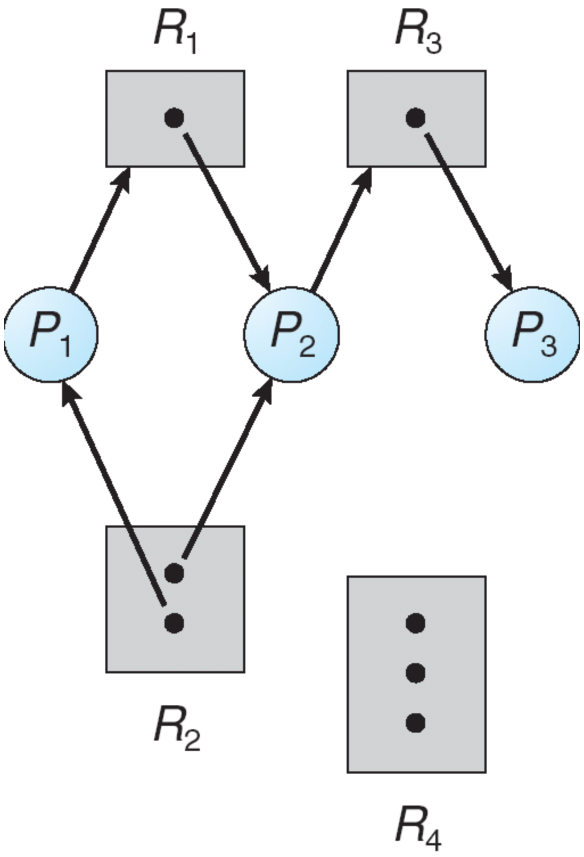
- P_i requests instance of R_j



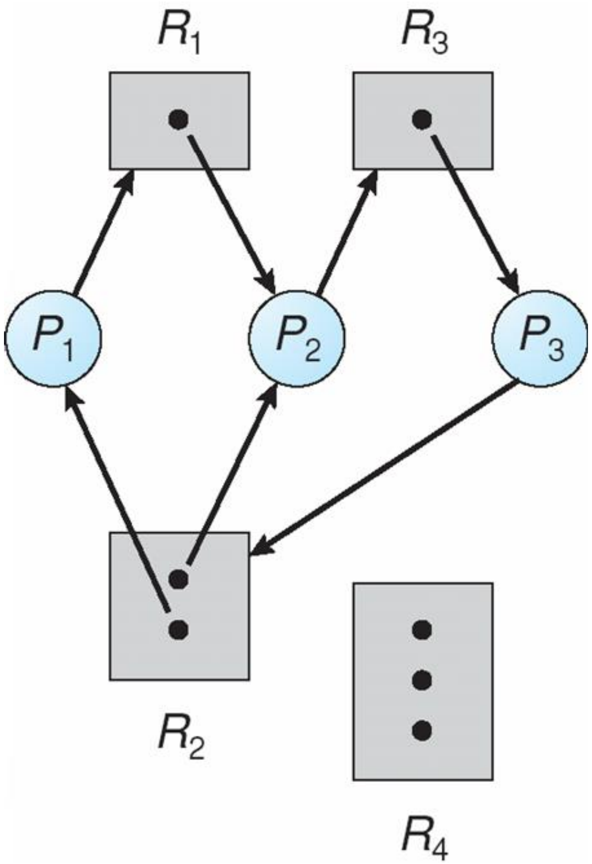
- P_i is holding an instance of R_j



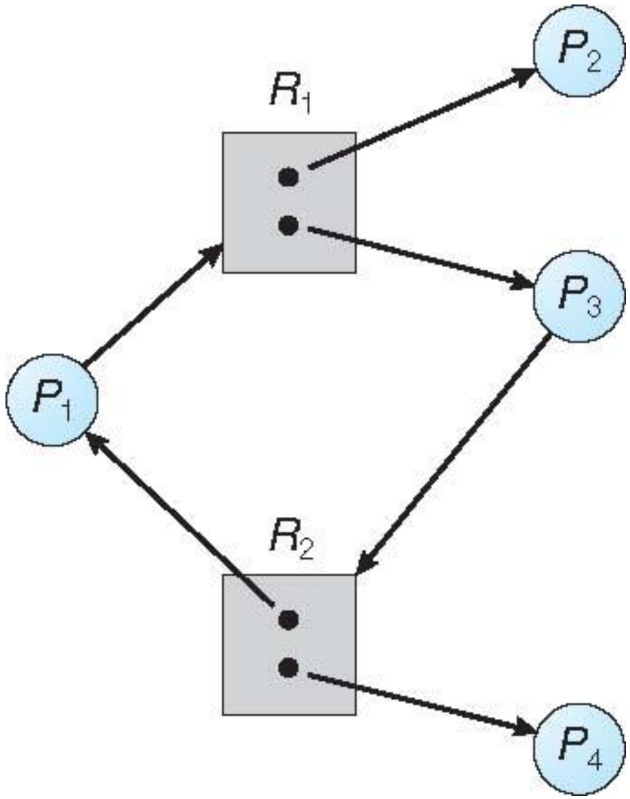
Example of a Resource Allocation Graph



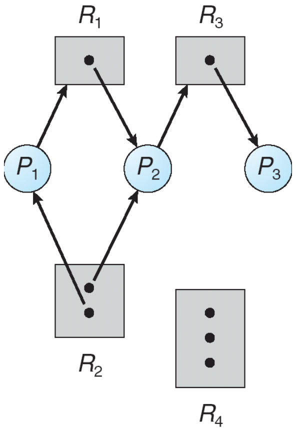
Resource Allocation Graph With A Deadlock



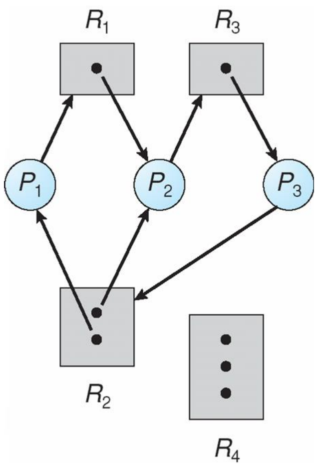
Graph With A Cycle But No Deadlock

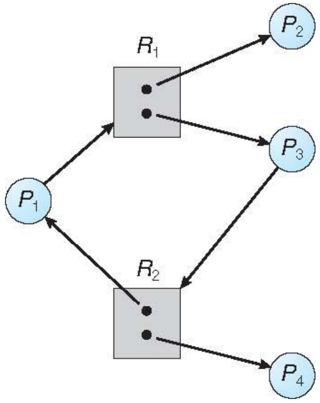


Basic Facts



- If graph contains no cycles $\Rightarrow$ 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:
  - Deadlock prevention
  - Deadlock avoidence
- 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

Deadlock can arise if four conditions hold simultaneously.

- **Mutual exclusion:** only one process at a time can use a resource
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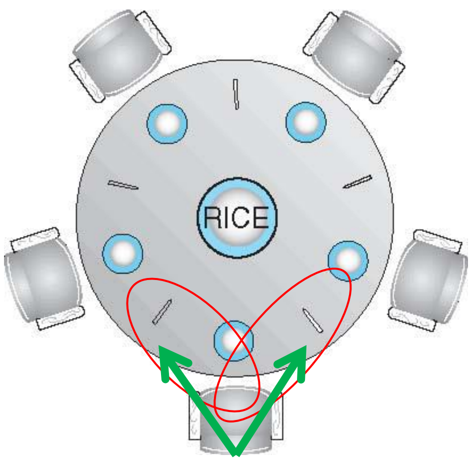
Deadlock Prevention aim to ensure one the these conditions cannot hold

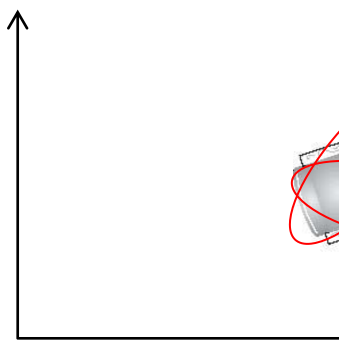
Deadlock Prevention

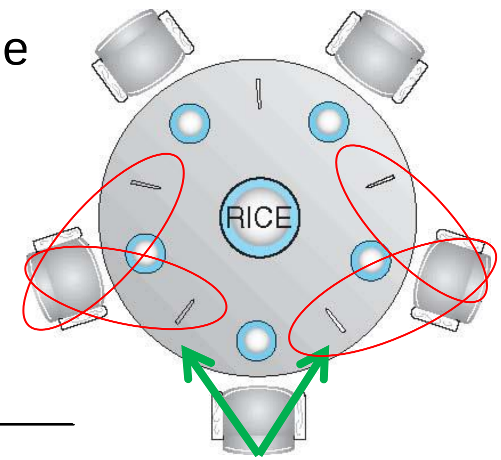
Restrain the ways request can be made

- **Mutual Exclusion** – not required for sharable resources (e.g., read-only files); must hold for non-sharable resources (**cannot prevent**)
- **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

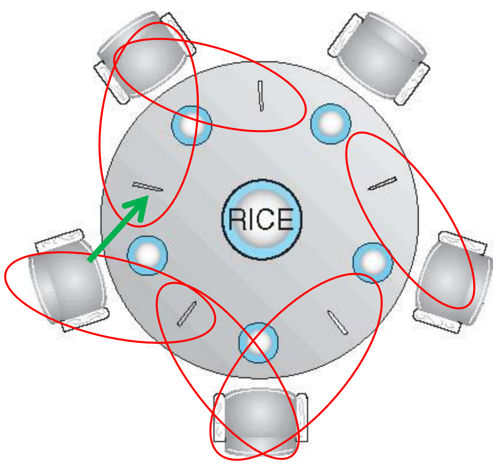


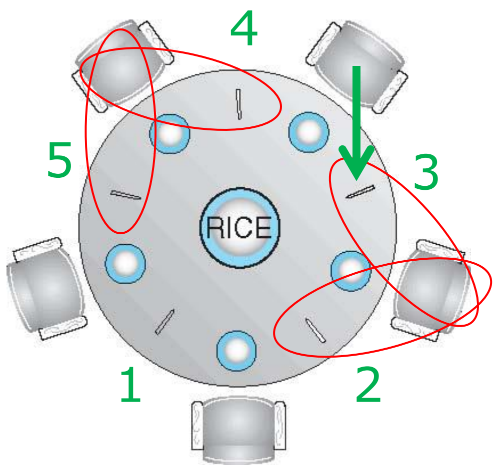


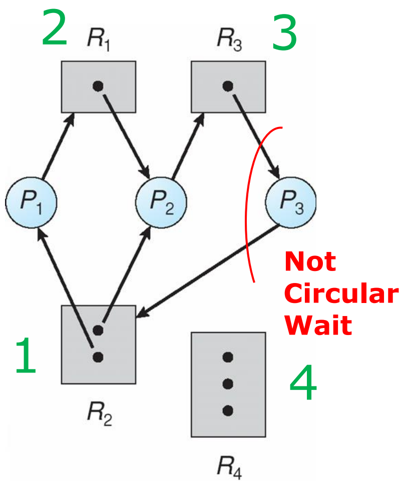


Deadlock Prevention (Cont.)

- **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** – one way to ensure that this condition never hold is to impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration







Deadlock Prevention - Circular Wait

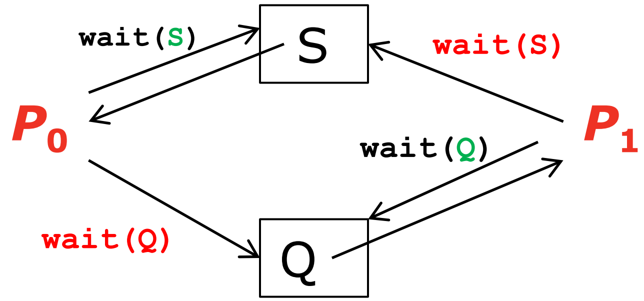
- Assume we have a function that transfers funds between two accounts. To prevent a race condition, each account has an associated mutex lock **S, Q** initialized to 1.
  - Deadlock may happen in the following situations due to circular wait

P_0

```
wait(S);
wait(Q);
 ...
signal(S);
signal(Q);
```

P_1

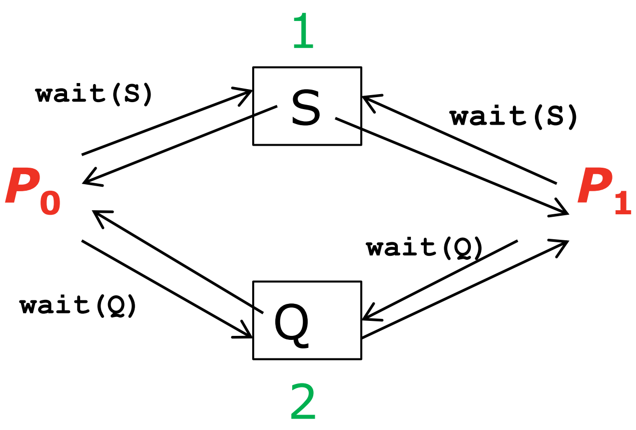
```
wait(Q);
wait(S);
 ...
signal(Q);
signal(S);
```



Deadlock Prevention - Circular Wait

- Deadlock is prevented by ensuring no circular wait

P_0	P_1
`wait(S);`	`wait(S);`
`wait(Q);`	`wait(Q);`
`...`	`...`
`signal(Q);`	`signal(Q);`
`signal(S);`	`signal(S);`



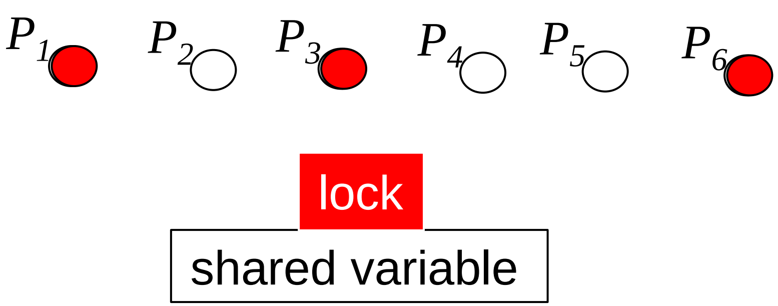
Deadlock Avoidance

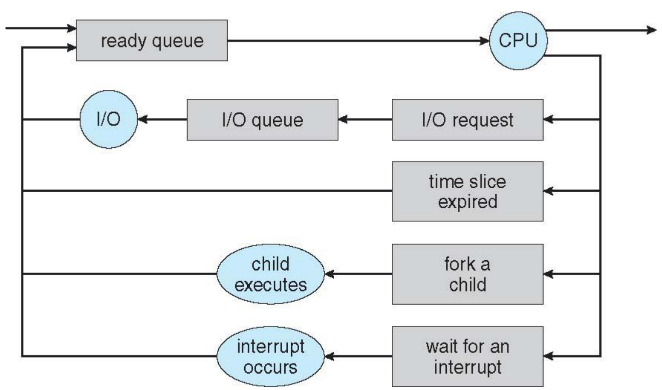
Requires that the system has some additional ***a priori*** information available

- 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 system is in a safe state only if there exists a safe sequence.
  - The sequence of process < P_1, P_2, …, P_n > is a safe sequence for the current allocation state if, for each P_i , the source requests can be satisfied by the currently available recourses + 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

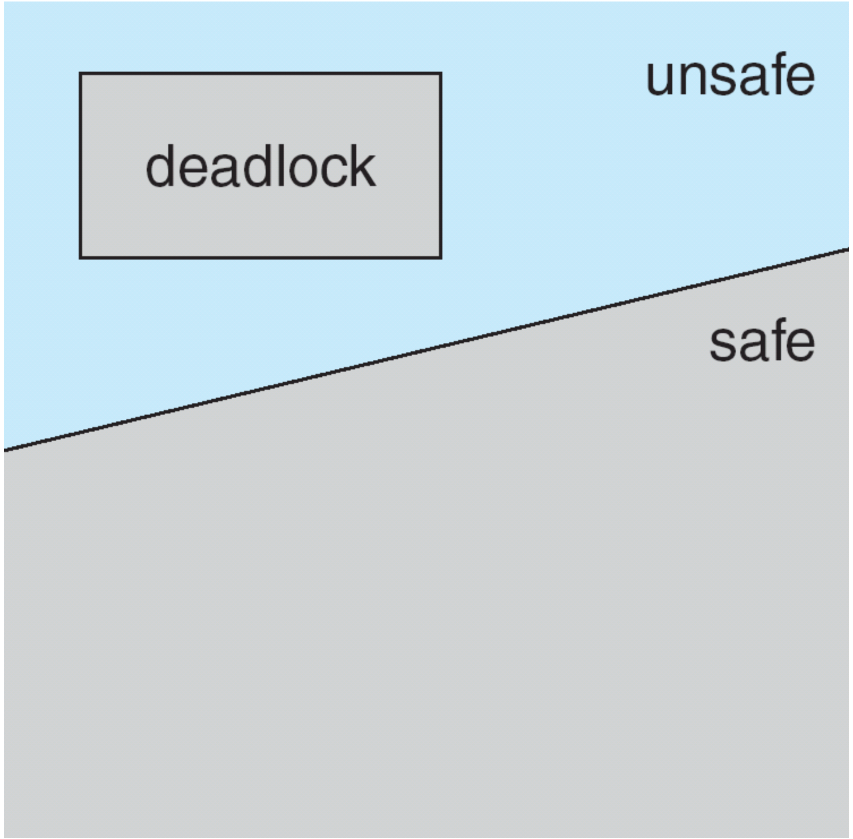




Basic Facts

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

Safe, Unsafe, Deadlock State

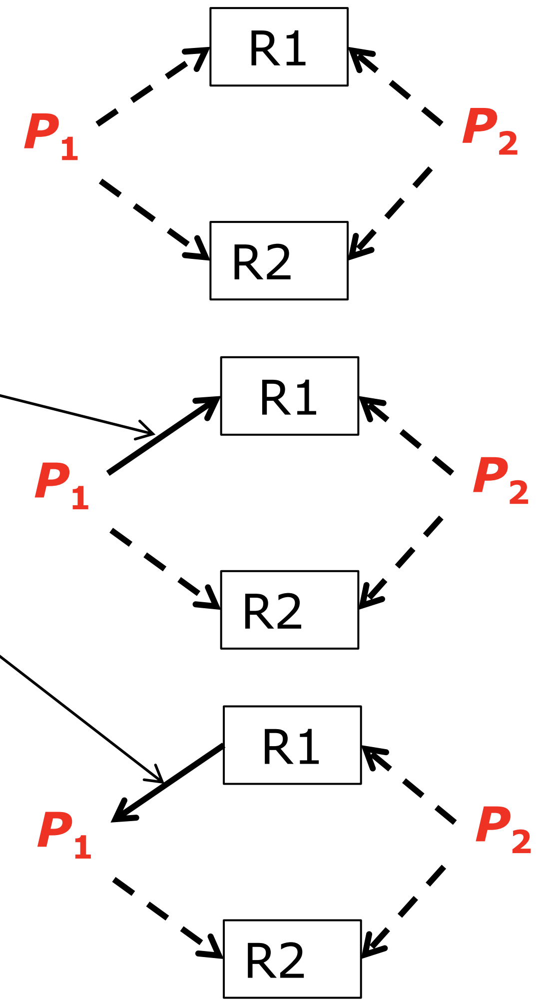


Avoidance Algorithms

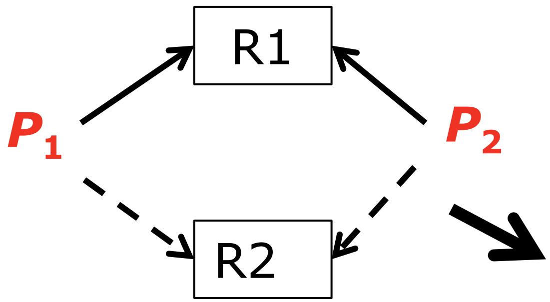
- Single instance of a resource type
  - Use a resource-allocation graph

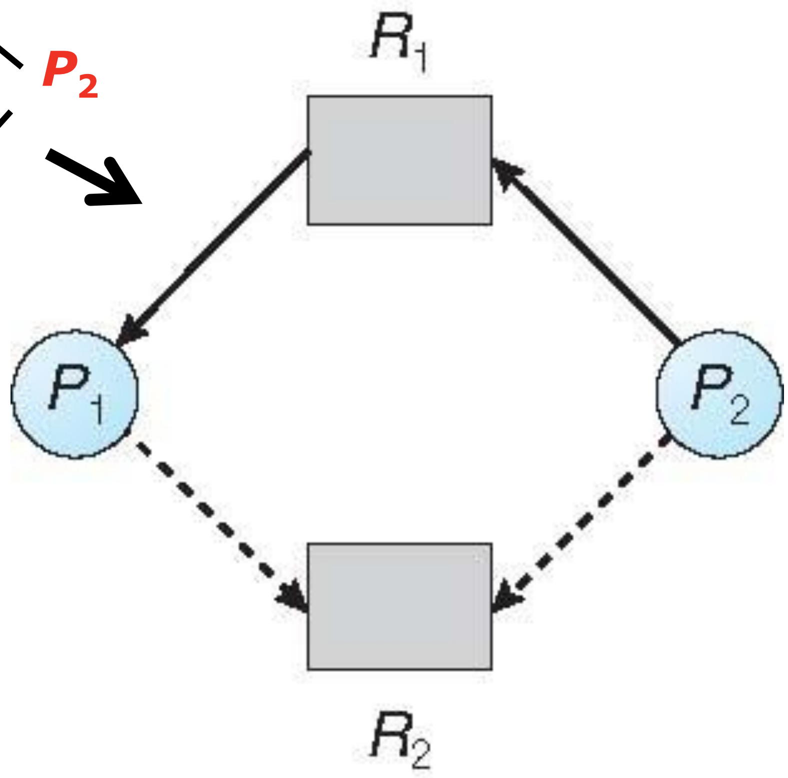
Resource-Allocation Graph Scheme

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

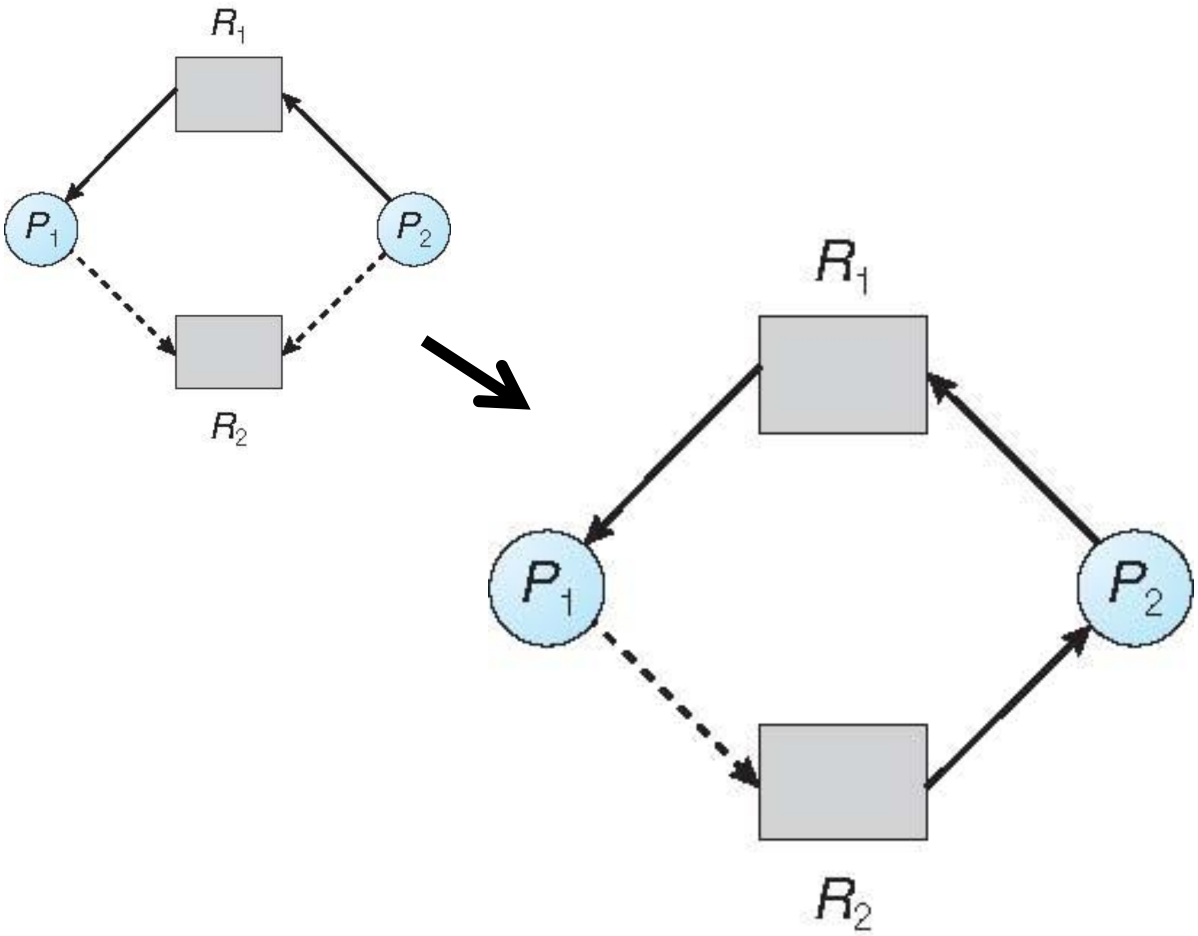




$< P_1, P_2 >$

$\cancel{< P_2, P_1 >}$

Unsafe State In Resource-Allocation Graph



$\cancel{< P_1, P_2 >}$

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

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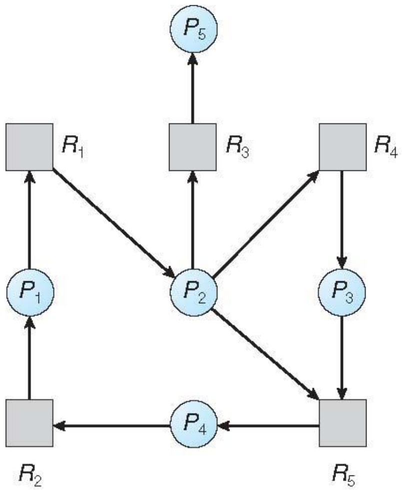
Deadlock Detection

- Allow system to enter deadlock state
- Detection algorithm
- Recovery scheme

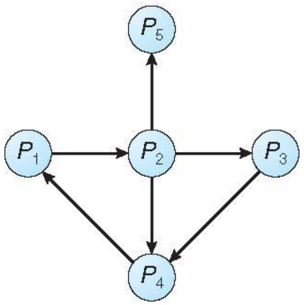
Single Instance of Each Resource Type

- 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



(a)

Resource-Allocation Graph



(b)

Corresponding wait-for graph

- 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

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

- When a detection algorithm determines that a deadlock exists, several alternatives are available.
  - One possibility is to inform the operator that a deadlock has occurred and to let the operator deal with the deadlock manually.
  - Another possibility is to let the system **recover** from the deadlock automatically. There are two options for breaking a deadlock.
    - One is simply to abort one or more processes to break the circular wait.
    - The other is to preempt some resources from one or more of the deadlocked processes.

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?
  1. Priority of the process
  2. How long process has computed, and how much longer to completion
  3. Resources the process has used
  4. Resources process needs to complete
  5. How many processes will need to be terminated
  6. Is process interactive or batch?

Recovery from Deadlock: Resource Preemption

To eliminate deadlocks using resource preemption, we successively preempt some resources from processes and give these resources to other processes until the deadlock cycle is broken. If 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? Clearly, it cannot continue with its normal execution; it is missing some needed resource. We must roll back the process to some safe state and restart it from that state.return to some safe state, restart process for that state
- **Starvation**
  - Same process may always be picked as victim, include number of rollback in cost factor

Next Week

Lecture 7 – Main and Virtual Memory

Tutorial 6