



COS 318: Operating Systems

Deadlocks

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



Today's Topics

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



Definitions

- ◆ Use processes and threads interchangeably
- ◆ Resources
 - Preemptable: CPU (can be taken away)
 - Non-preemptable: Disk, files, mutex, ... (can't be taken away)
- ◆ Operations with a resource
 - Request, Use, Release

More Definitions

◆ Starvation

- Processes wait indefinitely

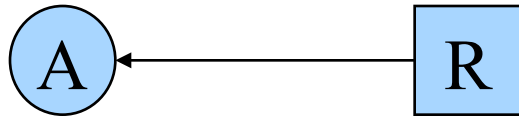
◆ Deadlock

- A set of processes have a deadlock if **each** process is waiting for an event that only another process in the set can cause

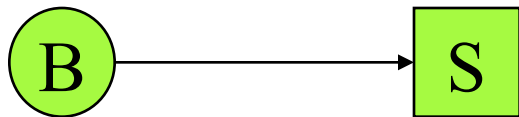


Resource Allocation Graph

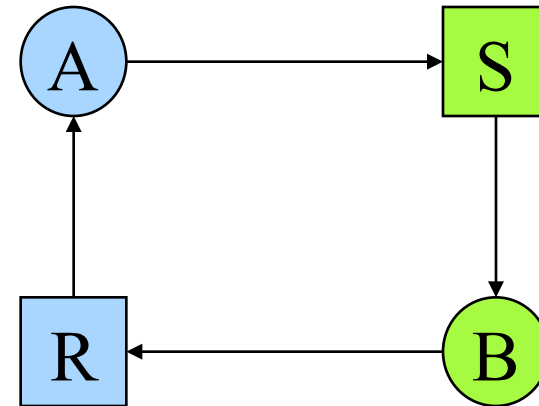
- ◆ Process A is holding resource R



- ◆ Process B requests resource S



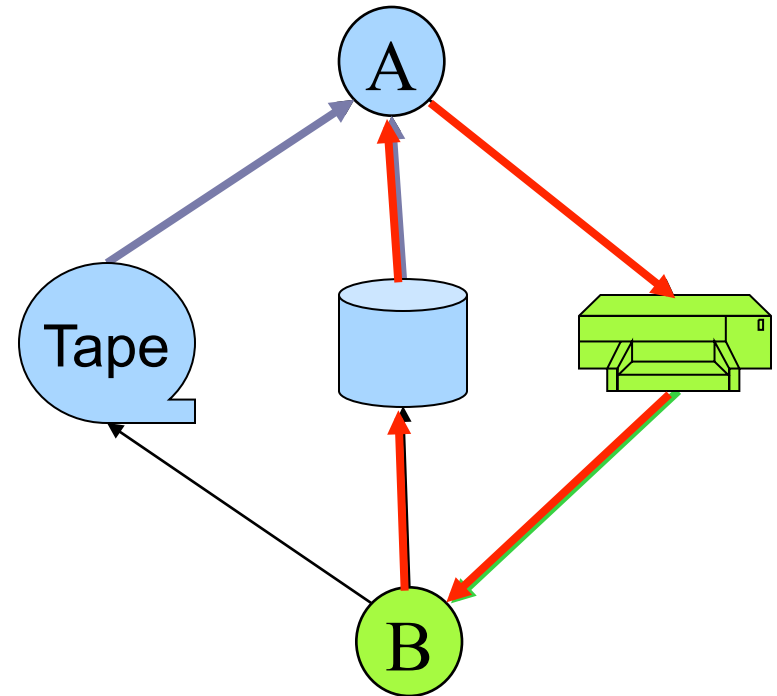
- ◆ A cycle in resource allocation graph \Rightarrow deadlock
- ◆ Example: A requests for S while holding R, and B requests for R while holding S, then



How do you deal with multiple instances of a resource?

An Example

- ◆ A utility program
 - Copy a file from tape to disk
 - Print the file to printer
- ◆ 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



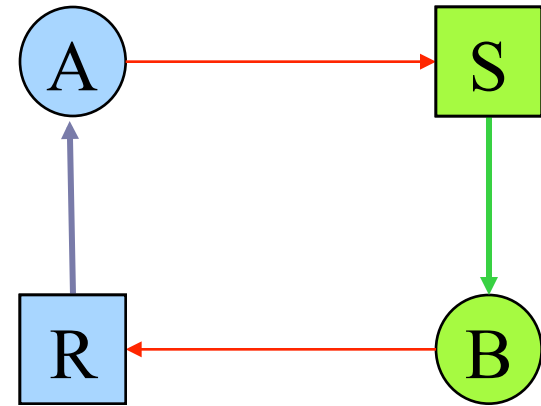
Conditions for Deadlock

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



Eliminate Competition for Resources?

- ◆ If running A to completion and then running B, there will be no deadlock
- ◆ Generalize this idea for all processes?
- ◆ Is it a good idea to develop a CPU scheduling algorithm that causes no deadlock?



Previous example

Strategies

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



Ignore the Problem

- ◆ The OS kernel locks up
 - Reboot
- ◆ Device driver locks up
 - Remove the device
 - Restart
- ◆ An application hangs (“not responding”)
 - Kill 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



Detection and Recovery

◆ Detection

- Scan resource graph
- Detect cycles

◆ Recovery (difficult)

- Kill process/threads (can you always do this?)
- Roll back actions of deadlocked threads



Avoidance

- ◆ Safety Condition:
 - It is not deadlocked
 - There is some scheduling order in which every process can run to completion (even if all request their max resources)

- ◆ Banker's algorithm (Dijkstra 65)
 - Single resource
 - Each process has a credit
 - Total resources may not satisfy all credits
 - Track resources assigned and needed
 - Check on each allocation for safety
 - Multiple resources
 - Two matrices: allocated and needed
 - See textbook for details



Examples (Single Resource)

Total: 8

	Has	Max
P ₁	2	6
P ₂	2	3
P ₃	3	5

Free: 1

	Has	Max
P ₁	2	6
P ₂	3	3
P ₃	3	5

Free: **0**

	Has	Max
P ₁	2	6
P ₂	0	0
P ₃	3	5

Free: **3**

	Has	Max
P ₁	2	6
P ₂	0	0
P ₃	5	5

Free: **1**

	Has	Max
P ₁	2	6
P ₂	0	0
P ₃	0	0

Free: **6**

	Has	Max
P ₁	4	6
P ₂	1	3
P ₃	2	5

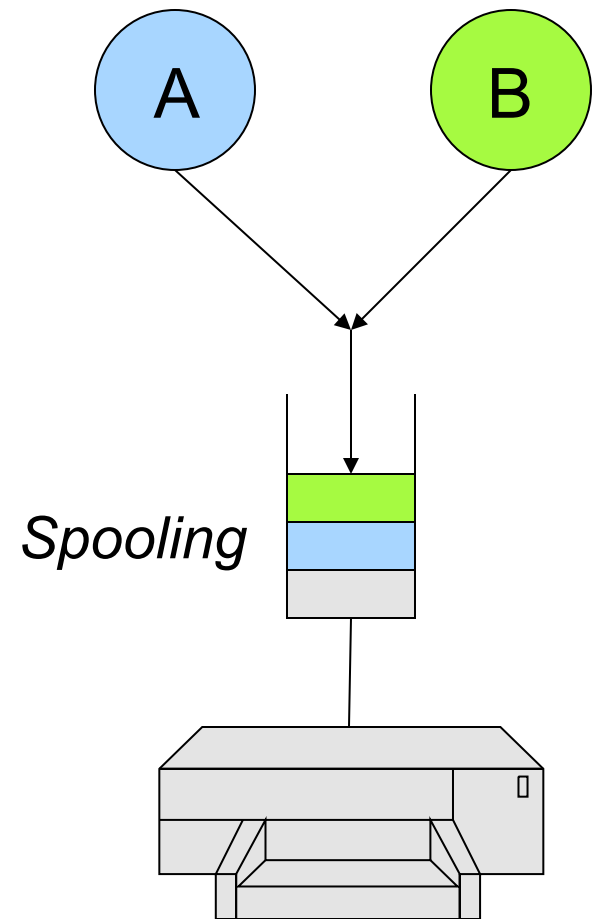
Free: 1

?



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
 - Use a queue to schedule
 - Does this apply to all resources?
- ◆ What about the tape-disk-printer example?



Prevention: Avoid Hold and Wait

◆ 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

◆ Application

- Telephone company's circuit switching

◆ What about the tape-disk-printer example?



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?



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?
- ◆ Can we prove that this method has no circular wait?



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



Tradeoffs and Applications

- ◆ 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



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

