


COS 318: Operating Systems

Deadlock

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(<http://www.cs.princeton.edu/courses/cos318/>)



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Today's Topics



- ◆ Conditions for deadlock
- ◆ Strategies to deal with deadlocks



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Definitions



- ◆ Use “processes” and “threads” interchangeably (1 thread per proc)
- ◆ Resource: a (passive) object that can be granted to a thread and that it needs to do its job
 - Preemptable: CPU, Memory (can be taken away from thread without harm)
 - Non-preemptable: files, mutex, CD recorder ... (can't just be taken away)
- ◆ Operations on a resource: Request, Use, Release
- ◆ Starvation: At least one thread waits forever for resource
- ◆ Deadlock: A set of processes have a deadlock if **every** process in the set is waiting for an event that only another process in the set can cause
- ◆ Livelock?
- ◆ In general, deadlock happens with non-preemptable resources
 - Or resource can be taken away and reallocated to alleviate deadlock



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Example from CPU Scheduling

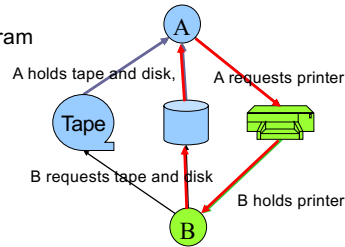
- ◆ T1 at priority 4, T2 at priority 1 and T2 holds lock L
- ◆ T1 needs lock, but for it to get lock T2 must release lock
- ◆ T2 needs to get on CPU to release lock
- ◆ But T2 does not get CPU until T1 gets lock and makes progress and gives up CPU, and T1 does not get lock until T2 gets CPU
- ◆ Introducing another thread T3 at priority 3 creates a less contrived situation



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Another Example

- ◆ A utility program
 - Copy a file from tape to disk
 - Print the file to printer
 - Two processes running program
- ◆ Resources
 - Tape
 - Disk
 - Printer
- ◆ A deadlock
 - A holds tape and disk,
 - B holds printer,
 - A requests for a printer
 - B requests for tape and disk

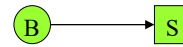
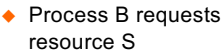
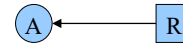


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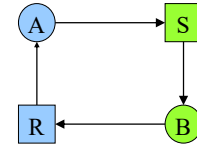
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Resource Allocation Graph

- ◆ Process A is holding resource R
- ◆ A requests S while holding R
- ◆ Process B requests resource S
- ◆ B requests R while holding S
- ◆ A cycle in resource allocation graph \Rightarrow deadlock



Example:



- ◆ B requests R while holding S
- ◆ A cycle in resource allocation graph \Rightarrow deadlock

How do you deal with multiple instances of a resource?



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Conditions for Deadlock

- ◆ Mutual exclusion condition
 - A resource is assigned to no more than one process at a time
- ◆ Hold and Wait
 - Processes holding resources can request new resources while continuing to hold the old resources
- ◆ No preemption
 - Resources cannot be taken away once obtained
- ◆ Circular chain of requests
 - One process waits for another in a circular fashion
- ◆ Question
 - Are all conditions necessary?

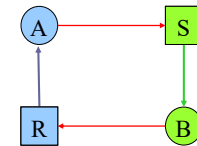


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Eliminate Competition for Resources?

- ◆ If run A to completion and then run B, there will be no deadlock
- ◆ Generalize this idea for all processes?
- ◆ Is this a good idea for CPU scheduling?



Previous example



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Strategies

- ◆ Ostrich Algorithm
- ◆ Detection and recovery
 - Fix the problem afterwards
- ◆ Dynamic avoidance
 - Careful allocation of resources to avoid deadlock
- ◆ Prevention
 - Negate one of the four conditions



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Ignore the Problem

- ◆ The OS kernel locks up
 - Reboot
- ◆ Device driver locks up
 - Remove the device
 - Restart
- ◆ An application hangs (“not responding”)
 - Terminate the application and restart
 - Familiar with this?
- ◆ An application runs for a while and then hangs
 - Checkpoint the application
 - Change the environment (reboot OS)
 - Restart from the previous checkpoint



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Detection and Recovery

- ◆ Detection
 - Scan resource graph
 - Detect cycles
- ◆ Recovery (difficult)
 - Terminate some process/threads (can you always do this?)
 - Roll back actions of deadlocked threads and retry
 - E.g. transactions: all operations are provisional until they have the required resources to complete operation
 - Roll back a process that holds a needed resource to its last checkpoint, releasing resources



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Deadlock Avoidance

- ◆ Always maintain Safety Condition when allocating resources:
 - Not currently deadlocked
 - There is some scheduling order in which every process can run to completion (even if all request their max resource needs at once)
- ◆ Banker's algorithm (Dijkstra 65)
 - Single resource type
 - Every process has a credit
 - Total resources may not satisfy all credits
 - Track resources assigned to and needed by each process
 - On every resource allocation, check for Safety Condition



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Examples (Single Resource Type)

Total: 8

	Has	Max		Has	Max		Has	Max		Has	Max		Has	Max
P ₁	2	6	P ₁	2	6	P ₁	2	6	P ₁	2	6	P ₁	2	6
P ₂	2	3	P ₂	3	3	P ₂	0	0	P ₂	0	0	P ₂	0	0
P ₃	3	5	P ₃	3	5	P ₃	3	5	P ₃	5	5	P ₃	0	0

Free: 1

Free: 0

Free: 3

Free: 1

Free: 6

	Has	Max
P ₁	4	6
P ₂	1	3
P ₃	2	5

Free: 1

?

- Multiple resource types
 - Two matrices: "allocated" and "needed"
- See textbook for details
- Can we all be bankers and go home?

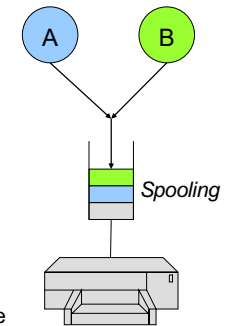


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Prevention: Avoid Mutual Exclusion

- ◆ Some resources are not physically sharable
 - Printer, tape, etc
- ◆ Some can be made sharable
 - Read-only files, memory, etc
 - Read/write locks
- ◆ Some can be virtualized by spooling
 - Use storage to virtualize a resource into multiple resources, thus eliminating the non-sharable (mutually exclusive) resource from the equation
- ◆ What about the tape-disk-printer example?
- ◆ Process doesn't have to wait for printer while another process is holding it
 - Move the problem to disk: much bigger



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Prevention: Avoid Hold and Wait

- ◆ Can't get all resources you need? Don't hold any
- ◆ Two-phase locking
 - Phase I:
 - Try to lock all resources at the beginning
 - Phase II:
 - If successful, use the resources and release them
 - Otherwise, release all resources and start over
- ◆ What about the tape-disk-printer example?



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Prevention: No Preemption

- ◆ Make the scheduler be aware of resource allocation
- ◆ Method
 - If the system cannot satisfy a request from a process holding resources, preempt the process and release all resources
 - Schedule it only if the system satisfies all resources
- ◆ Alternative
 - Preempt the process holding the requested resource
- ◆ Copying
 - Copying to a buffer to release the resource?
- ◆ What about the tape-disk-printer example?

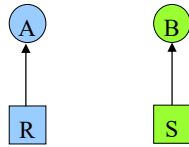


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Prevention: No Circular Wait

- ◆ Impose an order of requests for all resources
- ◆ Method
 - Assign a unique id to each resource
 - All requests must be in an ascending order of the ids
- ◆ A variation
 - Assign a unique id to each resource
 - No process requests a resource lower than what it is holding
- ◆ What about the tape-disk-printer example?



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Which Is Your Favorite?

- ◆ Ignore the problem
 - It is user's fault
- ◆ Detection and recovery
 - Fix the problem afterwards
- ◆ Dynamic avoidance
 - Careful allocation
- ◆ Prevention (Negate one of the four conditions)
 - Avoid mutual exclusion
 - Avoid hold and wait
 - No preemption
 - No circular wait

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In Practice

- ◆ Ignore the problem for applications
 - It is application developers' job to deal with their deadlocks
 - OS provides mechanisms to break applications' deadlocks
- ◆ Kernel should not have any deadlocks
 - Use prevention methods
 - Most popular is to apply no-circular-wait principle everywhere
- ◆ Other application examples
 - Routers for a parallel machine (typically use the no-circular-wait principle)
 - Process control in manufacturing

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Summary

- ◆ Deadlock conditions
 - Mutual exclusion
 - Hold and wait
 - No preemption
 - Circular chain of requests
- ◆ Strategies to deal with deadlocks
 - Simpler ways are to negate one of the four conditions

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