COS 318: Operating Systems

Deadlocks

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http://www.cs.princeton.edu/courses/archive/fall10/cos318/

Today's Topics

- Conditions for a deadlock
- Strategies to deal with deadlocks

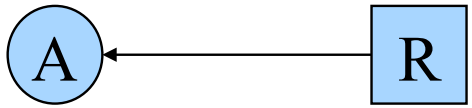
- Announcement
  - Last year's midterm and solution is on the course web page

Definitions

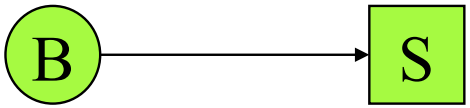
- Use processes and threads interchangeably
- Resources
  - Preemptable: CPU (can be taken away)
  - Non-preemptable: Disk, files, mutex, ... (can't be taken away)
- Use a resource
  - Request, Use, Release
- Starvation
  - Processes wait indefinitely
- Deadlocks
  - A set of processes have a deadlock if each process is waiting for an event that only another process in the set can cause

Resource Allocation Graph

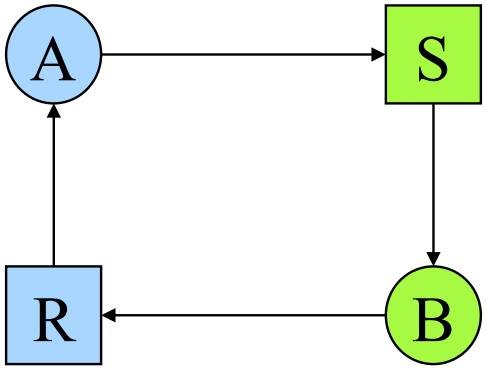
- Process A is holding resource R



- Process B requests resource S



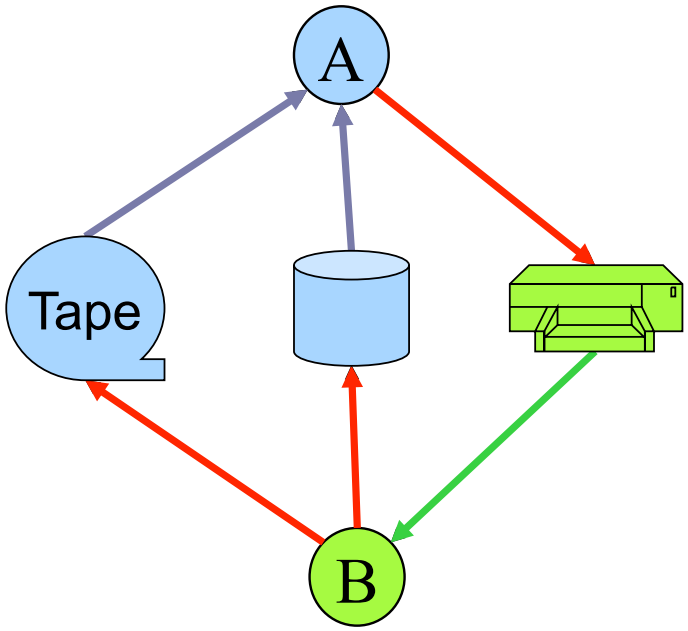
- A cycle in resource allocation graph ⇒ deadlock
- If A requests for S while holding R, and B requests for R while holding S, then



How do you deal with multiple instances of a resource?

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



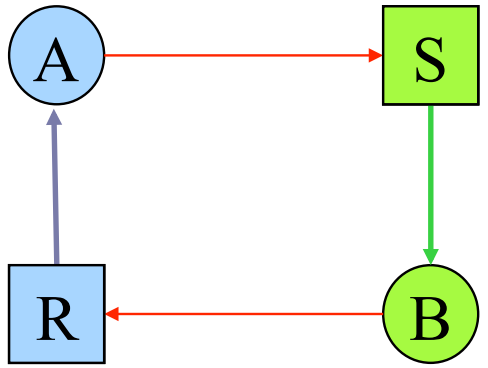
Conditions for Deadlock

- 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**

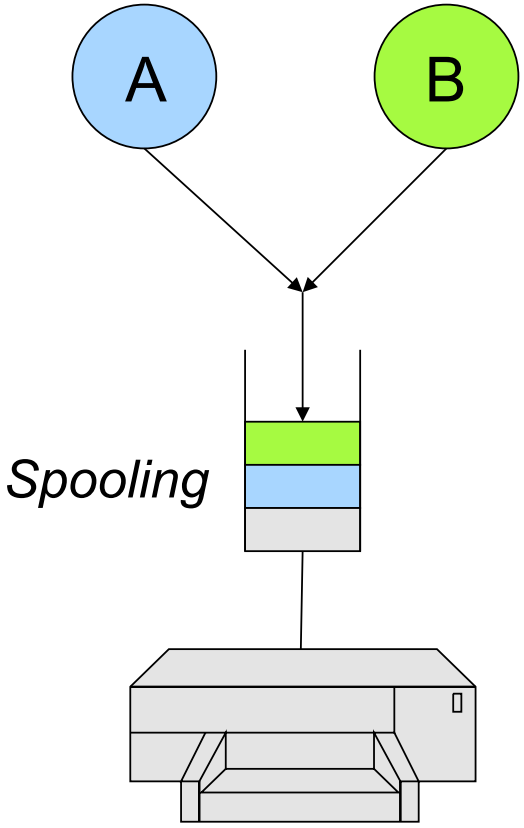
	Has	Max
P_1	4	6
P_2	1	3
P_3	2	5

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?

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

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)
  ...
}
```

Non-Resource Deadlock

Guns don’t cause deadlocks – people do

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