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

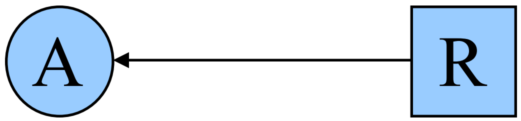
- Use processes and threads interchangeably
- Resources
  - Preemptible: CPU, Memory (can be taken away)
  - Non-preemptible: Disk, files, mutex, ... (can’t be taken away)
- Operations with a resource
  - Request, Use, Release

More Definitions

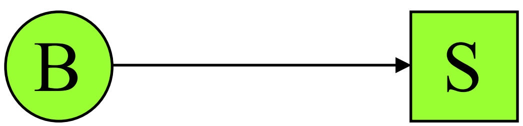
- Starvation
  - (Some) Processes wait indefinitely
- Deadlock
  - A set of processes have a deadlock if every process is waiting for an event that only another process in the set can cause

Resource Allocation Graph

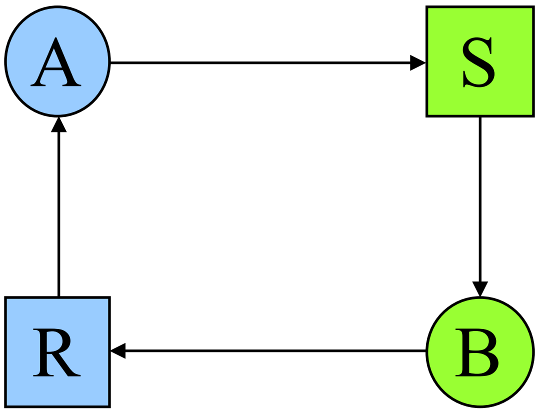
- Process A is holding resource R



- Process B requests resource S



- Example: A requests for S while holding R, and B requests for R while holding S, then

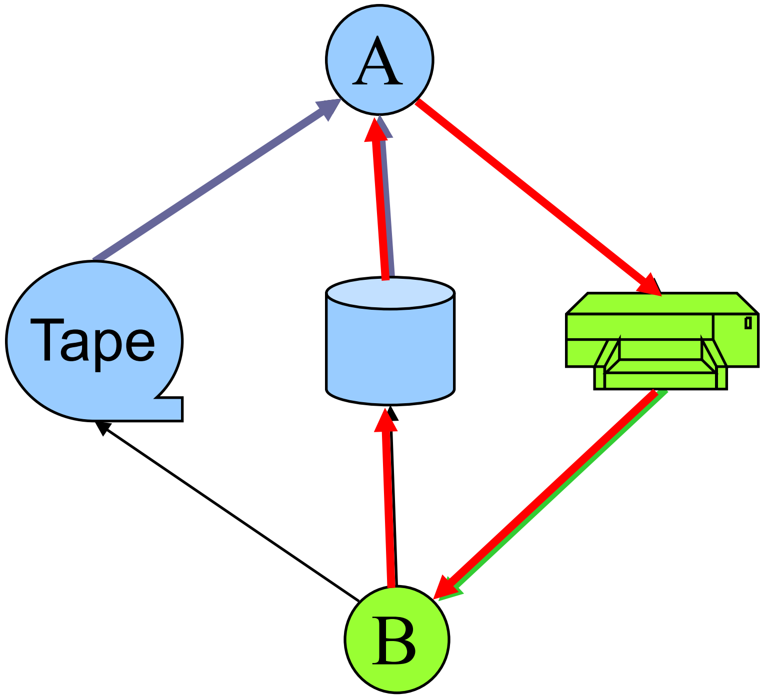


- A cycle in resource allocation graph $\Rightarrow$ deadlock

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



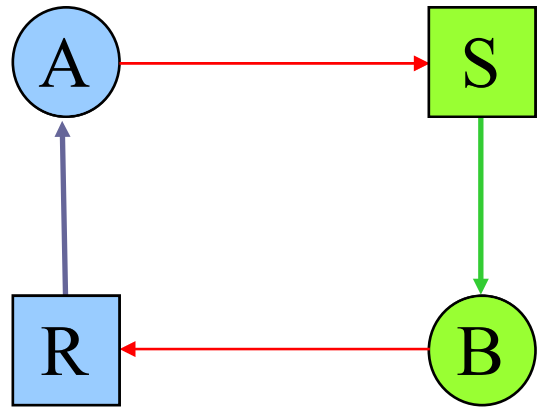
Conditions for Deadlock

- 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
  - 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**

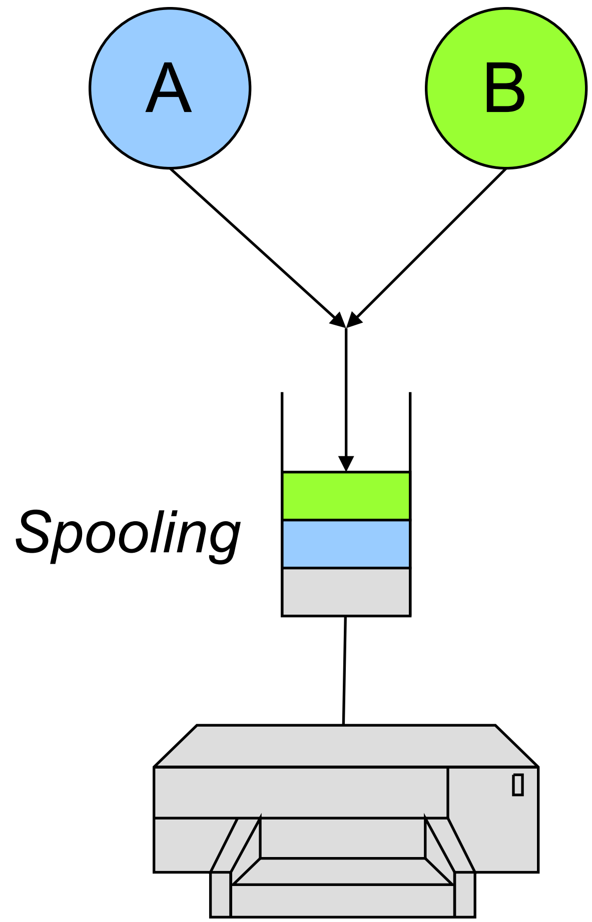
	Has	Max
P_1	4	6
P_2	1	3
P_3	2	5

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

- 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