CSE 421/521 - Operating Systems
Fall 2011

LECTURE - XII
DEADLOCKS &
MAIN MEMORY MANAGEMENT

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Roadmap

- Deadlocks
  - Resource Allocation Graphs
  - Deadlock Detection
  - Deadlock Prevention
  - **Deadlock Avoidance**
  - **Deadlock Recovery**
- Main Memory Management

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.

Example

P1:	**P2:**
Request Disk	Request Printer
Request Printer	Request Disk
....	....
Release Printer	Release Disk
Release Disk	Release Printer

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.

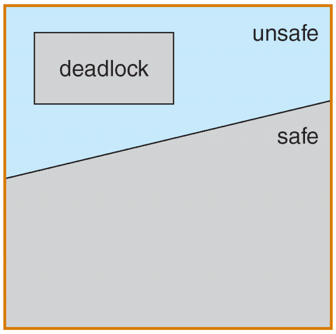
Safe State

- Sequence <P_1, P_2, …, 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!**

Basic Facts

- If a system is in safe state ⇒ no deadlocks.
- If a system is in unsafe state ⇒ possibility of deadlock.
- Avoidance ⇒ 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.

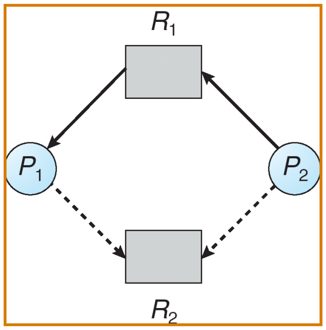
At t = t1;

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

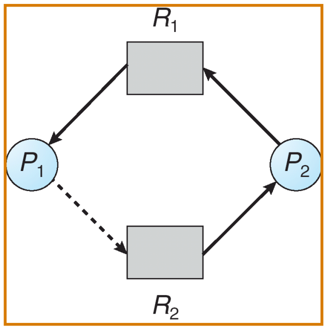
Resource-Allocation Graph Algorithm

- *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.
- 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) $Need_i \le Work$
   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 $Request_i \le Need_i$ go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim.
2. If $Request_i \le Available$, 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?

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?

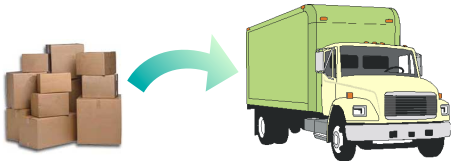
Recovery from Deadlock: Resource Preemption

- 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.

Main Memory Management

Memory Management Requirements

- **The O/S must fit multiple processes in memory**
  - ✓ memory needs to be subdivided to accommodate multiple processes
  - ✓ memory needs to be allocated to ensure a reasonable supply of ready processes so that the CPU is never idle
  - ✓ memory management is an **optimization** task under **constraints**



Fitting processes into memory is like fitting boxes into a fixed amount of space

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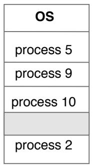
Memory Allocation

- Fixed-partition allocation
  - Divide memory into fixed-size partitions
  - Each partition contains exactly one process
  - The degree of multi programming is bound by the number of partitions
  - When a process terminates, the partition becomes available for other processes



OS

process 5

process 9

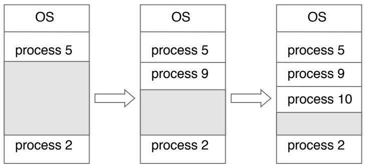
process 10

process 2

➔no longer in use

Memory Allocation (Cont.)

- Variable-partition Scheme (Dynamic)
  - When a process arrives, search for a hole large enough for this process
  - Hole - block of available memory; holes of various size are scattered throughout memory
  - Allocate only as much memory as needed
  - Operating system maintains information about: a) allocated partitions b) free partitions (hole)



Dynamic Storage-Allocation Problem

How to satisfy a request of size *n* from a list of free holes

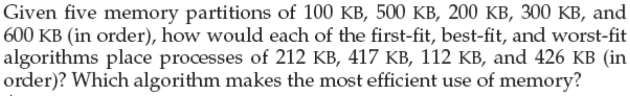
- **First-fit**: Allocate the *first* hole that is big enough
- **Best-fit**: Allocate the *smallest* hole that is big enough; must search entire list, unless ordered by size. Produces the smallest leftover hole.
- **Worst-fit**: Allocate the *largest* hole; must also search entire list. Produces the largest leftover hole.

First-fit is faster.

Best-fit is better in terms of storage utilization.

Worst-fit may lead less fragmentation.

Example


Given five memory partitions of 100 KB, 500 KB, 200 KB, 300 KB, and 600 KB (in order), how would each of the first-fit, best-fit, and worst-fit algorithms place processes of 212 KB, 417 KB, 112 KB, and 426 KB (in order)? Which algorithm makes the most efficient use of memory?

Summary

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Acknowledgements

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