國立陽明交通大學
NATIONAL YANG MING CHIAO TUNG UNIVERSITY

Institute of Artificial Intelligence Innovation
Department of Computer Science

Operating System

Lecture 06-1: Deadlocks

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Wed. 10:10 - 12:00 EC115 +
Fri. 11:10 – 12:00 Online

Course Schedule

W	Date	Lecture	Online	Homework
1	Sept. 4	Lec00: Couse Overview & Historical Prospective		
2	Sept. 11	Lec01: Introduction	V	
3	Sept. 18	Lec02: OS Structure	V	HW01 Due 10/5
4	Sept. 25	Lec03: Processes Concept	X	
5	Oct. 2	Typhoon – No class	V	
6	Oct. 9	Lec07: Memory Management	V	
7	Oct. 16	Lec08: Virtual Memory Management	V	HW02 Due 11/2
8	Oct. 23	Lec04: Multithreaded Programming	V	
9	Oct. 30	Midterm Exam		
10	Nov. 6	Lec05: Process Scheduling	V	Let's take a breath
11	Nov. 13	Lec06: Process Synchronization & Deadlocks	X	HW03
12	Nov. 20	School Event – No class	V	
13	Nov. 27	Lec09: File System Interface	V	
14	Dec. 4	Lec10: File System Implementation	V	HW04
15	Dec. 11	Lec11: Mass Storage System & Lec12: IO Systems	V	
16	Dec. 18	School Final Exam		

Overview

- System Model
- Deadlock Characterization
- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Recovery from Deadlock

Deadlock Problem

- A set of blocked processes each holding some resources and waiting to acquire a resource held by another process in the set
- Ex1: 2 processes and 2 tape drivers
  - Each process holds a tape drive
  - Each process requests another tape drive
- Ex2: 2 processes, and semaphores A & B
  - P1 (hold B, wait A): wait(A), signal(B)
  - P2 (hold A, wait B): wait(B) , signal(A)

Necessary Conditions

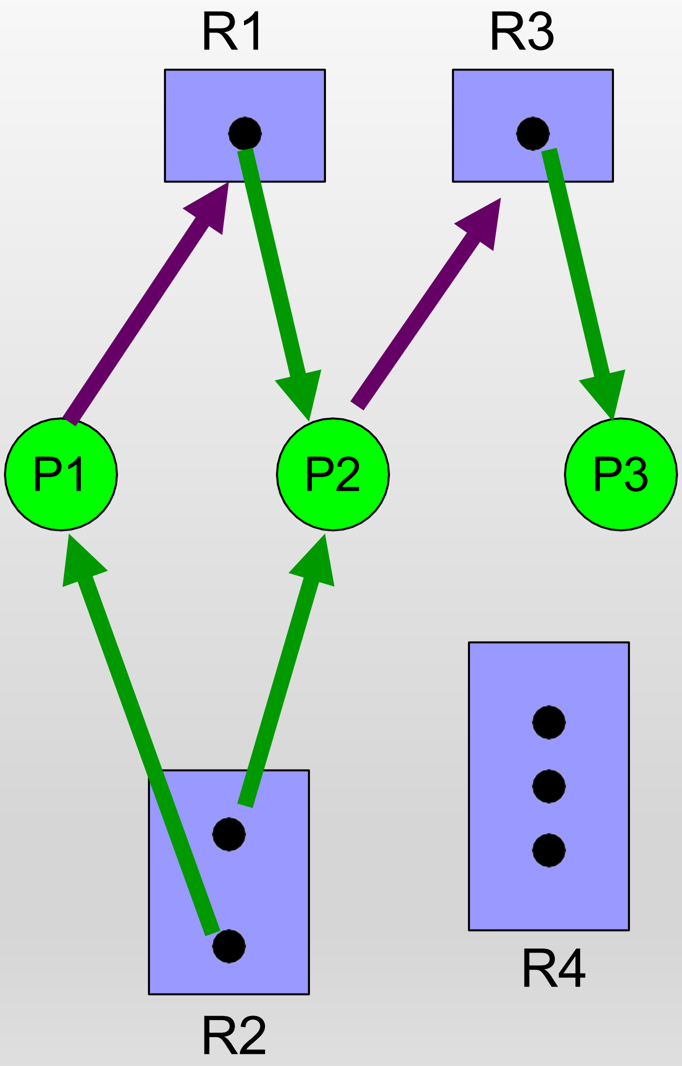
- Mutual exclusion:
  - only 1 process at a time can use a resource
- Hold & Wait:
  - a process holding some resources and is waiting for another resource
- No preemption:
  - a resource can be only released by a process voluntarily
- Circular wait:
  - there exists a set *{P0, P1, …, Pn}* of waiting processes such that P0 -> P1 -> P2 -> ... -> Pn -> P0
- -> All four conditions must hold for possible deadlock!

System Model

- Resources types $R1, R2, \ldots, Rm$
  - E.g. CPU, memory pages, I/O devices
- Each resource type Ri has Wi instances
  - E.g. a computer has 2 CPUs
- Each process utilizes a resource as follows:
  - Request -> use -> release

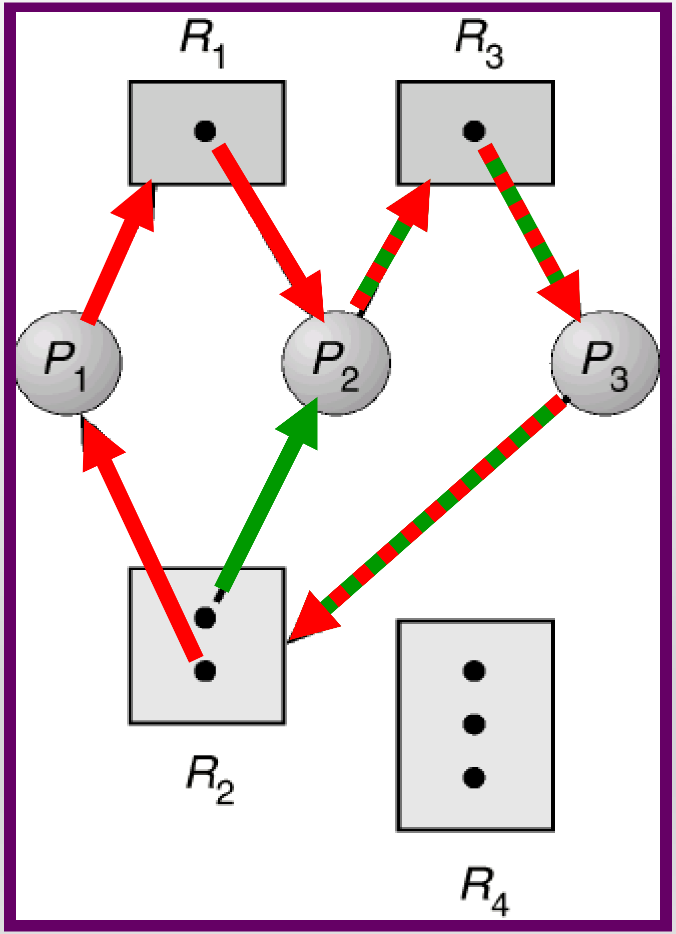
Resource-Allocation Graph

- 3 processes, P1 ~ P3
- 4 resources, R1 ~ R4
  - R1 and R3 each has one instance
  - R2 has two instances
  - R4 has three instances
- Request edges:
  - *P1-> R1*: P1 requests R1
- Assignment edges:
  - *R2 -> P1:* One instance of R2 is allocated to P1
- -> P1 is hold on an instance of R2 and waiting for an instance of R1



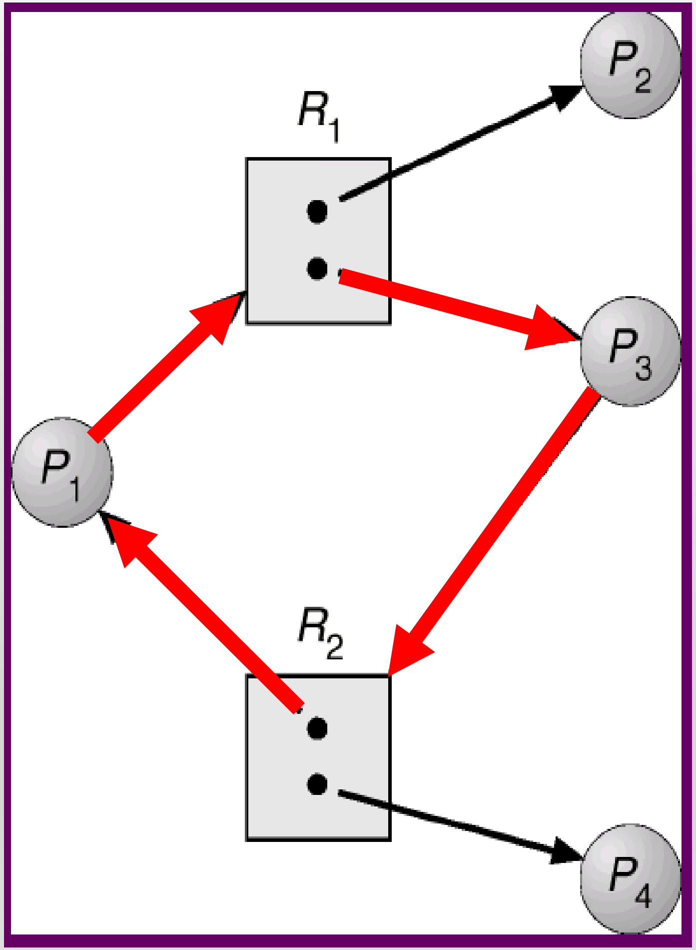
Resource-Allocation Graph w/ Deadlock

- If the graph contains a cycle, a deadlock may exist
- In the example:
  - P1 is waiting for P2
  - P2 is waiting for P3
  - -> P1 is also waiting for P3
  - Since P3 is waiting for P1 or P2, and they both waiting for P3
  - -> deadlock!



RA Graph w/ Cycle but NO Deadlock

- If the graph contains a cycle, a deadlock may exist
- In the example:
  - P1 is waiting for P2 or P3
  - P3 is waiting for P1 or P4
  - Since P2 and P4 wait no one
  - -> no deadlock between P1 & P3!



Deadlock Detection

- If graph contains no cycle → no deadlock
  - Circular wait cannot be held
- If graph contains a cycle:
  - if one instance per resource type → deadlock
  - if multiple instances per resource type → possibility of deadlock

Handling Deadlocks

- Ensure the system will never enter a deadlock state
  - deadlock prevention: ensure that at least one of the 4 necessary conditions cannot hold
  - deadlock avoidance: dynamically examines the resource-allocation state before allocation
- Allow to enter a deadlock state and **then recover**
  - deadlock detection
  - deadlock recovery
- Ignore the problem and pretend that deadlocks never occur in the system
  - used by most operating systems, including UNIX.

Review Slides (I)

- deadlock necessary conditions?
    - mutual exclusion
    - hold & wait
    - no preemption
    - circular wait
- resource-allocation graph?
    - cycle in RAG → deadlock?
- deadlock handling types?
    - deadlock prevention
    - deadlock avoidance
    - deadlock recovery
    - ignore the problem

Deadlock Prevention & Deadlock Avoidance

Deadlock Prevention

- Mutual exclusion (ME): do not require ME on sharable resources
  - e.g. there is no need to ensure ME on read-only files
  - Some resources are not shareable, however (e.g. printer)
- Hold & Wait:
  - When a process requests a resource, it does not hold any resource
  - Pre-allocate all resources before executing
  - resource utilization is low; starvation is possible

Deadlock Prevention (con't)

- No preemption
  - When a process is waiting on a resource, all its holding resources are preempted
    - e.g. P1 request R1, which is allocated to P2, which in turn is waiting on R2. *(P1 -> R1 -> P2 -> R2)*
    - R1 can be preempted and reallocated to P1
  - Applied to resources whose states can be easily saved and restored later
    - e.g. CPU registers & memory
  - It cannot easily be applied to other resources
    - e.g. printers & tape drives

Deadlock Prevention (con’t)

- Circular wait
  - impose a total ordering of all resources types
  - a process requests resources in an increasing order
    - Let R={R0, R1, …, RN} be the set of resource types
    - When request Rk, should release all Ri, i >= k
  - Example:
    - F(tape drive) = 1, F(disk drive) = 5, F(printer) = 12
    - A process must request tape and disk drive before printer
  - proof: counter-example does not exist
    - P0 (R0) -> R1, P1 (R1) -> R2, …, PN(RN) -> R0
    - Conflict: R0 < R1 < R2 < … < RN < R0

PN hold RN, wait R0

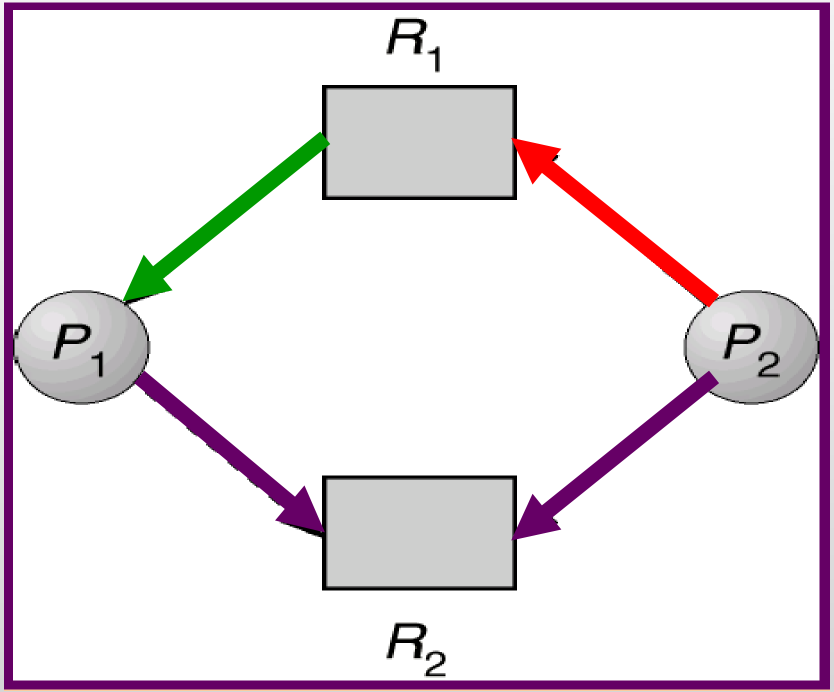
Avoidance Algorithms

- Single instance of a resource type
  - resource-allocation graph (RAG) algorithm based on circle detection

- Multiple instances of a resource type
  - banker's algorithm based on safe sequence detection

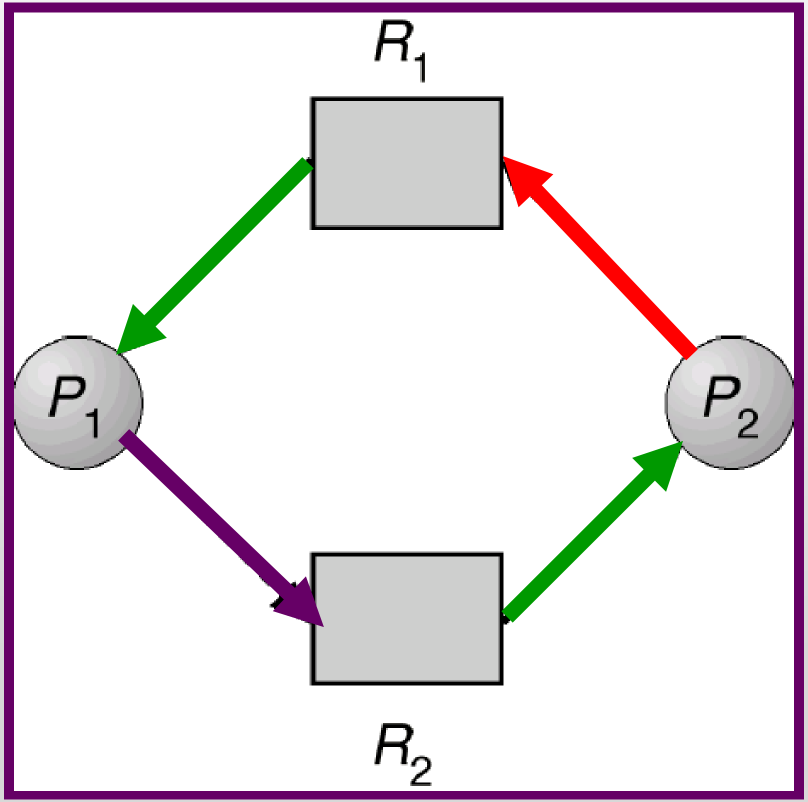
Resource-Allocation Graph (RAG) Algorithm

- Request edge: Pi -> Rj
  - Process Pi is waiting for resource Rj
- Assignment edge: Rj -> Pi
  - Resource Rj is allocated and held by process Pi
- Claim edge: Pi -> Rj
  - process Pi may request Rj in the future
- Claim edge converts to request edge
  - When a resource is requested by process
- Assignment edge converts to a claim edge
  - When a resource is released by a process



Resource-Allocation Graph (RAG) Algorithm

- Resources must be claimed a priori in the system
- Grant a request only if NO cycle created
- Check for safety using a cycle-detection algorithm, O(n2)
- Example: R2 cannot be allocated to P2



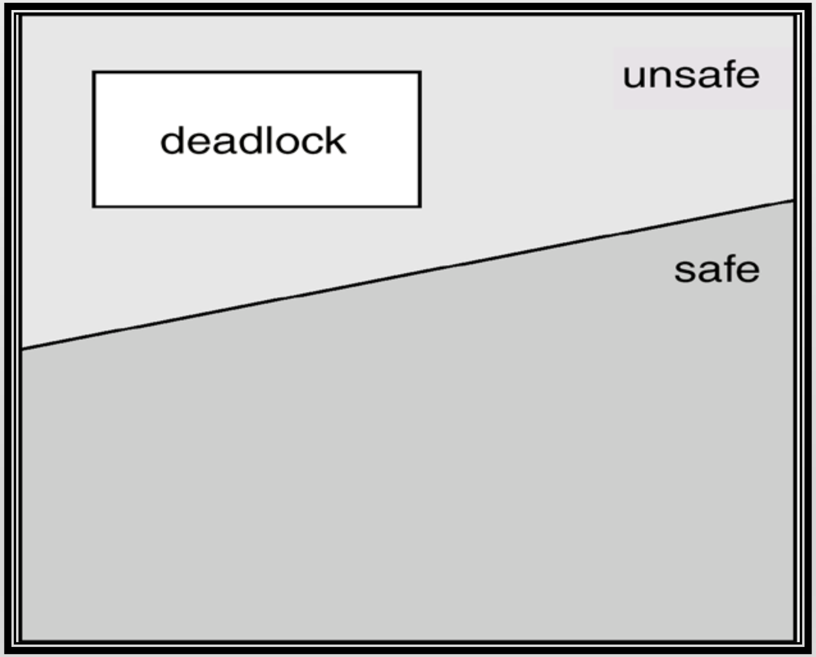
Avoidance Algorithms

- Single instance of a resource type
  - resource-allocation graph (RAG) algorithm based on circle detection

- Multiple instances of a resource type
  - banker's algorithm based on safe sequence detection

Deadlock Avoidance

- safe state: a system is in a safe state if there exists a sequence of allocations to satisfy requests by all processes
  - This sequence of allocations is called safe sequence
- safe state -> no deadlock
- unsafe state -> possibility of deadlock
- deadlock avoidance -> ensure that a system never enters an unsafe state



Safe State with Safe Sequence

- There are 12 tape drives
- Assuming at t0:

Hint from processes →

	Max Needs	Current Holding
P0	10	5
P1	4	2
P2	9	2

→ <P1, P0, P2> is a safe sequence

Safe State with Safe Sequence

- There are 12 tape drives
- Assuming at t0:

	Max Needs	Current Holding	Available
P0	10	5	
P1	4	2	3
P2	9	2	

➔ <P1, P0, P2> is a safe sequence

1. P1 satisfies its allocation with 3 available resources

Safe State with Safe Sequence

- There are 12 tape drives
- Assuming at t0:

	Max Needs	Current Holding	Available
P0	10	5	5
P1	4	0	
P2	9	2	

➔ <P1, P0, P2> is a safe sequence

1. P1 satisfies its allocation with 3 available resources
2. P0 satisfies its allocation with 5 available resources

Safe State with Safe Sequence

- There are 12 tape drives
- Assuming at t0:

	Max Needs	Current Holding	Available
P0	10	0	
P1	4	0	
P2	9	2	10

➔ <P1, P0, P2> is a safe sequence

1. P1 satisfies its allocation with 3 available resources
2. P0 satisfies its allocation with 5 available resources
3. P2 satisfies its allocation with 10 available resources

Un-Safe State w/o Safe Sequence

- Assuming at t1:

	Max Needs	Current Holding	Available
P0	10	5	
P1	4	2	2
P2	9	~~2~~ 3	

if P2 requests & is allocated 1 more tape drive

➔No safe sequence exist…

➔ this allocation enters the system into an unsafe state

- A request is only granted if the allocation leaves the system in a safe state

Banker's Algorithm

- Use for multiple instances of each resource type
- Banker algorithm:
  - Use a general safety algorithm to pre-determine if any safe sequence exists after allocation
  - Only proceed the allocation if safe sequence exists
- Safety algorithm:
  1. Assume processes need maximum resources
  2. Find a process that can be satisfied by free resources
  3. Free the resource usage of the process
  4. Repeat to step 2 until all processes are satisfied

Banker's Algorithm Example (Safety Algo.)

- Total instances: A:10, B:5, C:7
- Available instances: A:3, B:3, C:2

	Max			Allocation			Need(Max.-Alloc.)		
	A	B	C	A	B	C	A	B	C
P0	7	5	3	0	1	0	7	4	3
P1	3	2	2	2	0	0	1	2	2
P2	9	0	2	3	0	2	6	0	0
P3	2	2	2	2	1	1	0	1	1
P4	4	3	3	0	0	2	4	3	1

- Safe sequence: P1

Banker's Algorithm Example (Safety Algo.)

- Total instances: A:10, B:5, C:7
- Available instances: A:5, B:3, C:2

	Max			Allocation			Need(Max.-Alloc.)		
	A	B	C	A	B	C	A	B	C
P0	7	5	3	0	1	0	7	4	3
P1	3	2	2	2	0	0	1	2	2
P2	9	0	2	3	0	2	6	0	0
P3	2	2	2	2	1	1	0	1	1
P4	4	3	3	0	0	2	4	3	1

- Safe sequence: P1, P3

Banker's Algorithm Example (Safety Algo.)

- Total instances: A:10, B:5, C:7
- Available instances: A:7, B:4, C:3

	Max			Allocation			Need(Max.-Alloc.)		
	A	B	C	A	B	C	A	B	C
P0	7	5	3	0	1	0	7	4	3
P1	3	2	2	2	0	0	1	2	2
P2	9	0	2	3	0	2	6	0	0
P3	2	2	2	2	1	1	0	1	1
P4	4	3	3	0	0	2	4	3	1

- Safe sequence: P1, P3, P4

Banker's Algorithm Example (Safety Algo.)

- Total instances: A:10, B:5, C:7
- Available instances: A:7, B:4, C:5

	Max			Allocation			Need(Max.-Alloc.)		
	A	B	C	A	B	C	A	B	C
P0	7	5	3	0	1	0	7	4	3
P1	3	2	2	2	0	0	1	2	2
P2	9	0	2	3	0	2	6	0	0
P3	2	2	2	2	1	1	0	1	1
P4	4	3	3	0	0	2	4	3	1

- Safe sequence: P1, P3, P4, P2

Banker's Algorithm Example (Safety Algo.)

- Total instances: A:10, B:5, C:7
- Available instances: A:10, B:4, C:7

	Max			Allocation			Need(Max.-Alloc.)		
	A	B	C	A	B	C	A	B	C
P0	7	5	3	0	1	0	$\boxed{7}$	$\boxed{4}$	$\boxed{3}$
P1	3	2	2	2	0	0	1	2	2
P2	9	0	2	3	0	2	6	0	0
P3	2	2	2	2	1	1	0	1	1
P4	4	3	3	0	0	2	4	3	1

- Safe sequence: P1, P3, P4, P2, P0

Banker's Algorithm Example

- Total instances: A:10, B:5, C:7
- Available instances: A:3, B:3, C:2

	Max			Allocation			Need(Max-Alloc)		
	A	B	C	A	B	C	A	B	C
P0	7	5	3	0	1	0	7	4	3
P1	3	2	2	2	0	0	1	2	2
P2	9	0	2	3	0	2	6	0	0
P3	2	2	2	2	1	1	0	1	1
P4	4	3	3	0	0	2	4	3	1

- If Request (P1) = (1, 0, 2): P1 allocation ➔ 3, 0, 2
  - Enter another safe state (Safe sequence: P1, P3, P4, P0, P2)
- If Request (P4) = (3, 3, 0): P4 allocation ➔ 3, 3, 2
  - enter into an unsafe state (no safe sequence can be found!)

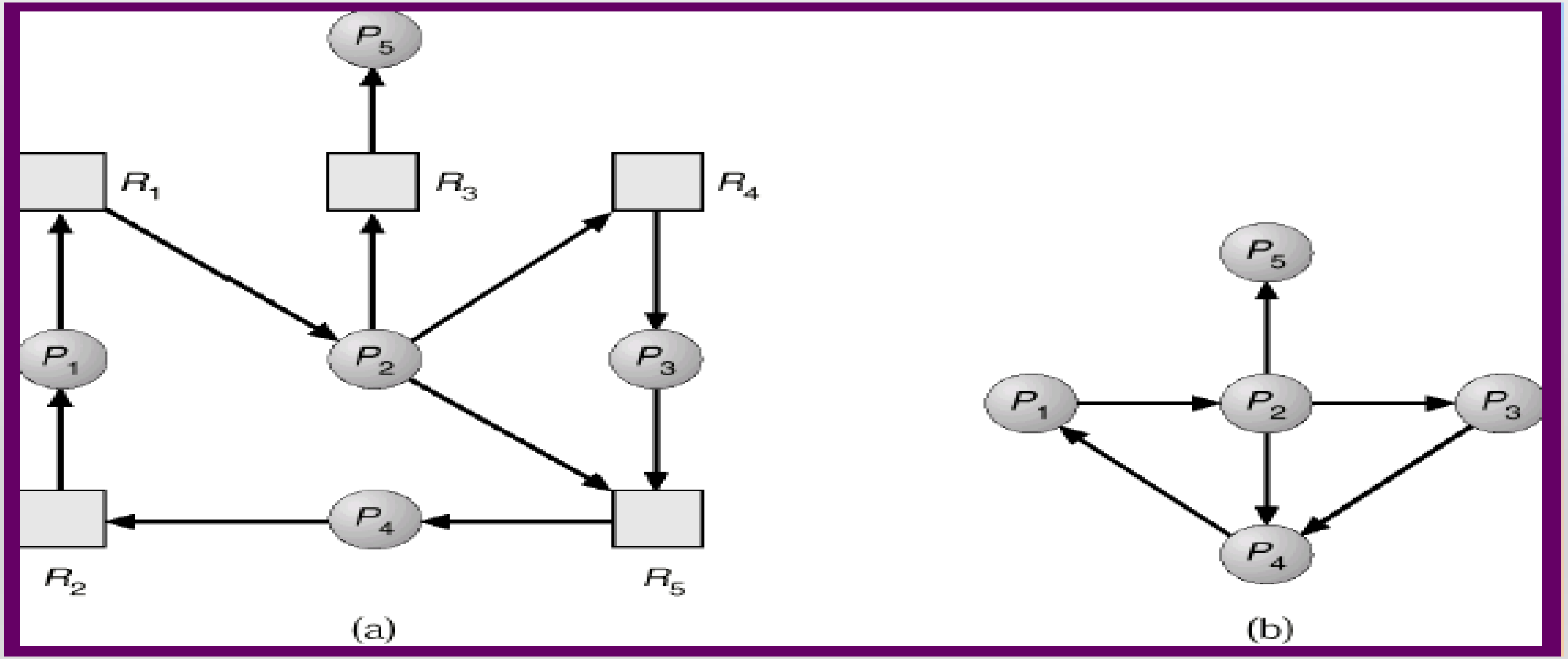
Review Slides (II)

- deadlock prevention methods?
  - mutual exclusion
  - hold & wait
  - no preemption
  - circular wait
- deadlock avoidance methods?
  - safe state definition?
  - safe sequence?
  - claim edge?

Deadlock Detection & Deadlock Recovery

Deadlock Detection

- Single instance of each resource type
    - convert request/assignment edges into wait-for graph
    - deadlock exists if there is a cycle in the wait-for graph



Resource-Allocation Graph

Corresponding wait-for graph

Multiple-Instance for Each Resource Type

- Total instances: A:7, B:2, C:6
- Available instances: A:0, B:0, C:0

	Allocation			Request		
	A	B	C	A	B	C
P0	0	1	0	0	0	0
P1	2	0	0	2	0	2
P2	3	0	3	0	0	0
P3	2	1	1	1	0	0
P4	0	0	2	0	0	2

- The system is in a safe state ➔ <P0, P2, P3, P1, P4> ➔ no deadlock
- If P2 request = <0, 0, 1> ➔ no safe sequence can be found ➔the system is deadlocked

Deadlock Recovery

- Process termination
  - abort all deadlocked processes
  - abort 1 process at a time until the deadlock cycle is eliminated
    - which process should we abort first?
- Resource preemption
  - select a victim: which one to preempt?
  - rollback: partial rollback or total rollback?
  - starvation: can the same process be preempted always?

Reading Material & HW

- Chap 7
- Problem Set
  - 7.6, 7.7, 7.8, 7.9, 7.12, 7.13

Q & A

Thank you for your attention