CS 537
Lecture 23
Deadlock

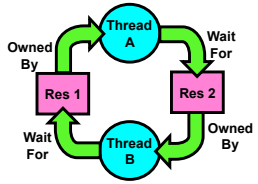
CSE 537

What can go wrong?

- **Starvation**: A policy that can leave some a thread not executing in some situation (even one where the others collaborate)
- **Deadlock**: A policy that leaves all the threads "stuck", so that nobody can do anything at all
- **Livelock**: A policy that makes them all do something endlessly without ever making progress!

Starvation vs Deadlock

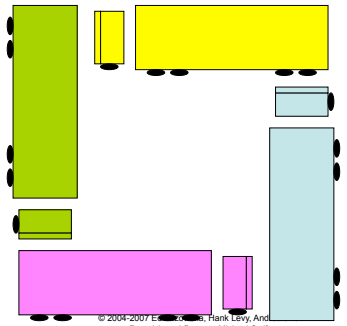
- Starvation vs. Deadlock
  - Starvation: thread waits indefinitely
    - Example, low-priority thread waiting for resources constantly in use by high-priority threads
  - Deadlock: circular waiting for resources
    - Thread A owns Res 1 and is waiting for Res 2
      Thread B owns Res 2 and is waiting for Res 1



  - Deadlock ⇒ Starvation but not vice versa
    - Starvation can end (but doesn't have to)
    - Deadlock can't end without external intervention

Real World Deadlocks?

- Gridlock



Testing for deadlock

- How do cars do it?
  - Never block an intersection
  - Must back up if you find yourself doing so
- Why does this work?
  - "Breaks" a wait-for relationship
  - Illustrates a sense in which intransigent waiting (refusing to release a resource) is one key element of true deadlock!

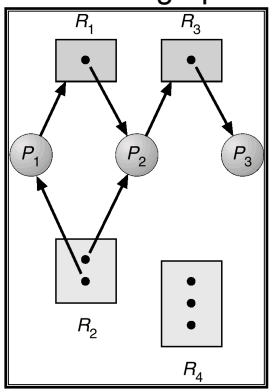
Testing for deadlock

- Steps
  - Collect "process state" and use it to build a graph
    - Ask each process "are you waiting for anything"?
    - Put an edge in the graph if so
  - We need to do this in a single instant of time, not while things might be changing
- Now need a way to test for cycles in our graph

Testing for deadlock

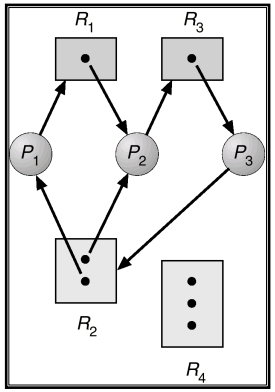
- One way to find cycles
  - Look for a node with no outgoing edges
  - Erase this node, and also erase any edges coming into it
    - Idea: This was a process people might have been waiting for, but it wasn't waiting for anything else
  - If (and only if) the graph has no cycles, we'll eventually be able to erase the whole graph!
- This is called a graph reduction algorithm

Resource allocation graph with no cycle

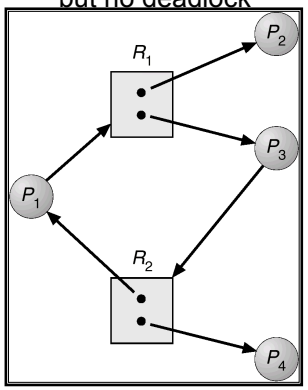


What would cause a deadlock?

Resource allocation graph with a deadlock



Resource allocation graph with a cycle but no deadlock



Some questions you might ask

- If a system is deadlocked, could this go away?
  - No, unless someone kills one of the threads or something causes a process to release a resource
  - Many real systems put time limits on "waiting" precisely for this reason. When a process gets a timeout exception, it gives up waiting and this also can eliminate the deadlock
  - But that process may be forced to terminate itself because often, if a process can't get what it needs, there are no other options available!

Some questions you might ask

- Suppose a system isn't deadlocked at time T.
- Can we assume it will still be free of deadlock at time T+1?
  - No, because the very next thing it might do is to run some process that will request a resource…
    - … establishing a cyclic wait
    - … and causing deadlock

Deadlocks

- Definition: Deadlock exists among a set of processes if
  - Every process is waiting for an event
  - This event can be caused only by another process in the set
    - Event is the acquire or release of another resource



One-lane bridge

Four Conditions for Deadlock

- Coffman et. al. 1971
- Necessary conditions for deadlock to exist:
  - **Mutual Exclusion**
    - At least one resource must be held is in non-sharable mode
  - **Hold and wait**
    - There exists a process holding a resource, and waiting for another
  - **No preemption**
    - Resources cannot be preempted
  - **Circular wait**
    - There exists a set of processes $\{P_1, P_2, \ldots P_N\}$, such that
      - P_1 is waiting for P_2, P_2 for P_3, …. and P_N for P_1

All four conditions must hold for deadlock to occur

Dealing with Deadlocks

- Reactive Approaches: detect and recover
  - Periodically check for evidence of deadlock
    - For example, using a graph reduction algorithm
  - Then need a way to recover
    - Could blue screen and reboot the computer
    - Could pick a "victim" and terminate that thread
      - But this is only possible in certain kinds of applications
      - Basically, thread needs a way to clean up if it gets terminated and has to exit in a hurry!
    - Often thread would then "retry" from scratch
- Despite drawbacks, database systems do this

Dealing with Deadlocks

- Proactive Approaches:
  - Deadlock Prevention
    - Prevent one of the 4 necessary conditions from arising
    - …. This will prevent deadlock from occurring
- Ignore the problem
  - Pretend deadlocks will never occur
  - Ostrich approach… but surprisingly common!

Deadlock Prevention #1

- Approach
  - Ensure 1 of 4 conditions cannot occur
  - Negate each of the 4 conditions
- No single approach is appropriate (or possible) for all circumstances
- No mutual exclusion --> Make resource sharable
  - Example: Read-only files

Deadlock Prevention #2

- No Hold-and-wait --> Two possibilities
- 1) Only request resources when have none
  - Release resource before requesting next one

Thread 1
```
lock(x);
A += 10;
unlock(x);
lock(y);
B += 20;
unlock(y);
lock(x);
A += 30;
unlock(x);
```

Thread 2
```
lock(y);
B += 10;
unlock(y);
lock(x);
A += 20;
unlock(x);
lock(y);
B += 30;
unlock(y);
```


Deadlock Prevention #2

- No Hold-and-wait
- 2) Atomically acquire all resources at once
  - Example #1: Single lock to protect all

Thread 1
```
lock(z);
A += 10;
B += 20;
A += B;
A += 30;
unlock(z);
```

Thread 2
```
lock(z);
B += 10;
A += 20;
A += B;
B += 30;
unlock(z);
```


Deadlock Prevention #2

- No Hold-and-wait
- 2) Atomically acquire all resources at once
  - Example #2: New primitive to acquire two locks

Thread 1
```
lock(x,y);
A += 10;
B += 20;
A += B;
unlock(y);
A += 30;
unlock(x);
```

Thread 2
```
lock(x,y);
B += 10;
A += 20;
A += B;
unlock(x);
B += 30;
unlock(y);
```

Deadlock Prevention #2

- Problems w/ acquiring many resources atomically
  - Low resource utilization
    - Must make pessimistic assumptions about resource usage

```
if (cond1) {
  lock(x);
}
if (cond2) {
  lock(y);
}
```

  - Starvation
    - If need many resources, others might keep getting one of them

Deadlock Prevention #3

- No "no preemption" --> Preempt resources
- Example: A waiting for something held by B, then take resource away from B and give to A
  - Only works for some resources (e.g., CPU and memory)
  - Not possible if resource cannot be saved and restored
    - Can't take away a lock without causing problems

Deadlock Prevention #4

- No circular wait --> Impose ordering on resources
  - Give all resources a ranking; must acquire highest ranked first
  - How to change Example?

- Problems?

Summary: Handing Deadlock

- Deadlock prevention
  - Ensure deadlock does not happen
  - Ensure at least one of 4 conditions does not occur
- Deadlock detection and recovery
  - Allow deadlocks, but detect when occur
  - Recover and continue
- Ignore
  - Easiest and most common approach