CSE 421/521 - Operating Systems
Fall 2018

Lecture - XI
Deadlocks - II

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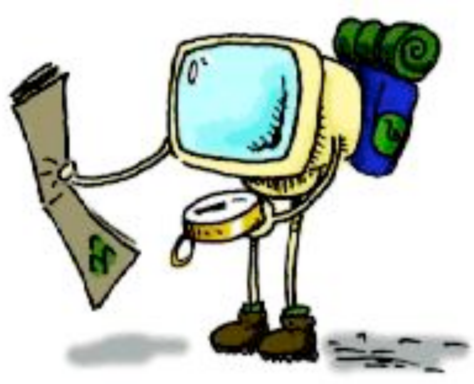
October 2nd, 2018

Roadmap

- Deadlocks
  - Deadlock Detection
  - Deadlock Recovery
  - Deadlock Avoidance

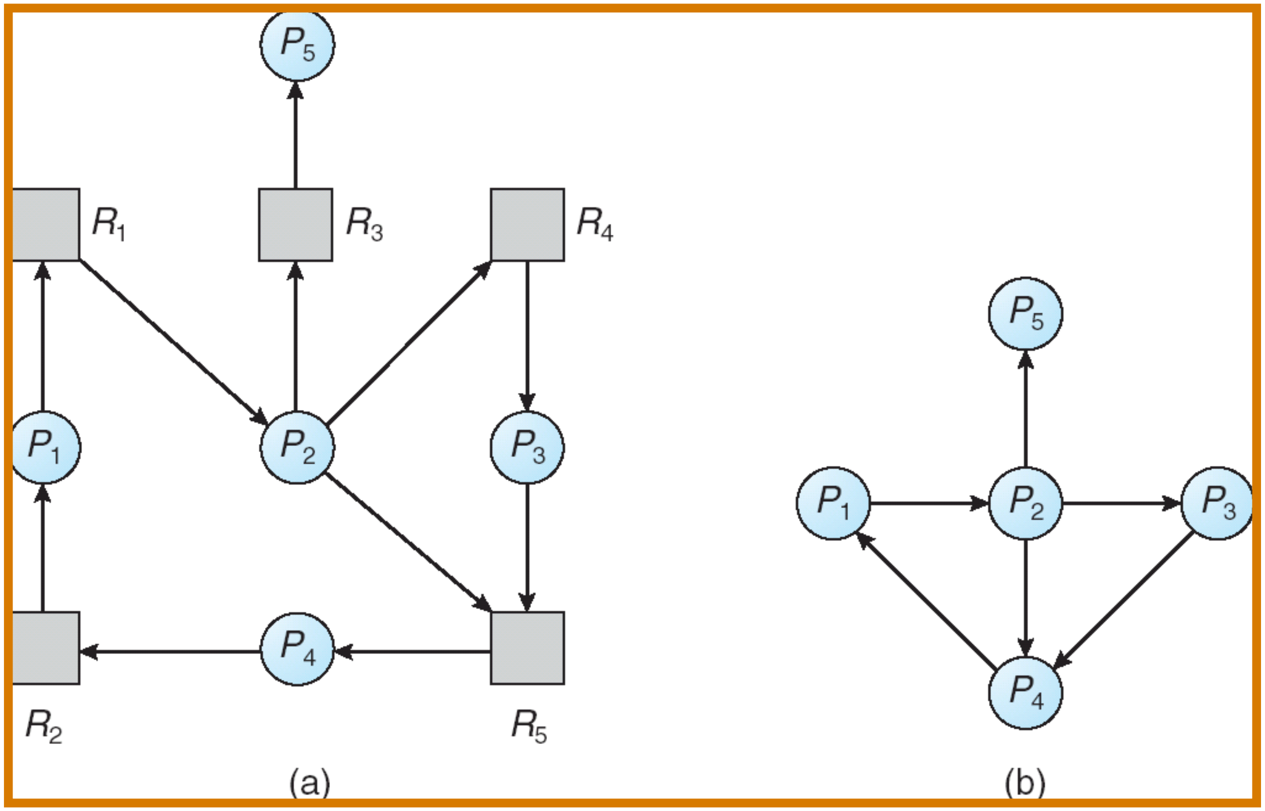


Deadlock Detection

- 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.



Resource-Allocation Graph Corresponding wait-for graph

Single Instance of Each Resource Type

- Periodically invoke an algorithm that searches for a cycle in the 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.
- Only good for single-instance resource allocation systems.

Several Instances of a Resource Type

- *Available:* A vector of length *m* indicates the number of available resources of each type.

- *Allocation:* An *n* x *m* matrix defines the number of resources of each type currently allocated to each process.

- *Request:* An *n* x *m* matrix indicates the current request of each process. If *Request* $[i_j] = k$, then process P_i is requesting *k* more instances of resource type. R_j.

Detection Algorithm

1. Let *Work* and *Finish* be vectors of length *m* and *n*, respectively Initialize:
   (a) *Work* = *Available*
   (b) For *i* = 0,1, 2, …, *n-1*, *Finish*[i] = false.

2. Find an index *i* such that both:
   (a) *Finish*[*i*] == *false*
   (b) $Request_i \leq Work$

   If no such *i* exists, go to step 4.

Detection Algorithm (Cont.)

3. $Work = Work + Allocation_i$
   $Finish[i] = true$
   go to step 2.

4. If $Finish[i]$ == false, for some i, $0 \leq i \leq n-1$, then the system is in deadlock state. Moreover, if $Finish[i]$ == *false*, then P_i is deadlocked.

Algorithm requires an order of O(m x n^2) operations to detect whether the system is in deadlocked state.

Example of Detection Algorithm

- Five processes P_0 through P_4; three resource types A (7 instances), *B* (2 instances), and *C* (6 instances).
- Snapshot at time T_0:

	Allocation	*Request*	*Available*	*Work*
	A B C	*A B C*	*A B C*	*A B C*
P_0	0 1 0	0 0 0	0 0 0	0 0 0
P_1	2 0 0	2 0 2		
P_2	3 0 3	0 0 0		
P_3	2 1 1	1 0 0		
P_4	0 0 2	0 0 2		

- Sequence <P_0, P_2, P_3, P_1, P_4> will result in *Finish*[*i*] = true for all *i*.

Example (Cont.)

- P_2 requests an additional instance of type C.

	Allocation	*Request*	*Available*	*Work*
	A B C	*A B C*	*A B C*	*A B C*
P_0	0 1 0	0 0 0	0 0 0	0 0 0
P_1	2 0 0	2 0 2		
P_2	3 0 3	0 0 1		
P_3	2 1 1	1 0 0		
P_4	0 0 2	0 0 2		

- State of system?
  - Can reclaim resources held by process P_0, but insufficient resources to fulfill other processes; requests.
  - Deadlock exists, consisting of processes P_1, P_2, P_3, and P_4.

Recovery from Deadlock: Process Termination

- Abort all deadlocked processes. --> expensive

- Abort one process at a time until the deadlock cycle is eliminated. --> overhead of deadlock detection alg.

- In which order should we choose to abort?
  - Priority of the process.
  - How long process has computed, and how much longer to completion.
  - Resources the process has used.
  - Resources process needs to complete.
  - How many processes will need to be terminated.
  - Is process interactive or batch?

Recovery from Deadlock: Resource Preemption

- Selecting a victim – minimize cost.
- Rollback – 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.

Deadlock Avoidance

Deadlock Prevention: prevent deadlocks by restraining resources and making sure one of 4 necessary conditions for a deadlock does not hold. (system design)

--> possible side effect: low device utilization and reduced system throughput

Deadlock Avoidance: Requires that the system has some additional *a priori* information available. (dynamic request check)

i.e. request disk and then printer..

or request at most n resources

--> allows more concurrency

- **Similar to the difference between a traffic light and a police officer directing the traffic!**

Deadlock Avoidance

- 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

- A state is **safe** if the system can allocate resources to each process (upto its maximum) in some order and can still avoid a deadlock.
- When a process requests an available resource, system must decide if immediate allocation leaves the system in a safe state.
- System is in safe state if there exists a **safe sequence** of all processes.

Safe State

- Sequence $<P_1, P_2, \ldots, P_n>$ is safe if for each P_i, the resources that P_i can still request can be satisfied by currently available resources + resources held by all the P_j, with $j<i$.
  - 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.
- If no such sequence exists, the state is **unsafe!**

Example of Safe State

- Five processes P_0 through P_4; three resource types A (7 instances), *B* (2 instances), and *C* (6 instances).
- Snapshot at time T_0:

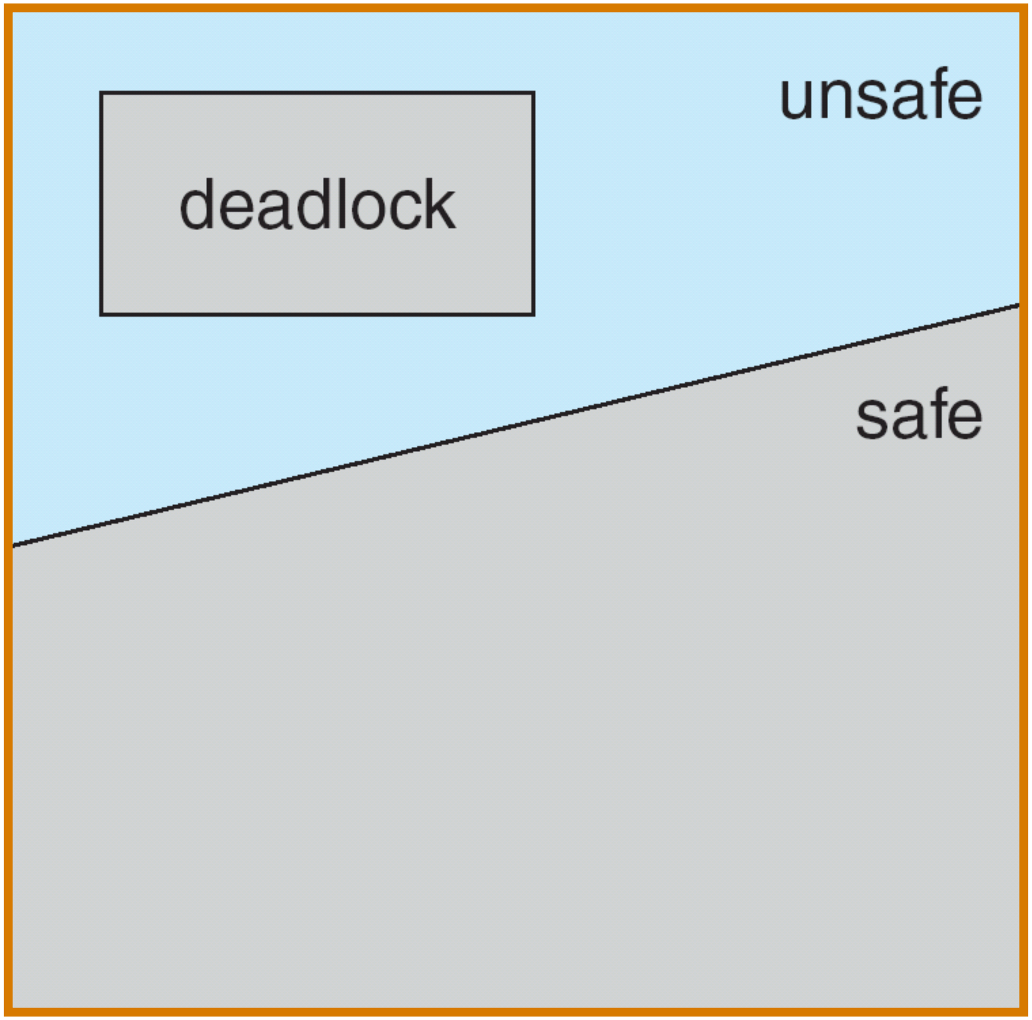
	Allocation	*Request*	*Available*	*Work*
	A B C	*A B C*	*A B C*	*A B C*
P_0	0 1 0	0 0 0	0 0 0	0 0 0
P_1	2 0 0	2 0 2		
P_2	3 0 3	0 0 0		
P_3	2 1 1	1 0 0		
P_4	0 0 2	0 0 2		

- Sequence <P_0, P_2, P_3, P_1, P_4> represents a safe state

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



Example

Consider a system with 3 processes and 12 disks.

At t = t0;

	Maximum Needs	Current Allocation
P1	10	5
P2	4	2
P3	9	2

Example *(cont.)*

Consider a system with 3 processes and 12 disks.

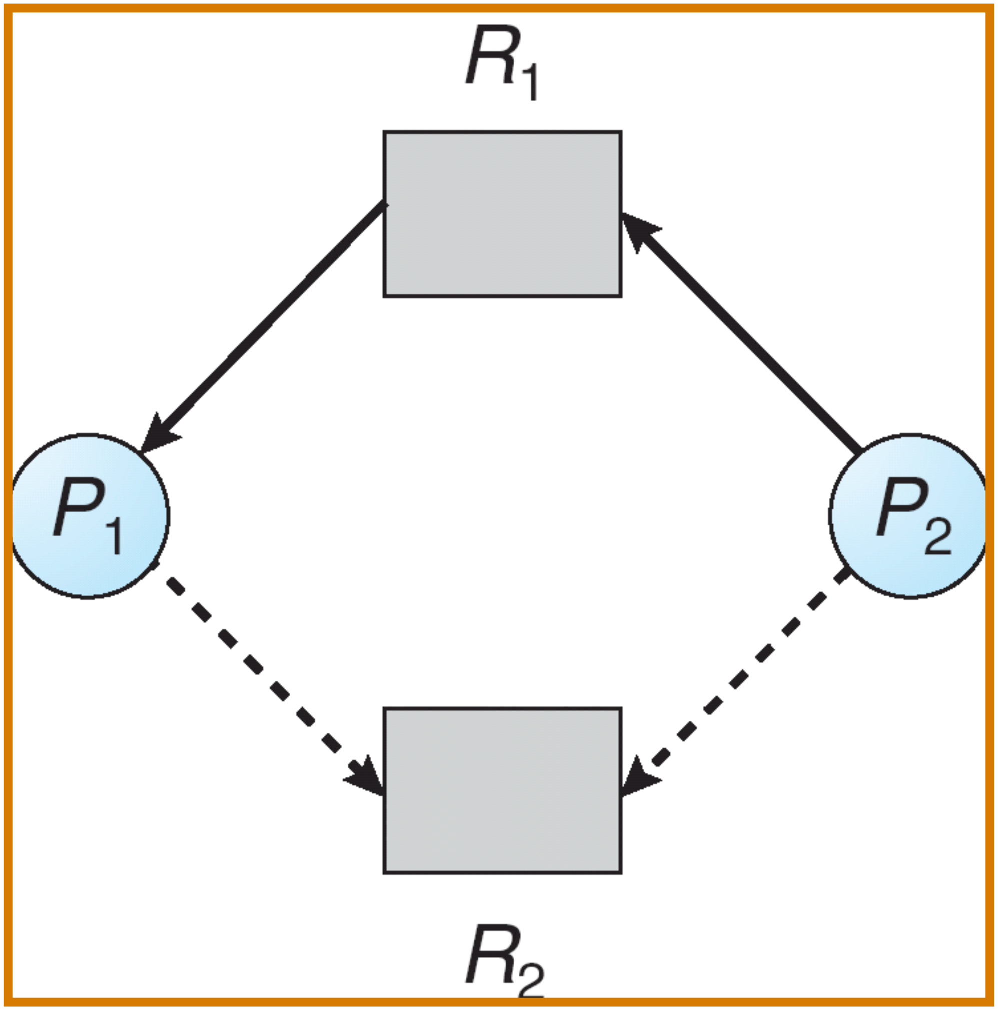
At t = t1;

	Maximum Needs	Current Allocation
P1	10	5
P2	4	2
P3	9	3

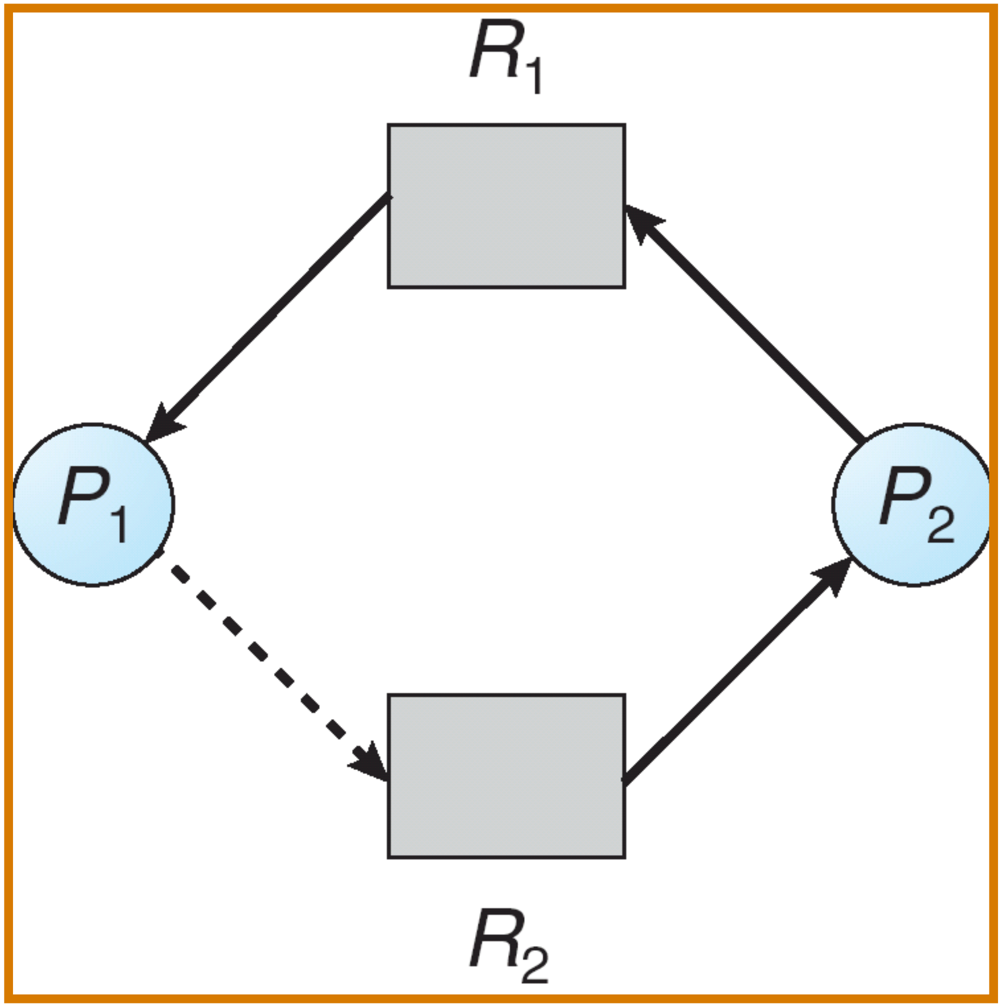
Resource-Allocation Graph Algorithm

- *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.
- When a resource is released by a process, assignment edge reconverts to a claim edge.
- If a new allocation results in a cycle in the graph (unsafe state), we cannot allow that allocation.
- Resources must be claimed *a priori* in the system.

Resource-Allocation Graph For Deadlock Avoidance



Unsafe State In Resource-Allocation Graph



Banker's Algorithm

- Works for multiple resource instances.
- Each process declares maximum # of resources it may need.
- When a process requests a resource, it may have to wait if this leads to an unsafe state.
- When a process gets all its resources it must return them in a finite amount of time.

Data Structures for the Banker's Algorithm

Let n = number of processes, and m = number of resources types.

- *Available*: Vector of length m. If available $[j]$ = k, there are k instances of resource type R_j available.
- *Max:* n x m matrix. If *Max* $[i,j] = k$, then process P_i may request at most k instances of resource type R_j.
- *Allocation:* n x m matrix. If Allocation$[i,j] = k$ then P_i is currently allocated k instances of R_j.
- *Need:* n x m matrix. If *Need*$[i,j] = k$, then P_i may need k more instances of R_j to complete its task.

$$Need\ [i,j] = Max[i,j] - Allocation\ [i,j].$$

Safety Algorithm

1. Let *Work* and *Finish* be vectors of length *m* and *n*, respectively. Initialize:

   Work = *Available*

   Finish [*i*] = *false* for *i* = 1,2, …, *n*.

2. Find an *i* such that both:

   (a) *Finish* [*i*] = *false*

   (b) $Need_i \leq Work$

   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.

Resource-Request Algorithm for Process P_i

Let Request$_i$ be the request vector for process P_i.

If *Request$_i$* [j] = k then process P_i wants k instances of resource type R_j.

1. If *Request$_i$* ≤ *Need$_i$* go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim.
2. If *Request$_i$* ≤ *Available*, go to step 3. Otherwise P_i must wait, since resources are not available.
3. Pretend to allocate requested resources to P_i by modifying the state as follows:

   Available = Available - Request$_i$;

   Allocation$_i$ = Allocation$_i$ + Request$_i$;

   Need$_i$ = Need$_i$ – Request$_i$;

- *If safe ⇒ the resources are allocated to Pi.*
- *If unsafe ⇒ Pi must wait, and the old resource-allocation state is restored*

Example of Banker's Algorithm

- 5 processes P_0 through P_4; 3 resource types:
  A (10 instances), *B* (5 instances), and *C* (7 instances).
- Snapshot at time T_0:

	Allocation	*Max*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 5 3	3 3 2
P_1	2 0 0	3 2 2	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

Example of Banker's Algorithm

- The content of the matrix. Need is defined to be Max – Allocation.

	Need
	A B C
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

Example of Banker's Algorithm

- Snapshot at time T_0:

	Allocation	Max	Available	*Need*
	A B C	A B C	A B C	*A B C*
P_0	0 1 0	7 5 3	3 3 2	7 4 3
P_1	2 0 0	3 2 2		1 2 2
P_2	3 0 2	9 0 2		6 0 0
P_3	2 1 1	2 2 2		0 1 1
P_4	0 0 2	4 3 3		4 3 1

Example of Banker's Algorithm

- Snapshot at time T_0:

	Allocation	Max	Available	*Need*
	A B C	A B C	A B C	*A B C*
P_0	0 1 0	7 5 3	3 3 2	7 4 3
P_1	2 0 0	3 2 2		1 2 2
P_2	3 0 2	9 0 2		6 0 0
P_3	2 1 1	2 2 2		0 1 1
P_4	0 0 2	4 3 3		4 3 1

- The system is in a safe state since the sequence < P_1, P_3, P_4, P_2, P_0> satisfies safety criteria.

Example: P_1 Requests (1,0,2)

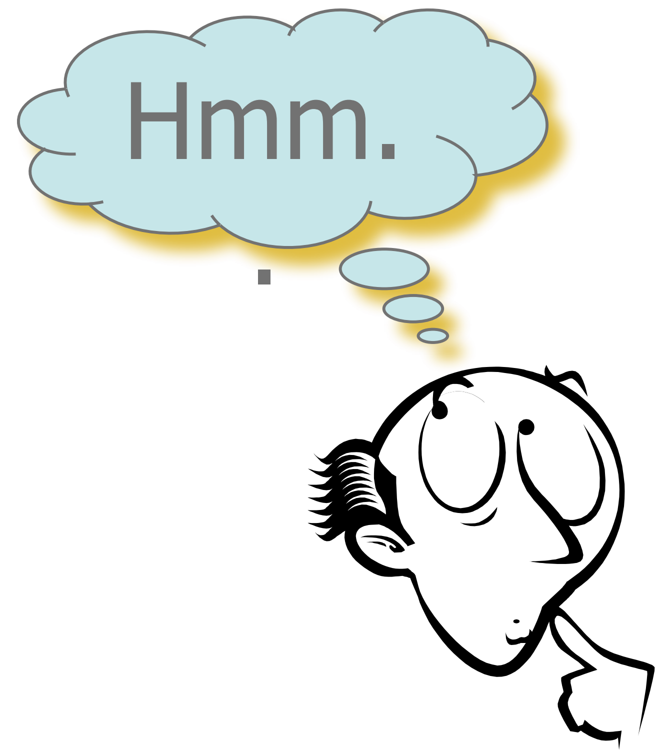
- Check that Request ≤ Available (that is, (1,0,2) ≤ (3,3,2) ⇒ true.

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	2 3 0
P_1	3 0 2	0 2 0	
P_2	3 0 1	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence <P1, P3, P4, P0, P2> satisfies safety requirement.
- Can request for (3,3,0) by P4 be granted?
- Can request for (0,2,0) by P0 be granted?

Summary

- Deadlocks
  - Deadlock Prevention
  - Deadlock Detection
  - Deadlock Recovery
  - Deadlock Avoidance



Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
- R. Doursat and M. Yuksel from UNR