7. Deadlocks

ECE30021/ITP30002 Operating Systems

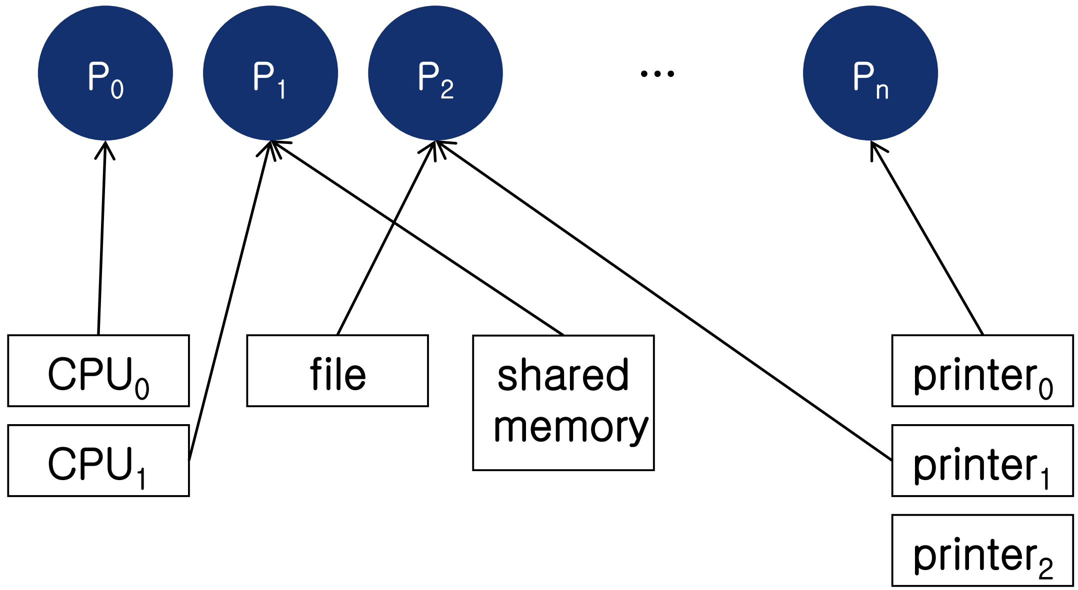
Agenda

- Introduction
- Deadlock prevention
- Deadlock avoidance
- Deadlock detection
- Recovery from deadlock

System Model

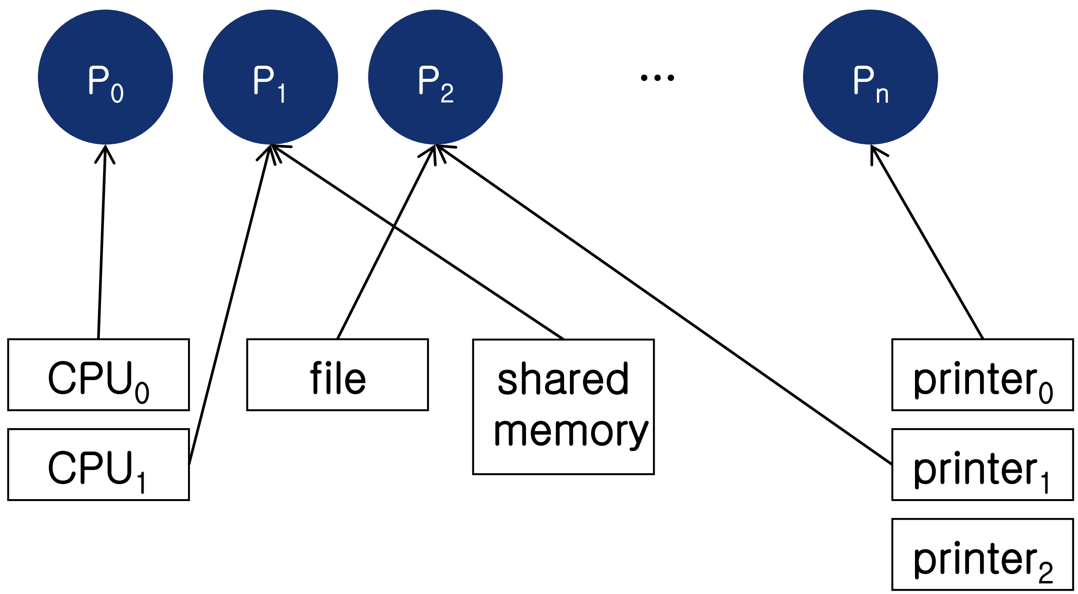
- A system consists of …
  - A finite number of resources
    - Resources are partitioned into several types

    Ex) two identical printers
  - A number of competing processes



System Model

- Steps to utilize a resource
  1. Request
     - Process should wait until the request is granted
  2. Use
  3. Release



Deadlock State

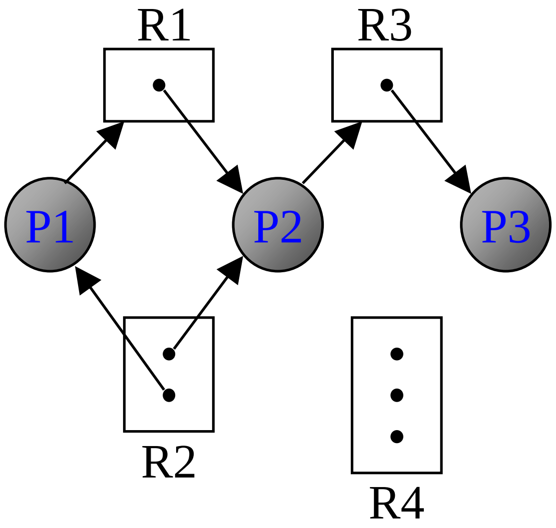
- A set of processes is in deadlock state
  - Each process is waiting for an event that can be caused only by another process in the set.
  - Mainly concerned with resource acquisition and release

Deadlock Characterization

- Necessary conditions for deadlock
  1. Mutual exclusion
  2. Hold and wait
  3. No preemption
  4. Circular wait

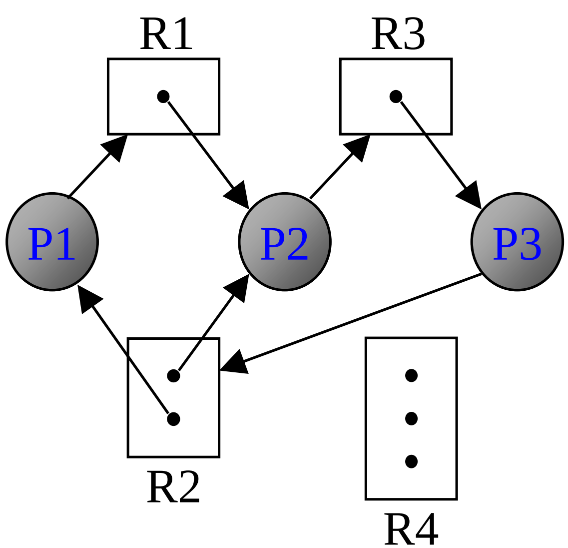
Resource-Allocation Graph

- G(V, E)
  - V: two types of vertices
    - $P = \{P_1, P_2, \cdots, P_n\}$: a set of processes
    - $R = \{R_1, R_2, \cdots, R_m\}$: a set of resource types
  - E: two types of directed edges
    - P_i -> R_j: request edge
    - R_j -> P_i: assignment edge
    - If a request edge is fulfilled, it become assignment edge

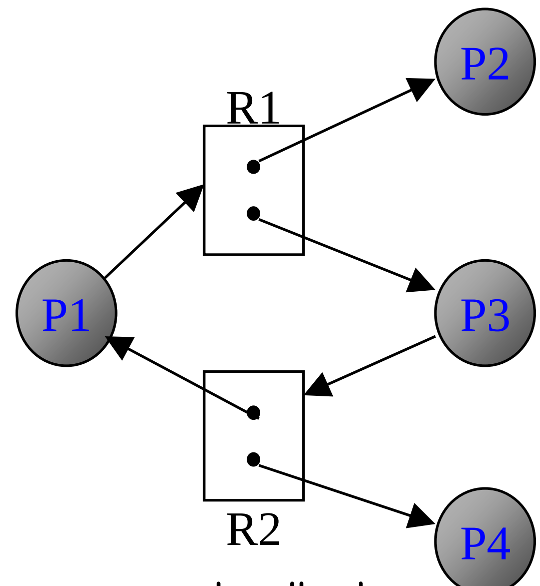


Resource-Allocation Graph

- Cycle vs. deadlock state
  - No cycle -> no deadlock
  - Cycle -> deadlock (?)
    - Only one instance per resource type – deadlock occurred
    - Several instances per resource type – possibility of deadlock



deadlock



no deadlock

Methods for Handling Deadlock

- Three methods to handle deadlock
  - Prevent or avoid deadlock
  - Detect deadlock and recover
  - Ignore
    - Most common case
    - Deadlock is very infrequent (once a year)

Methods for Handling Deadlock

- Deadlock prevention
  - A set of method for ensuring at least one of necessary conditions cannot hold
  - Constraint on request for resources
- Deadlock avoidance
  - Keep the system in safe state in which deadlock cannot occur using additional information, such as …
    - Resources currently available or allocated to each process
    - Additional information about future requests and release of each process.

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- Deadlock avoidance
- Deadlock detection
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Deadlock Prevention

- Mutual exclusion
  - Possible only for sharable resources.

    Ex) read-only file
  - Many resources are intrinsically non-sharable.

- Hold and wait: guarantee whenever a process requests a resource, it does not hold other resources
  - Allocate all required resources before it begins execution.
  - Allow a process to request resources only when it has none.

  -> Inefficient utilization of resource

  -> Starvation

Deadlock Prevention

- No Preemption
  - If a process cannot allocate a resource immediately, it should release all resources it hold.
  - The process restarts when it regains its old resources and the new resource it requested.

- Circular wait
  - Impose total ordering of all resource types
  - All resources should be requested in that order.

Ex) F(tape drive) = 1

F(disk drive) = 5

F(printer) = 12

Deadlock Prevention

- Deadlock

P_0	P_1
$wait(S);$	$wait(Q);$
$wait(Q);$	$wait(S);$
$\vdots$	$\vdots$
$signal(S);$	$signal(Q);$
$signal(Q);$	$signal(S);$

Deadlock Prevention

- Problems of deadlock prevention
  - Low device utilization
  - Reduce system throughput

Deadlock Avoidance

- Require additional information about how resources are to be requested.
  Ex) Each process declares maximum # of resources of each type it may request.

- Deadlock avoidance algorithm dynamically examines resource-allocation state to ensure a circular-wait condition can never exist.

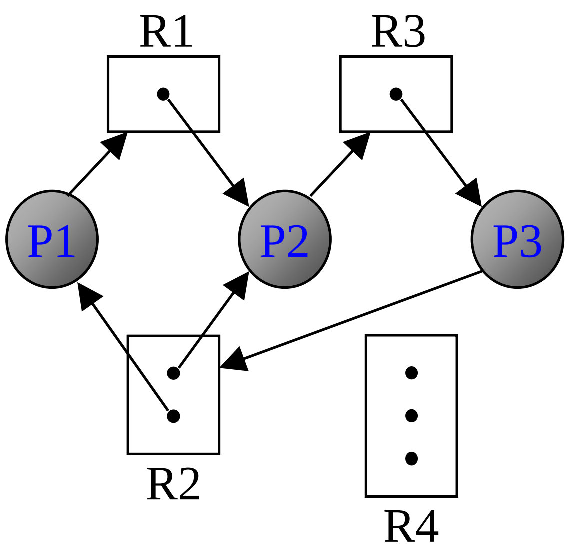
- Resource-allocation state is defined by
  - # of available resources
  - # of allocated resources
  - Maximum demand of processes

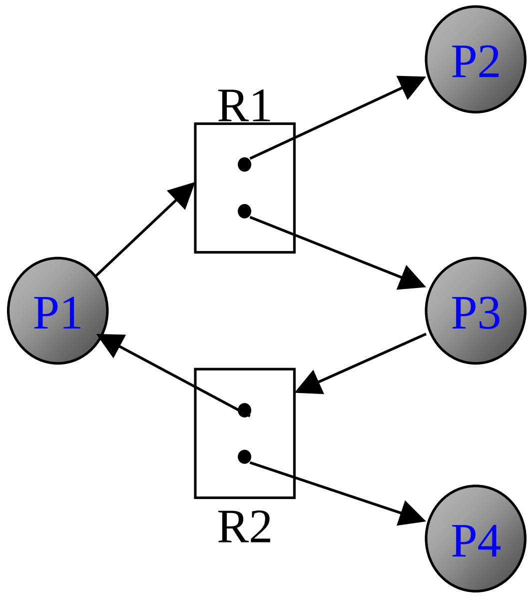
Safe State

- When a process requests an available resource, system must decide if immediate allocation leaves the system in safe state.
- Safe sequence: a sequence $<P_1, P_2, \cdots, P_n>$ is safe if for each P_i, the resource requests of P_i can be satisfied by …
  - Currently available resources, and
  - Resources held by P_j, where $j < i$
- Safe state: there exists a safe sequence of all process

Safe Sequence

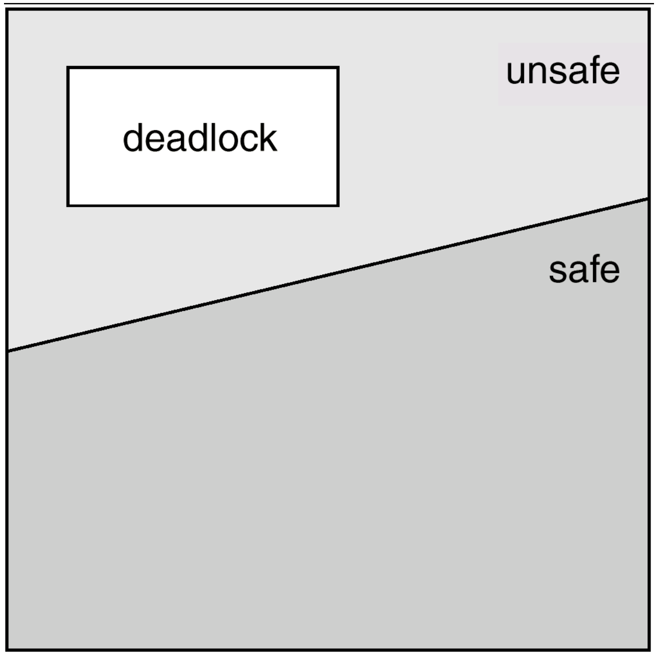
- Are they safe ?





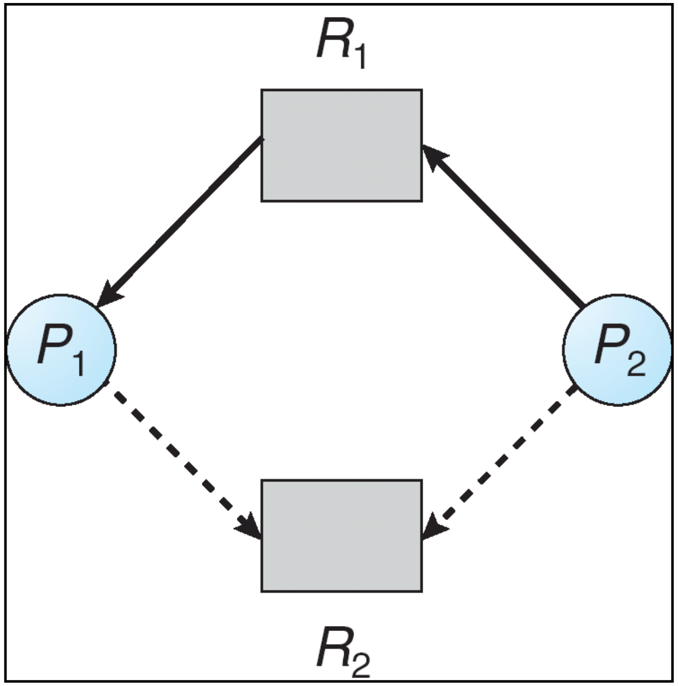
Safe State and Deadlock

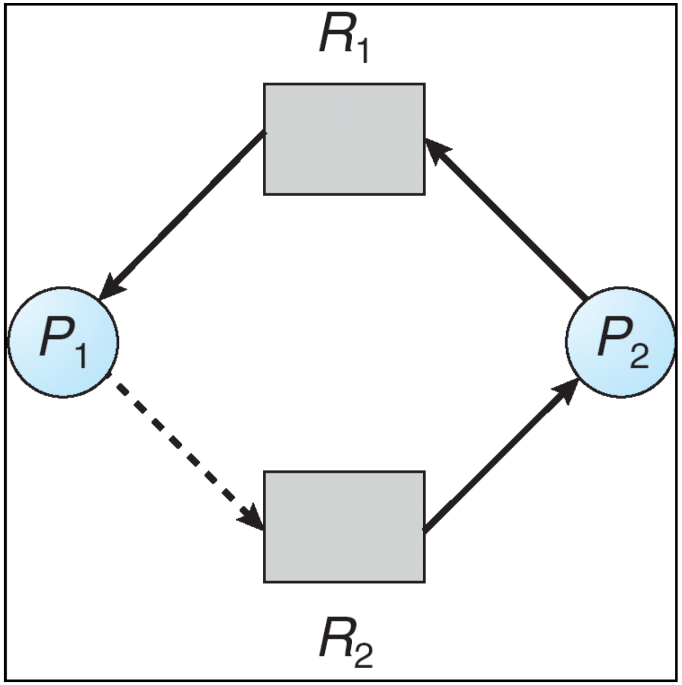
- If a system is in safe state -> no deadlock
- If a system is in unsafe state -> possibility of deadlock
- Deadlock avoidance -> keeping a system in safe state



Detecting Unsafe State

- Claim edge $P_i \rightarrow R_j$ (dashed line): process P_i may request resource R_j at some time
  - Claim edge can be converted into request edge





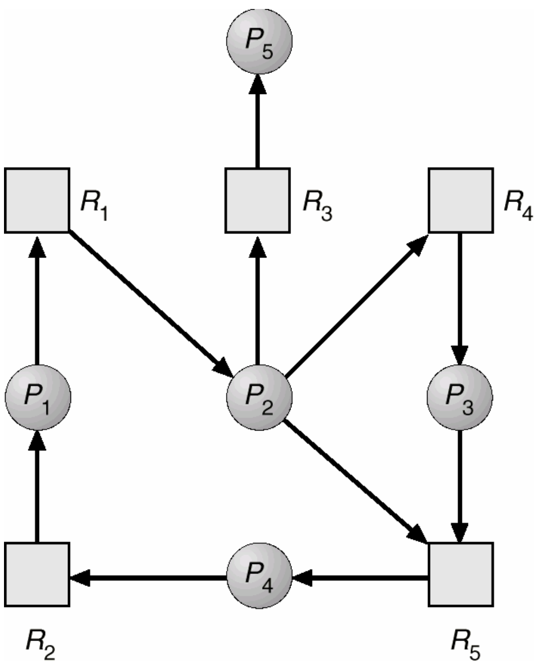
unsafe state !

Deadlock Detection

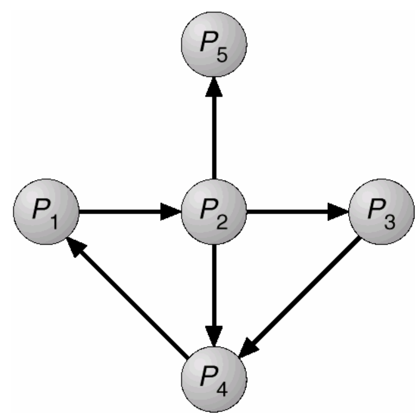
- Single instance of each resource type
- Several instances of a resource type (-> skip)

Single Instance of Each Resource Type

- Wait-for graph: removing resource nodes from resource-allocation graph and collapsing the appropriate edges



Resource-allocation graph



Wait-for graph

Single Instance of Each Resource Type

- A deadlock exists if and only if the wait-for graph contains a cycle.

- To detect deadlock, system should
  - Maintain wait-for graph
  - Invoke an algorithm to detect a cycle – $O(n^2)$

Detection-Algorithm Usage

- When should we invoke the detection algorithm?
  - How often is a deadlock likely to occur?
  - How many processes will be affected by deadlock when it happens?

- An observation
  - Deadlocks occur only when some processes makes a request that cannot be granted immediately

  -> We may invoke detection algorithm whenever a request for allocation cannot be granted immediately

    (In this case, we can find the process which caused deadlock.)

Recovery from Deadlock

- Process termination

- Resource preemption

Process Termination

- Abort all deadlocked processes
  - Too expensive

- Abort one process at a time until the deadlock is eliminated
  - Order of priority
    - Time from start / time to completion
    - Resources the process has used / needs to complete
    - How many processes will need to be terminated?
    - Is the process interactive or batch?

Resource Preemption

- Selecting a victim
  - Minimizing cost (# of resources a process has, amount of time consumed so far, …)
- Rollback
  - The selected process should return to some safe state and restart it.
- Starvation
  - How can we guarantee that resources will not always be preempted from the same process?