CS 318 Principles of Operating Systems

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Lecture 8: Deadlock

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Slides adapted from Geoff Voelker's lectures

Deadlock

- **Synchronization is a live gun – we can easily shoot ourselves in the foot**
  - Incorrect use of synchronization can block all processes
  - You have likely been intuitively avoiding this situation already
- **If one process tries to access a resource that a second process holds, and vice-versa, they can never make progress**
- **We call this situation deadlock, and we'll look at:**
  - Definition and conditions necessary for deadlock
  - Representation of deadlock conditions
  - Approaches to dealing with deadlock

Deadlock Definition

- **Deadlock is a problem that can arise:**
  - When processes compete for access to limited resources
  - When processes are incorrectly synchronized
- **Definition:**
  - Deadlock exists among a set of processes if every process is waiting for an event that can be caused only by another process in the set.

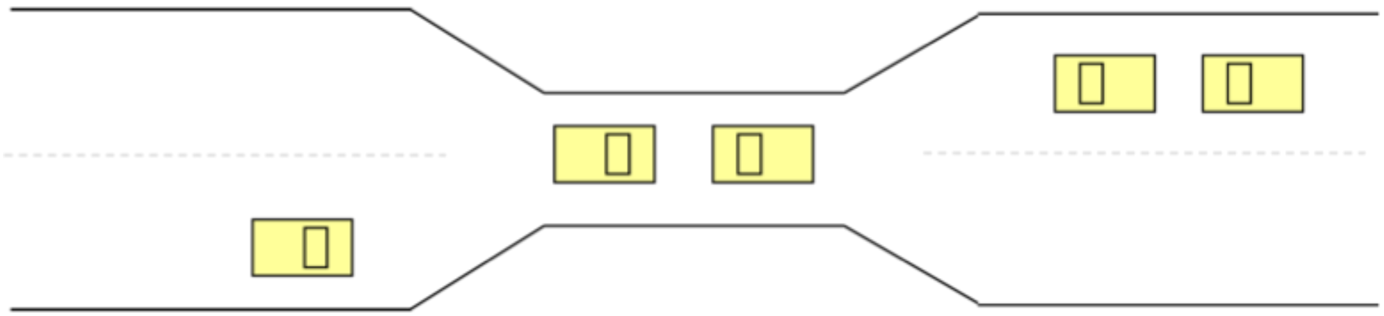
Deadlock Example

```
mutex_t m1, m2;
void p1(void *ignored) {
  lock(m1);
→ lock(m2);
  /* critical section */
  unlock(m2);
  unlock(m1);
}
void p2(void *ignored) {
  lock(m2);
→ lock(m1);
  /* critical section */
  unlock(m1);
  unlock(m2);
}
```

Deadlock Example

- **Can you have deadlock w/o mutexes?**
- **Same problem with condition variables**
  - Suppose resource 1 managed by c_1, resource 2 by c_2
  - A has 1, waits on c_2, B has 2, waits on c_1
- **Or have combined mutex/condition variable deadlock:**
  - `lock (a); lock (b); while (!ready) wait (b, c); unlock (b); unlock (a);`
  - `lock (a); lock (b); ready = true; signal (c); unlock (b); unlock (a);`
- **One lesson: dangerous to hold locks when crossing abstraction barriers!**
  - i.e., lock (a) then call function that uses condition variable

Deadlocks w/o Computers



- **Real issue is *resources* & how required**
- **E.g., bridge only allows traffic in one direction**
  - Each section of a bridge can be viewed as a resource.
  - If a deadlock occurs, it can be resolved if one car backs up (preempt resources and rollback).
  - Several cars may have to be backed up if a deadlock occurs.
  - Starvation is possible.

Conditions for Deadlock

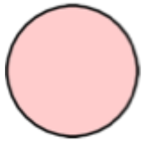
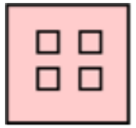
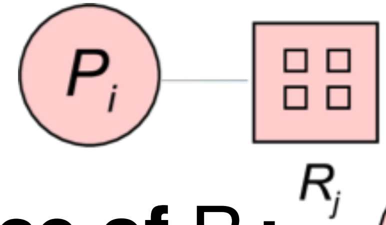
1. Mutual exclusion – At least one resource must be held in a non-sharable mode
2. Hold and wait – There must be one process holding one resource and waiting for another resource
3. No preemption – Resources cannot be preempted (critical sections cannot be aborted externally)
4. Circular wait – There must exist a set of processes [P_1, P_2, P_3,…,P_n] such that P_1 is waiting for P_2, P_2 for P_3, etc.

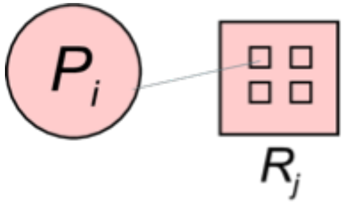
- **All of 1–4 necessary for deadlock to occur**
- **Two approaches to dealing with deadlock:**
  - Pro-active: prevention
  - Reactive: detection + corrective action

Prevent by Eliminating One Condition

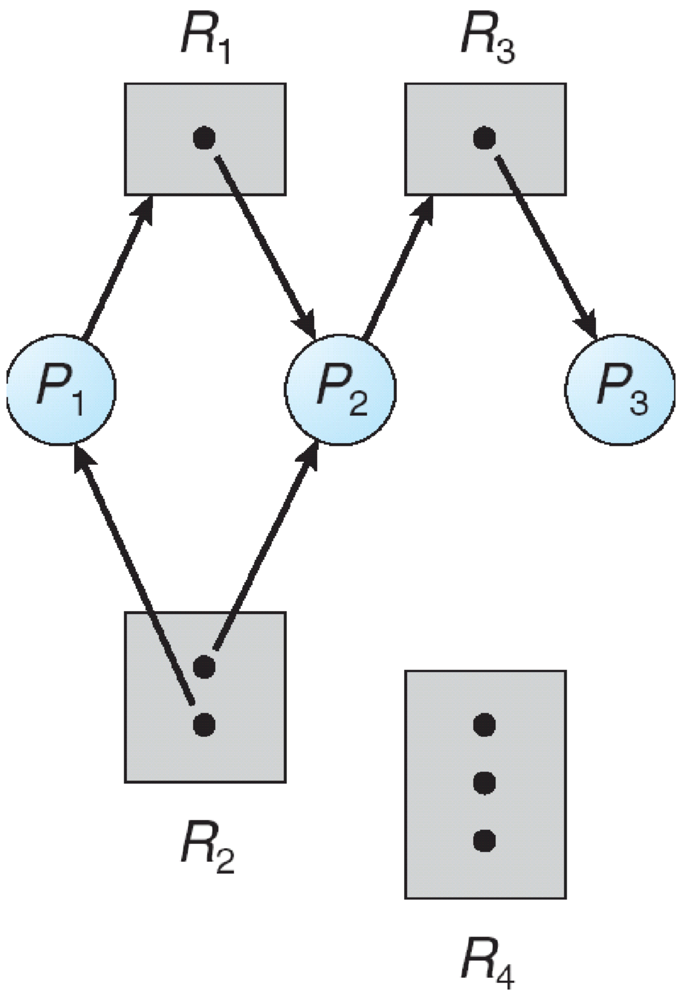
1. **Mutual exclusion**
   - Buy more resources, split into pieces, or virtualize to make "infinite" copies
   - Threads: threads have copy of registers = no lock
2. **Hold and wait**
   - Wait on all resources at once (must know in advance)
3. **No preemption**
   - Physical memory: virtualized with VM, can take physical page away and give to another process!
4. **Circular wait**
   - Single lock for entire system: (problems?)
   - Partial ordering of resources (next)

Resource Allocation Graph

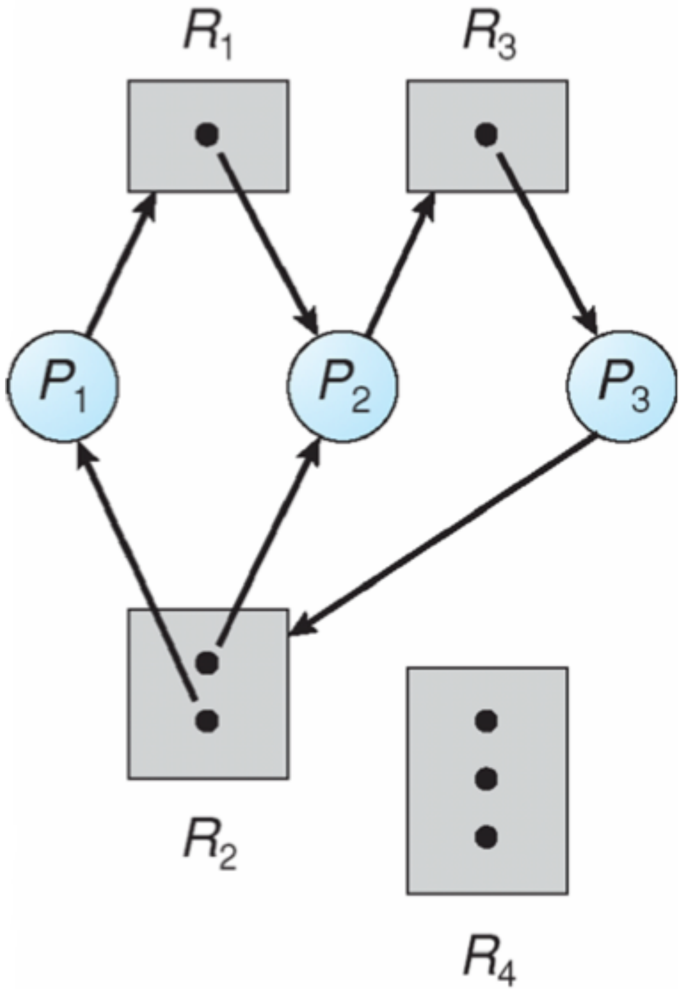
- **View system as graph**
  - Processes and Resources are nodes
  - Resource Requests and Assignments are edges
- **Process:** 
- **Resource with 4 instances:** 
- P_i **requesting** R_j**:** 

- P_i **holding instance of** R_j**:** 

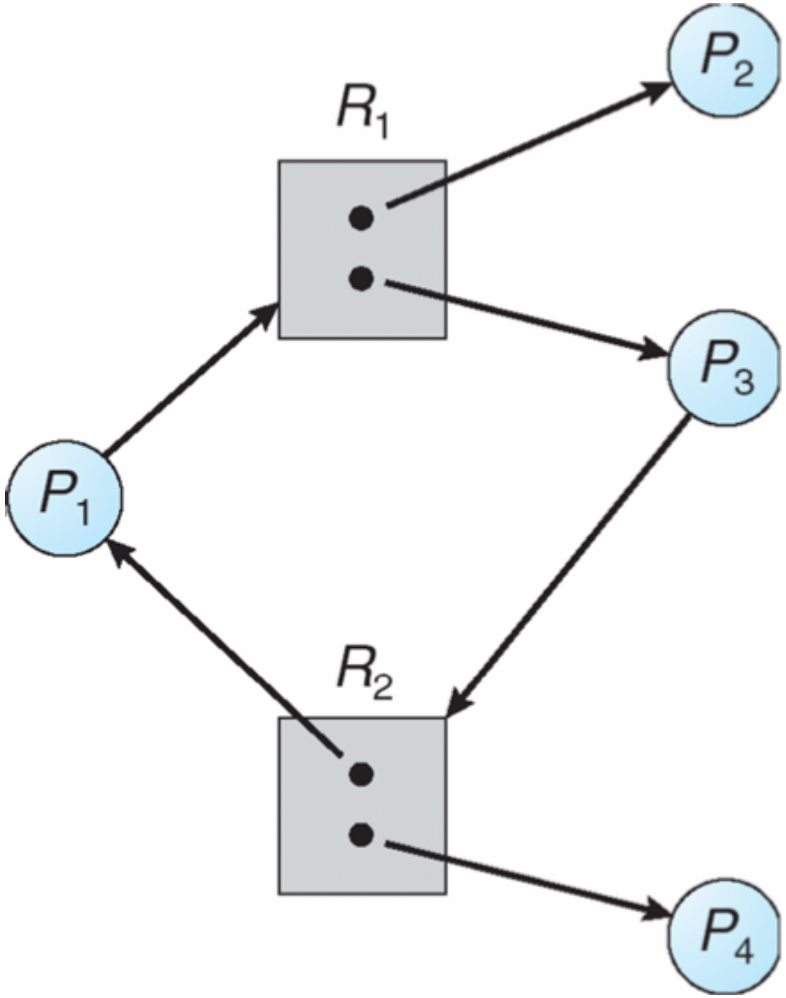
Example Resource Allocation Graph



Resource Allocation Graph with Deadlock



Is This Deadlock?



Cycles and Deadlock

- **If graph has no cycles ⇒ no deadlock**
- **If graph contains a cycle**
  - Definitely deadlock if only one instance per resource (waits-for graph (WFG))
  - Otherwise, maybe deadlock, maybe not
- **Prevent deadlock with partial order on resources**
  - e.g., always acquire mutex m_1 before m_2
  - Usually design locking discipline for application this way

Dealing With Deadlock

- **There are four approaches for dealing with deadlock:**
  - Ignore it – how lucky do you feel?
  - Prevention – make it impossible for deadlock to happen
  - Avoidance – control allocation of resources
  - Detection and Recovery – look for a cycle in dependencies

Deadlock Avoidance

- **Avoidance**
  - Provide information in advance about what resources will be needed by processes to guarantee that deadlock will not happen
  - System only grants resource requests if it knows that the process can obtain all resources it needs in future requests
  - Avoids circularities (wait dependencies)
- **Tough**
  - Hard to determine all resources needed in advance
  - Good theoretical problem, not as practical to use

Banker's Algorithm

- **The Banker's Algorithm is the classic approach to deadlock avoidance for resources with multiple units**

1. **Assign a credit limit to each customer (process)**
   - Maximum credit claim must be stated in advance
2. **Reject any request that leads to a dangerous state**
   - A dangerous state is one where a sudden request by any customer for the full credit limit could lead to deadlock
   - A recursive reduction procedure recognizes dangerous states
3. **In practice, the system must keep resource usage well below capacity to maintain a resource surplus**
   - Rarely used in practice due to low resource utilization

Detection and Recovery

- **Detection and recovery**
  - If we don’t have deadlock prevention or avoidance, then deadlock may occur
  - In this case, we need to detect deadlock and recover from it
- **To do this, we need two algorithms**
  - One to determine whether a deadlock has occurred
  - Another to recover from the deadlock
- **Possible, but expensive (time consuming)**
  - Implemented in VMS
  - Run detection algorithm when resource request times out

Deadlock Detection

- **Detection**
  - Traverse the resource graph looking for cycles
  - If a cycle is found, preempt resource (force a process to release)
- **Expensive**
  - Many processes and resources to traverse
- **Only invoke detection algorithm depending on**
  - How often or likely deadlock is
  - How many processes are likely to be affected when it occurs

Deadlock Recovery

Once a deadlock is detected, we have two options…

1. Abort processes

- Abort all deadlocked processes
  - Processes need to start over again
- Abort one process at a time until cycle is eliminated
  - System needs to rerun detection after each abort

2. Preempt resources (force their release)

- Need to select process and resource to preempt
- Need to rollback process to previous state
- Need to prevent starvation

Deadlock Summary

- **Deadlock occurs when processes are waiting on each other and cannot make progress**
  - Cycles in Resource Allocation Graph (RAG)
- **Deadlock requires four conditions**
  - Mutual exclusion, hold and wait, no resource preemption, circular wait
- **Four approaches to dealing with deadlock:**
  - Ignore it – Living life on the edge
  - Prevention – Make one of the four conditions impossible
  - Avoidance – Banker's Algorithm (control allocation)
  - Detection and Recovery – Look for a cycle, preempt or abort

Next time…

- **Read Chapter 15, 16, 18**