Operating Systems

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Lecture 6a

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Previously

Process Synchronisation

- Critical Section problem
- Synchronisation primitives:
  - Mutex, Semaphore, Monitor, Condition Variable, . . .
  - Transactional Memory
  - Message Passing

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Recap: Synchronisation primitives

Which synchronisation primitive would you use?

1. **Public transport rules**
   No more than the max. amount of people allowed enter a bus.
2. **Commissioning warehouse**
   Always put the same number of items in every box.
3. **Paying the parking fine**
   Customers get served individually in the order of their arrival.
4. **Occupied!**
   Only a single person can enter the bathroom at a time.
5. **Taking everyone onboard**
   A ship will only depart once all crew are back from land leave.
6. **Putting the cart before the horse**
   Before you can peel an egg you need to boil it first.

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Today

Deadlocks

- Deadlock conditions
- Methods of handling deadlocks

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Recap: Resources

Related operations

- Request: The process requests the resource. If the request cannot be granted immediately (for example, if the resource is being used by another process), then the requesting process must wait until it can acquire the resource.
- Use: The process can operate on the resource (for example, if the resource is a printer, the process can print on the printer).
- Release: The process releases the resource.

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Synchronisation and Priority Scheduling

Scenario

- Low-priority process **L** acquires resource **R**
- **L** is preempted by long-running medium-priority process **M**
- High-priority process **H** wants to acquire **R**, but is blocked
- **H** has to wait until **M** finishes before **L** can release **R**

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Problem: Priority inversion

- Higher priority process has to wait because lower priority process holds the resource it wants to access

Solution: Priority inheritance protocol

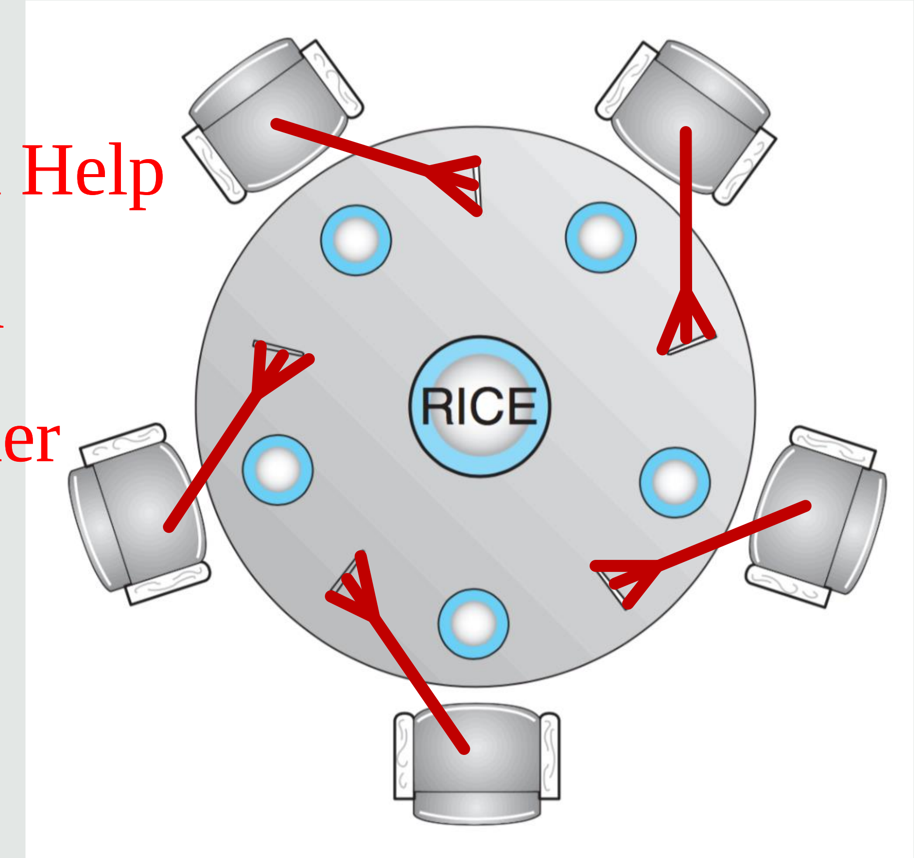
- Temporarily raise the priority of L to the maximum priority of all processes accessing the same resource
- Avoids priority inversion

Dining Philosophers Problem (Dijkstra 1965)

Rules

- The philosophers can either think or eat
- Each philosopher needs two chopsticks to eat
- They can pick up chopsticks from the left and the right as they become available

- How can we make sure they keep thinking and eating in turn, and no-one starves?



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Deadlocks

A set of processes is deadlocked if each process in the set is waiting for an event that only another process in the set can cause.

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Necessary and sufficient conditions:

- Mutual exclusion: Each resource is either currently assigned to exactly one process or is available.
- Hold-and-wait: Processes currently holding resources that were granted earlier can request new resources.
- No-preemption: Resources previously granted cannot be forcibly taken away from a process. They must be explicitly released by the process holding them.
- Circular wait: There must be a circular list of two or more processes, each of which is waiting for a resource held by the next member of the chain.

How do deal with deadlocks?

Unfortunately, there is no general solution.

- Deadlock prevention: Assignment Project Exam Help
  - Design the system so that at least one of the four conditions never arises.

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- Deadlock avoidance:

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  - Do not approve resource requests that might lead to a deadlock (Safety).
- Deadlock detection:
  - Always approve resource requests if resources are available.
  - Periodically check whether there is a deadlock.
  - If there is a deadlock, perform deadlock recovery.

Deadlock Prevention – Mutual Exclusion

System designed such that one of the four conditions never occurs

- Can we build a system with shared resource access not requiring mutual exclusion?

  No, it is always necessary to prevent race conditions

- General precautions:
  - Make any data resources read-only where there is no need for modification
  - Acquire only those resources that are really needed

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Deadlock Prevention – H&W and NP

- Hold-and-wait
  - Acquire all resources at once, i.e. block until all resources are available

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    + Process can execute once all required resources are held

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    - Long delays
    - Bad resource utilisation

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    - Advance knowledge needed about the resources required

- No-preemption

  (a) Process releases resources when it fails to acquire a resource, and re-tries later

  (b) Resource request forces another process to release a resource

  Only possible if the state of the resource can be saved and restored

Deadlock Prevention – Circular wait

- Enforce linear ordering of requests to resource types R_i
  e.g. O(disk drive) = 5, O(printer) = 12
- Process has to acquire all resources of type R_i at once

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- After having acquired R_i it can only request resources of type R_j where $O(R_j) > O(R_i)$

Does this prevent deadlocks? Yes

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- Assuming circular wait condition holds: Each process P_i of processes $P_0 \ldots P_{n-1}$ waits for resource R_i held by process $R_{(i+1) \bmod n}$
  - Our ordering ensures that for each **i** we have $O(R_i) < O(R_{(i+1) \bmod n})$
  - This would mean $O(R_0) < \ldots < O(R_{n-1}) < O(R_0)$
  - Impossible → circular wait condition does not hold

  However, there can be inefficiencies if ordering is poorly chosen

Deadlock Avoidance

Do not approve resource requests that might lead to a deadlock

- When do we know that the system is in a state that might lead to a deadlock?

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- Deadlock example with two processes:

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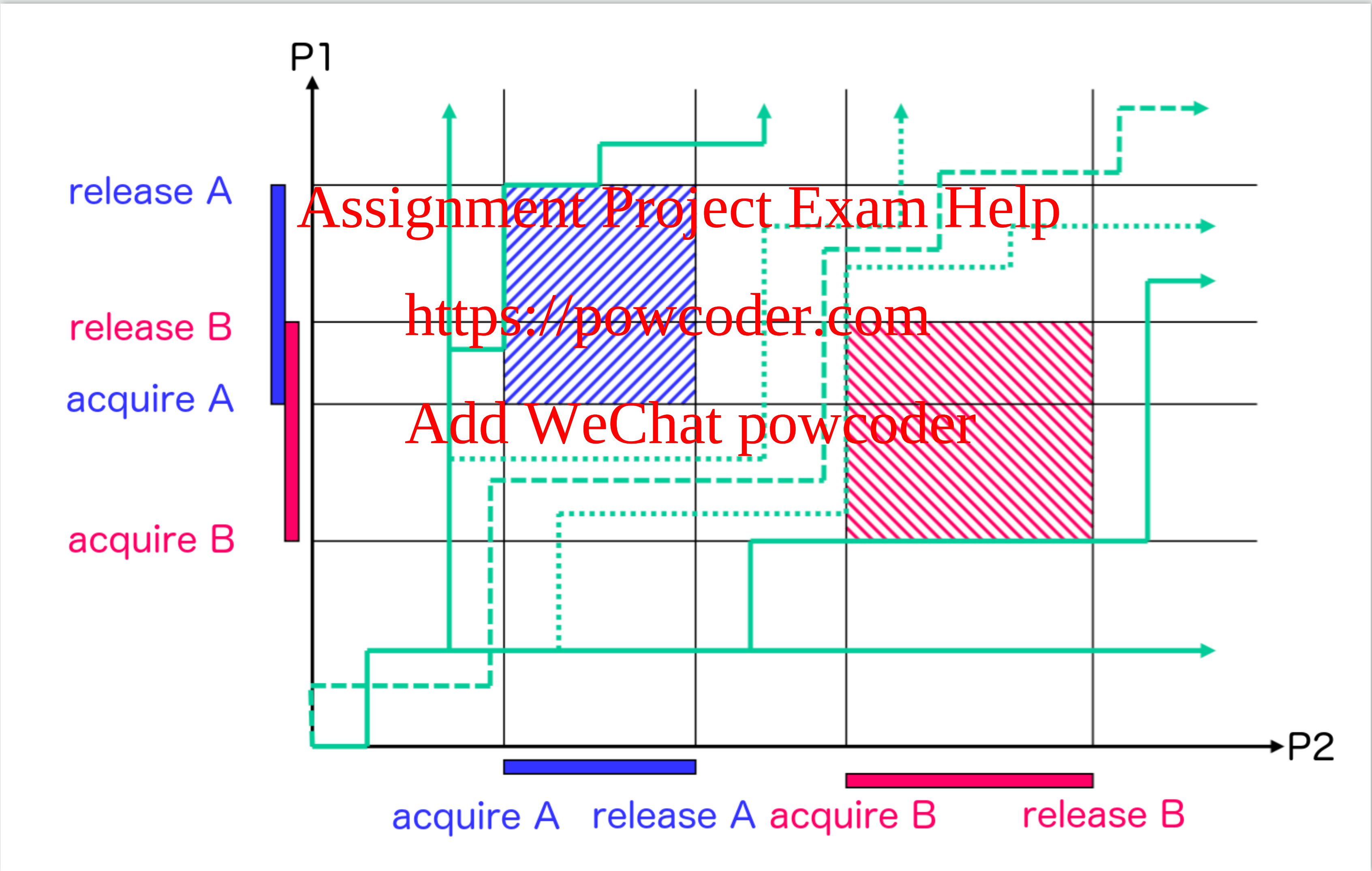
P1	P2
…	…
acquire B	acquire A
…	…
acquire A	release A
…	…
release B	acquire B
…	…
release A	release B
…	…

Resource Trajectories



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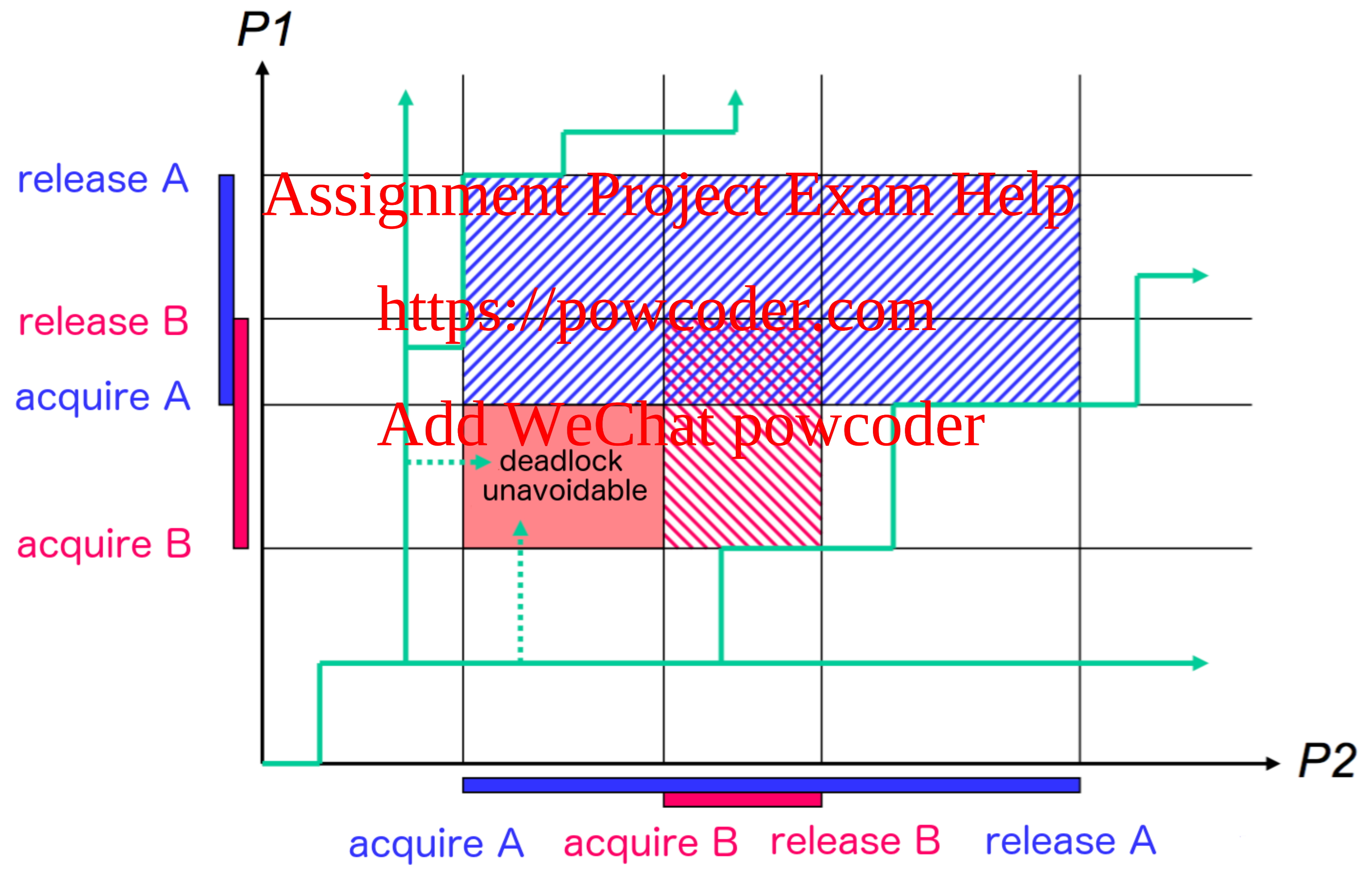
Resource Trajectories



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Safe and unsafe system states

- Deadlock or unavoidable-deadlock state
  - The system is deadlocked or it will be deadlocked on all trajectories.
- Unreachable state
  - No trajectory can reach such a state, e.g. because of mutual exclusion.
- Safe state:
  - All possible trajectories starting in a safe state are guaranteed to be deadlock-free
- Unsafe state:
  - Existing trajectories starting in unsafe state that lead to deadlock
  - Depends on scheduler

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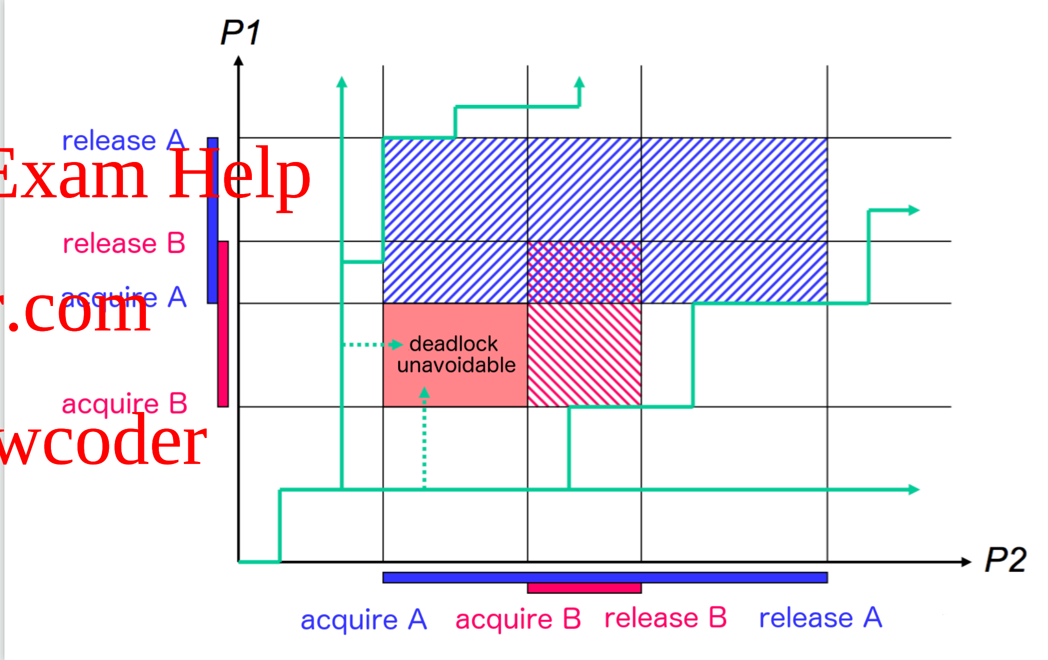

Banker's Algorithm

An algorithm for avoiding deadlocks

- There are `Available[j]` instances of each resource type R_j
- Each process P_i declares the maximum of instances `Maximum[i][j]` of each resource type R_j required
- `Allocation[i][j]` is the number of instances of resource type R_j held by process P_i

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Available		
R_0	R_1	R_2
3	3	2

Maximum			
	R_0	R_1	R_2
P_0	7	5	3
P_1	3	2	2
P_2	9	0	2
P_3	2	2	2
P_4	4	3	3

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	2	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Banker's Algorithm

An algorithm for avoiding deadlocks

- `Need[i][j] = Maximum[i][j] - Allocation[i][j]`

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Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	1	2	2
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

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Maximum			
	R_0	R_1	R_2
P_0	7	5	3
P_1	3	2	2
P_2	9	0	2
P_3	2	2	2
P_4	4	3	3

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Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	2	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Banker's Algorithm – Checking Safety

1. `Work := Available`
   `Finish[i] := false` for `i = 0 … n-1`
2. Find an index i such that `Finish[i] = false ^ Need[i] <= 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.

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Component-wise ordering on vectors:

`X <= Y` if for all i : `X[i] <= Y[i]`

Banker's Algorithm

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Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	2	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	1	2	2
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Finish	
P_0	false
P_1	false
P_2	false
P_3	false
P_4	false

Work		
R_0	R_1	R_2
3	3	2

Is there are process that can finish with the resources available (Work)?

Banker's Algorithm

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Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	2	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	1	2	2
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Finish	
P_0	false
P_1	false
P_2	false
P_3	false
P_4	false

Work		
R_0	R_1	R_2
3	3	2

Yes, P_1

Banker's Algorithm

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Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	0	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	0	0	0
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Finish	
P_0	false
P_1	true
P_2	false
P_3	false
P_4	false

Work		
R_0	R_1	R_2
5	3	2

Finish the process and then release all resources previously allocated to **P_1** , i.e. add previous allocation (2,0,0) to *Work* and set Finish = true

Banker's Algorithm

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	0	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	0	0	0
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Finish	
P_0	false
P_1	true
P_2	false
P_3	false
P_4	false

Work		
R_0	R_1	R_2
5	3	2

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Banker's Algorithm

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Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	0	0	0
P_2	3	0	2
P_3	0	0	0
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	0	0	0
P_2	6	0	0
P_3	0	0	0
P_4	4	3	1

Finish	
P_0	false
P_1	true
P_2	false
P_3	true
P_4	false

Work		
R_0	R_1	R_2
7	4	3

Banker's Algorithm

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	0	0	0
P_2	3	0	2
P_3	0	0	0
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	0	0	0
P_2	6	0	0
P_3	0	0	0
P_4	4	3	1

Finish	
P_0	false
P_1	true
P_2	false
P_3	true
P_4	false

Work		
R_0	R_1	R_2
7	4	3

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Banker's Algorithm

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Allocation			
	R_0	R_1	R_2
P_0	0	0	0
P_1	0	0	0
P_2	3	0	2
P_3	0	0	0
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	0	0	0
P_1	0	0	0
P_2	6	0	0
P_3	0	0	0
P_4	4	3	1

Finish	
P_0	true
P_1	true
P_2	false
P_3	true
P_4	false

Work		
R_0	R_1	R_2
7	5	3

Banker's Algorithm

Allocation

	R_0	R_1	R_2
P_0	0	0	0
P_1	0	0	0
P_2	3	0	2
P_3	0	0	0
P_4	0	0	2

Need

	R_0	R_1	R_2
P_0	0	0	0
P_1	0	0	0
P_2	6	0	0
P_3	0	0	0
P_4	4	3	1

Finish

P_0	true
P_1	true
P_2	false
P_3	true
P_4	false

Work

R_0	R_1	R_2
7	5	3

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Banker's Algorithm

- Safe!

Allocation			
	R_0	R_1	R_2
P_0	0	0	0
P_1	0	0	0
P_2	0	0	0
P_3	0	0	0
P_4	0	0	0

Need			
	R_0	R_1	R_2
P_0	0	0	0
P_1	0	0	0
P_2	0	0	0
P_3	0	0	0
P_4	0	0	0

Finish	
P_0	true
P_1	true
P_2	true
P_3	true
P_4	true

Work		
R_0	R_1	R_2
10	5	7

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Banker's Algorithm – Checking requests

`Request[i]` for process P_i

1. If `Request[i] <= Need[i]`, go to step 2.
   Otherwise, error (maximum exceeded).
2. If `Request[i] <= Available`, go to step 3.
   Otherwise, P_i must wait (resources not available).
3. Pretend to fulll request:

```
Available := Available - Request[i]
Allocation[i] := Allocation[i] + Request[i]
Need[i] := Need[i] - Request[i]
```

   Approve request if resulting state is safe.
   Otherwise, restore state and P_i has to wait.

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Banker's Algorithm – Checking requests

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	2	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	1	2	2
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Available		
R_0	R_1	R_2
3	3	2

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- Assume request `(1 0 2)` by P_1

Banker's Algorithm – Checking requests

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	2	0	0
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	1	2	2
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Available		
R_0	R_1	R_2
3	3	2

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- Assume request `(1 0 2)` by P_1

Request can be served

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	3	0	2
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	0	2	0
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Available		
R_0	R_1	R_2
2	3	0

Banker's Algorithm – Checking requests

Allocation			
	R_0	R_1	R_2
P_0	0	1	0
P_1	3	0	2
P_2	3	0	2
P_3	2	1	1
P_4	0	0	2

Need			
	R_0	R_1	R_2
P_0	7	4	3
P_1	0	2	0
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1

Available		
R_0	R_1	R_2
2	3	0

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- Assume request `(3 3 0)` by P_4

  Request cannot be granted (insufficient resources)

- Assume request `(0 2 0)` by P_0

  Request cannot be granted (would result in unsafe state)

Summary

Deadlocks

- Deadlock conditions:Assignment Project Exam Help
  - Mutual exclusion
  - Hold-and-wait
  - No preemption
  - Circular wait

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- Methods for handling deadlocks
  - Deadlock prevention
  - Deadlock avoidance
  - Deadlock detection and recovery (next lecture)

Read

- Tanenbaum & Bos., Modern Operating Systems
  - Chapter 6
- Silberschatz et al., Operating System Concepts
  - Chapter 7

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Next Lecture

- Introduction
- Operating System Architectures
- Processes
- Threads - Programming
- Process Scheduling - Evaluation
- Process Synchronisation
- **Deadlocks (continued)**
- Memory Management
- File Systems
- Input / Output
- Security and Virtualisation

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