COS 318: Operating Systems

Deadlocks

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http://www.cs.princeton.edu/courses/archive/fall13/cos318/

Today’s Topics

- Finish CPU scheduling algorithms
- Conditions for a deadlock
- Strategies to deal with deadlocks

4.3 BSD Scheduling with Multi-Queue

- "1 sec" preemption
  - Preempt if a process doesn't block or complete within 1 second
- Priority is recomputed every second
  - P_i = base + (CPU_{i-1}) / 2 + nice, where CPU_i = (U_i + CPU_{i-1}) / 2
  - Base is the base priority of the process
  - U_i is process utilization in interval i
- Priorities
  - Swapper
  - Block I/O device control
  - File operations
  - Character I/O device control
  - User processes

Linux Scheduling

- Time-sharing scheduling
  - Two priority arrays: active and expired
  - 40 priority levels, lower number = higher priority
  - Priority = base (user-set) priority + “bonus”
    - Bonus between -5 and +5, derived from *sleep_avg*
    - Bonus decremented when task sleeps, incremented when it runs
    - Higher priority gets longer timeslice
  - Move process with expired quantum from active to expired
  - When active array empty, swap active and expired arrays
- Real-time scheduling
  - 100 static priorities, higher than time sharing priorities
  - Soft real-time

Windows Scheduling

- Classes and priorities
  - Real time: 16 static priorities
  - User: 16 variable priorities, start at a base priority
    - If a process has used up its quantum, lower its priority
    - If a process waits for an I/O event, raise its priority
- Priority-driven scheduler
  - For real-time class, do round robin within each priority
  - For user class, do multiple queue
- Multiprocessor scheduling
  - For N processors, normally run N highest priority threads
  - Threads have hard or soft affinity for specific processors
  - A thread will wait for processors in its affinity set, if there are other threads available (for variable priorities)

Today's Topics

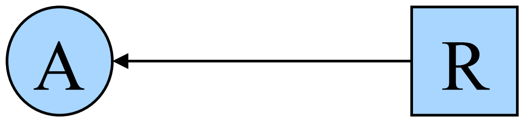
- Finish CPU scheduling algorithms
- Conditions for a deadlock
- Strategies to deal with deadlocks

Definitions

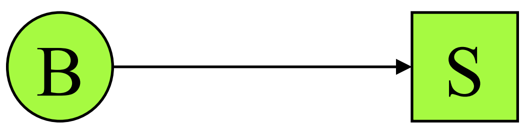
- Use processes and threads interchangeably
- Resources
  - Preemptable: CPU (can be taken away)
  - Non-preemptable: Disk, files, mutex, ... (can't be taken away)
- Use a resource
  - Request, Use, Release
- Starvation
  - Processes wait indefinitely
- Deadlocks
  - A set of processes have a deadlock 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

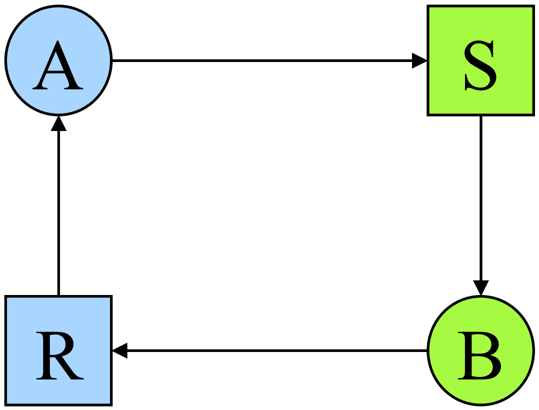


- Process B requests resource S



- A cycle in resource allocation graph ⇒ deadlock

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



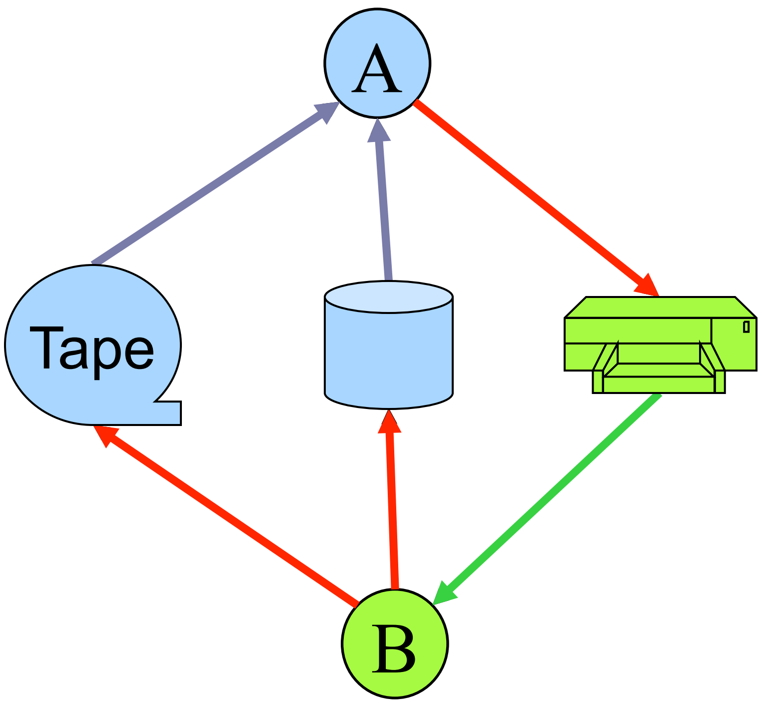
How do you deal with multiple instances of a resource?

Non-Resource Deadlock

Guns don't cause deadlocks – people do

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, then requests for a printer
  - **B** holds printer, then requests for tape and disk

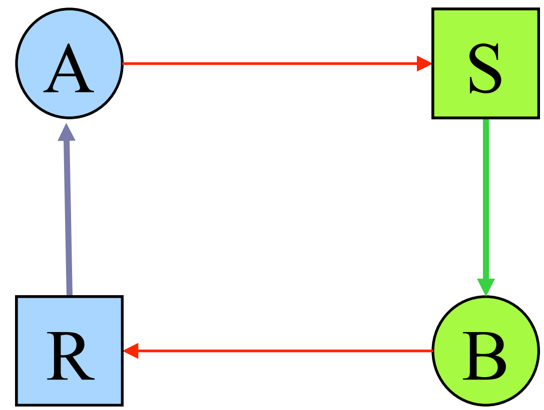


Conditions for Deadlock

- Mutual exclusion condition
  - Each resource is assigned to exactly one process
- 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

- 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

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 ran for a while and then hang
  - 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
- What about the tape-disk-printer example?

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**

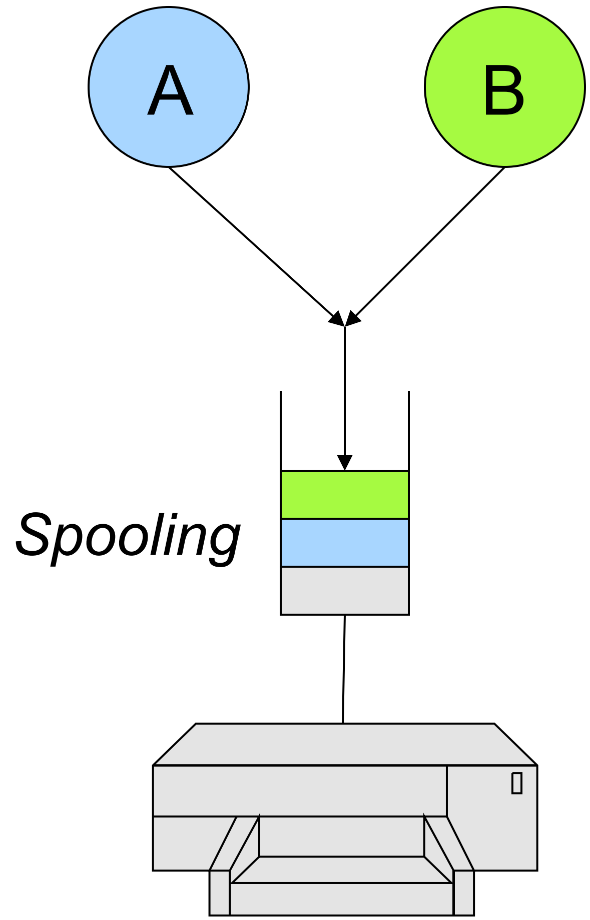
	Has	Max
P_1	4	6
P_2	1	3
P_3	2	5

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
- 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?

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

OpenLDAP deadlock, bug #3494

```
{
  lock(A)
  ...
  lock(B)
  ...
  unlock(A)
  ...
  if ( cursize > maxsize) {
   ...
     for (...)
      ...
       lock(A)
       ...
       unlock(A)
       ...
     }
  }
  ....
  unlock(B)
}
```

OpenLDAP deadlock, fix #1

```
{
  lock(A)
  ...
  lock(B)
  ...
  unlock(A)
  ...
  if ( cursize > maxsize) {
   ...
     for (...)
      ...
       lock(A)
       ...
       unlock(A)
       ...
     }
  }
  ....
  unlock(B)
}
```

```
{
  lock(A)
  ...
  lock(B)
  ...
  unlock(A)
  ...
  if ( cursize > maxsize) {
   ...
     for (...)
      ...
       if ( ! try_lock(A)) break;
       ...
       unlock(A)
       ...
     }
  }
  ....
  unlock(B)
}
```

Changes the algorithm, but maybe that's OK

OpenLDAP deadlock, fix #2

```
{
  lock(A)
  ...
  lock(B)
  ...
  unlock(A)
  ...
  if ( cursize > maxsize) {
   ...
     for (...)
      ...
       lock(A)
       ...
       unlock(A)
       ...
     }
  }
  ....
  unlock(B)
}
```

```
{
  lock(A)
  ...
  lock(B)
  ...
  ...
  if ( cursize > maxsize) {
   ...
     for (...)
      ...

      ...

       ...
     }
  }
  unlock(A)
  ....
  unlock(B)
}
```

Apache bug #42031

http://issues.apache.org/bugzilla/show_bug.cgi?id=42031
Summary: EventMPM child process freeze
Product: Apache httpd-2 Version: 2.3-HEAD
Platform: PC
OS/Version: Linux
Status: NEW
Severity: critical
Priority: P2
Component: Event MPM
AssignedTo: bugs@httpd.apache.org
ReportedBy: serai@lans-tv.com

Child process freezes with many downloading against MaxClients.

How to reproduce:

(1) configuration to httpd.conf StartServers 1 MaxClients 3 MinSpareThreads 1 MaxSpareThreads 3 ThreadsPerChild 3 MaxRequestsPerChild 0 Timeout 10 KeepAlive On MaxKeepAliveRequests 0 KeepAliveTimeout 5

(2) put a large file "test.mpg" (about 200MB) on DocumentRoot

(3) apachectl start

(4) execute many downloading simultaneously. e.g. bash and wget:

```
$ for (( i=0 ; i<20 ; i++ )); do wget -b http://localhost/test.mpg; done;
```

Then the child process often freezes. If not, try to download more.

(5) terminate downloading e.g. bash and wget: $ killall wget

(6) access to any file from web browser. However long you wait, server won't response.

Apache deadlock, bug #42031

```
listener_thread(...) {
  lock(timeout)
  ...
  lock(idlers)
  ...
  cond_wait (wait_for_idler, idlers)
  ...
  unlock(idlers)
  ...
  unlock(timeout)
}
```

```
worker_thread(...) {
  lock(timeout)
  ...
  unlock(timeout)
  ...
  lock (idlers)
  ...
  signal (wait_for_idler)
  ...
  unlock(idler)
  ...
}
```

Interlude

- Principle of Least Astonishment
  - People are part of the system. The design should match the user's experience, expectations, and mental models.
  - With this, system works intuitively
  - Without this, users get disoriented, confused, angry, …
- Example: original iPad (2010)
  - Precursors: Newton, PalmPilot, Pocket PC, Tablet PC, etc.
  - Less capable than a PC yet more expensive
  - But it took off… why?

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