SE350: Operating Systems

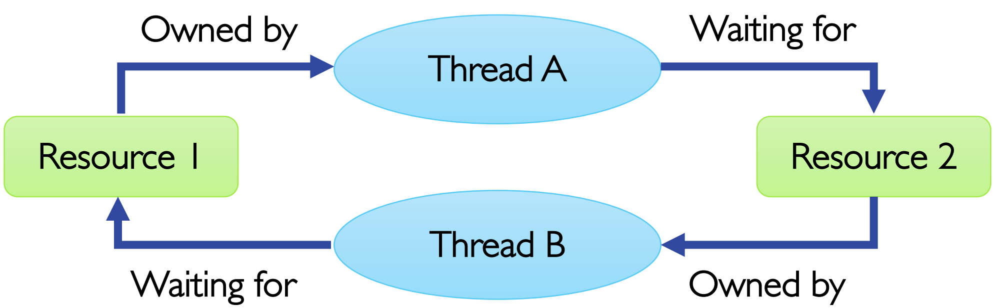
Lecture 9: Deadlock

Outline

- Definitions
- Four conditions for deadlocks
  - Mutual exclusion
  - Hold and wait
  - No preemption
  - Circular wait
- Techniques for addressing Deadlock

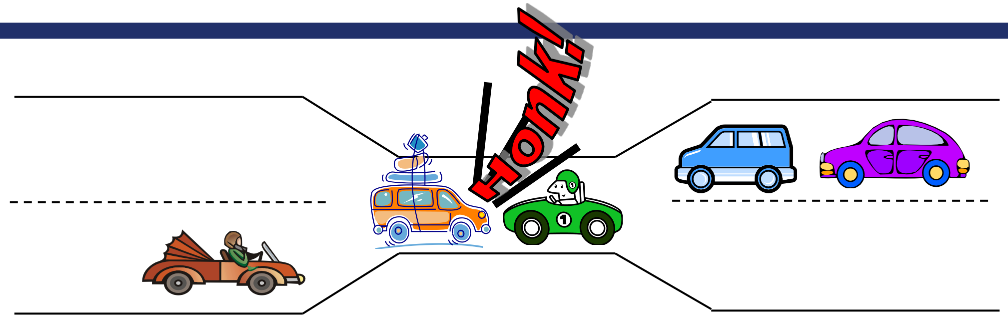
Starvation vs. Deadlock

- Starvation: thread waits indefinitely
  - E.g., 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 leads to starvation but not the other way around
  - Starvation can end (but doesn't have to)
  - Deadlock can't end without external intervention

Bridge Crossing Example



- Each segment of road can be viewed as resource
  - Cars must own segment under them and acquire segment they are moving to
- To cross bridge cars must acquire both halves
  - Traffic only in one direction at a time
  - Problem occurs when two cars in opposite directions on bridge: each acquires one segment and needs next
- If deadlock occurs, it can be resolved if one car backs up (preempt resources and rollback)
  - Several cars may have to be backed up
- Starvation is possible
  - East-going traffic really fast $\Rightarrow$ no one goes west

Conditions for Deadlock

- Deadlock is not always deterministic

Thread A	Thread B
`x.P();`	`y.P();`
`y.P();`	`x.P();`
`y.V();`	`x.V();`
`x.V();`	`y.V();`

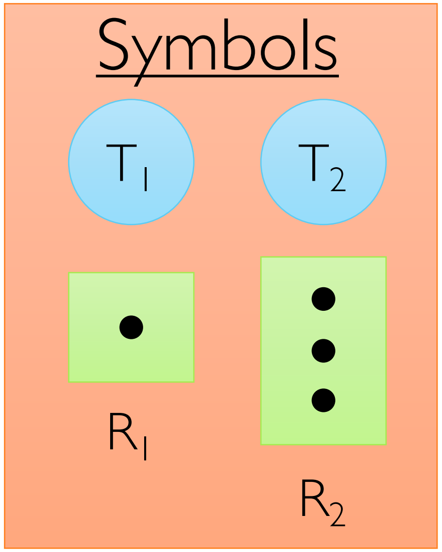
  - This code doesn't always lead to deadlock
    - Must have exactly right timing ("wrong" timing?)
    - So you release a piece of software, and you tested it, and there it is, controlling a nuclear power plant…
- Deadlocks occur with multiple resources
  - Can't solve deadlock for each resource independently

Four Requirements for Deadlock

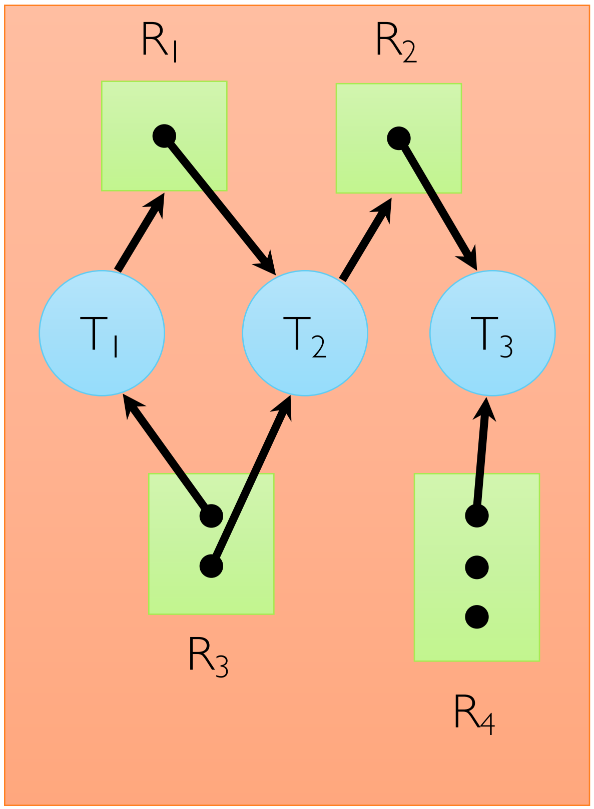
- Mutual exclusion
  - Only limited number of threads at a time can use resource
- Hold and wait
  - Thread hold resources while waiting to acquire additional ones
- No preemption
  - Resources are released only voluntarily by thread holding them
- Circular wait
  - There exists a set $T_1, \ldots, T_n$ of waiting threads
    - T_1 is waiting for resource that is held by T_2
    - T_2 is waiting for resource that is held by T_3
    - …
    - T_n is waiting for resource that is held by T_1

Resource Allocation Graph

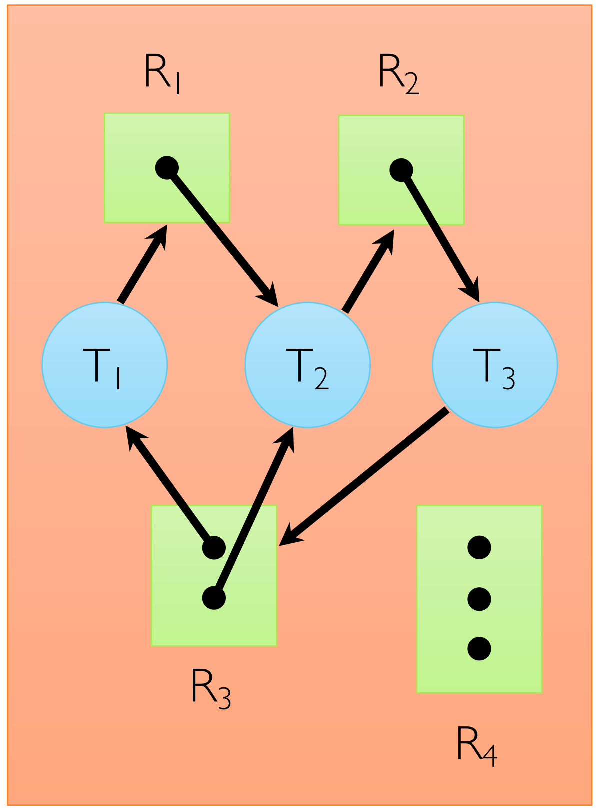
- System model
  - Threads $T_1, T_2, \ldots, T_n$
  - Resource types $R_1, R_2, \ldots, R_m$
    - CPU cycles, memory space, I/O devices
  - Each resource type R_i has W_{ij} instances
  - Each thread utilizes resources as follows
    - `Request() / Use() / Release()`
- Resource allocation graph
  - V is partitioned into two types
    - $T = \{T_1, \ldots, T_n\}$, set threads in system
    - $R = \{R_1, \ldots, R_m\}$, set of resource types in system
  - Request edge is directed edge $T_i \rightarrow R_j$
  - Assignment edge is directed edge $R_q \rightarrow T_p$



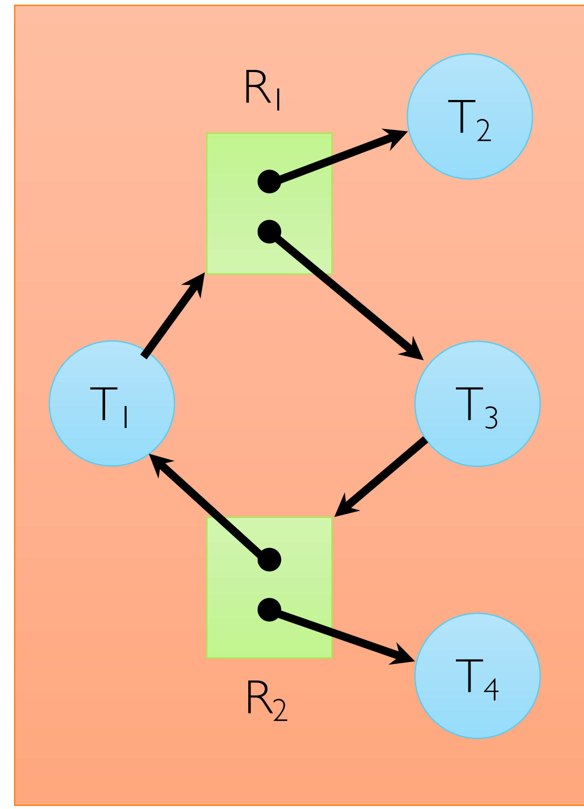
Resource Allocation Graph Examples



Simple resource allocation graph

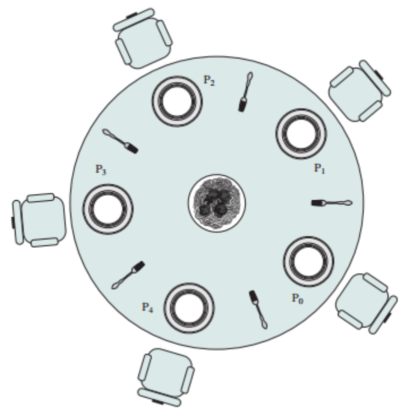


Allocation graph with deadlock



Allocation graph with cycle, but no deadlock

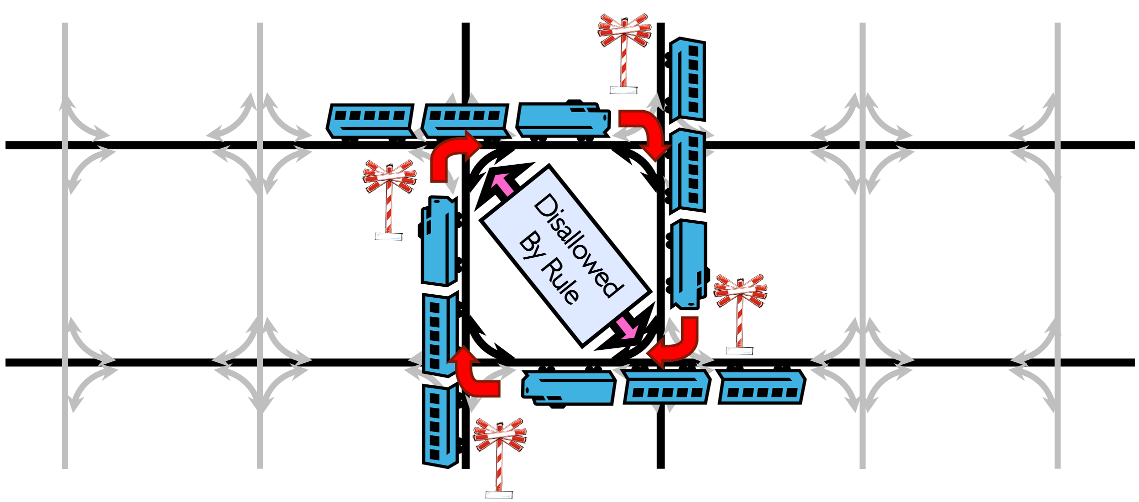
Dining ~~Philosophers~~ Politicians!



- Each politician needs two chopsticks to eat
- Each grabs chopstick on the right first (all right-handed)
- Deadlock if all grab chopstick at same time
- Deadlock depends on the order of execution
  - No deadlock if one was left-handed

Train Example (Wormhole-Routed Network)

- Each train wants to turn right but is blocked by other trains
- Similar problem to multiprocessor networks
- How to fix this? (Imagine grid extends in all four directions)
  - Force ordering of channels (tracks)
    - Protocol: Always go east-west first, then north-south
  - Called "dimension ordering" (X then Y)



Methods for Handling Deadlocks

- Allow system to enter deadlock and then recover
  - Requires deadlock detection algorithm
  - Technique for forcibly preempting resources and/or terminating tasks
- Ensure that system will never enter deadlock
  - Need to monitor all resources acquisitions
  - Selectively deny those that might lead to deadlock

- Ignore problem and pretend deadlocks never occur
  - Used by most operating systems, including UNIX

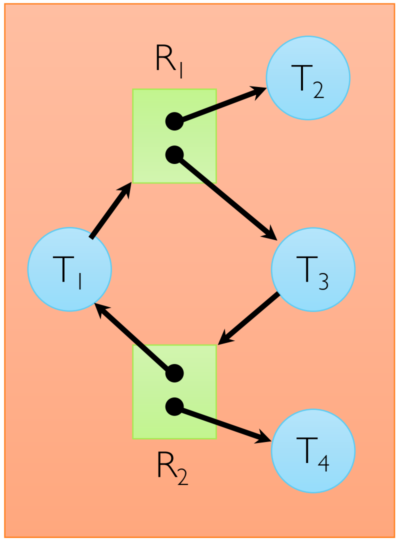
Deadlock Detection Algorithm

- If there is only one unit of each type of resource ⇒ look for loops
- More general deadlock detection algorithm
  - Let [x] represent m-ary vector of non-negative integers (units per type)

`[FreeResources]:`	Current free resources each type
`[Request_i]:`	Current requests from thread i
`[Alloc_i]:`	Current resources held by thread i

  - See if tasks can eventually terminate on their own

```
[Avail] = [FreeResources]
Add all nodes to UNFINISHED
do {
    done = true
    foreach node in UNFINISHED {
        if ([Request_node] <= [Avail]) {
            remove node from UNFINISHED
            [Avail] = [Avail] + [Alloc_node]
            done = false
        }
    }
} until(done)
```



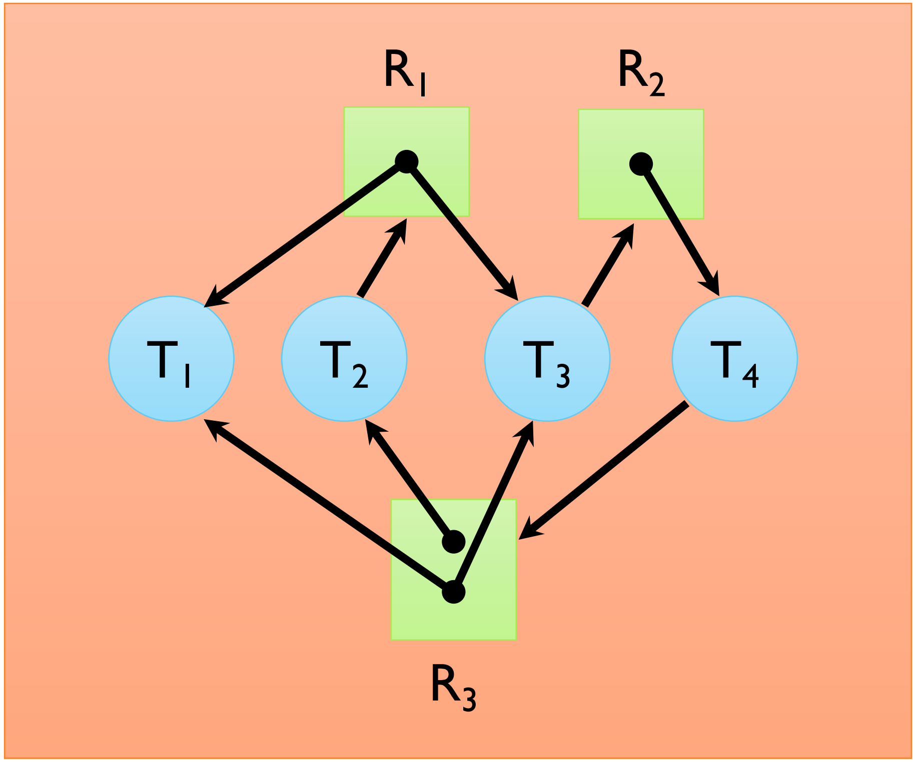
- Nodes left in **UNFINISHED** ⇒ deadlocked

What to Do When Detect Deadlock?

- Terminate thread, force it to give up resources
  - Bridge example: Godzilla picks up a car, hurls it into river. Deadlock solved!
  - But, not always possible: killing thread holding mutex leaves world inconsistent
- Proceed without the resource
  - Requires robust exception handling code
  - E.g., Amazon will say you can buy book, if inventory subsystem doesn't reply quickly enough (wrong answer quickly is better than right answer slowly)
- Roll back actions of deadlocked threads
  - Hit rewind button, pretend last few minutes never happened
  - Bridge example: make one car roll backwards (may require others behind him)
  - Common technique in databases (transactions)
  - Of course, if you restart in the same way, may reenter deadlock once again
- Many operating systems use other options

Resource Requests Over Time

- Applications usually don't know exactly when/what they'll request
- Resources are taken/released over time



Techniques for Preventing Deadlock

- Infinite resources
  - Include enough resources so that no one ever runs out of resources
    - Doesn't have to be infinite, just large
  - Give illusion of infinite resources (e.g. virtual memory)
  - Examples:
    - Bay bridge with 12,000 lanes. Never wait!
    - Infinite disk space (not realistic yet?)
- No Sharing of resources (totally independent threads)
  - Often true (most things don't depend on each other) but not very realistic in general
- Don't allow waiting
  - How phone company avoids deadlock
    - Call someone, either goes through or goes to voicemail
  - Technique used in Ethernet/some multiprocessor nets
    - Everyone speaks at once. On collision, back off and retry
  - Inefficient, since must keep retrying
    - Consider: driving to Toronto, when hit traffic jam, suddenly transported back and told to retry!

Techniques for Preventing Deadlock (cont.)

- Make all threads request everything they'll need at the beginning
  - Problem: Predicting future is hard, tend to over-estimate resources
  - Example:
    - If need 2 chopsticks, request both at same time
    - Don't leave home until we know no one is using any intersection between here and where you want to go; only one car on the bridge at a time
- Force all threads to request resources in fixed order preventing any cyclic use of resources
  - Thus, preventing deadlock
  - Example (x.P, y.P, z.P,…)
    - Make tasks request disk, then memory, then…
    - Keep from deadlock on freeways by requiring everyone to go clockwise

Banker's Algorithm

- Invariant: every request always would succeed
- We don't know order/amount of requests ahead of time
- We assume worst-case max required resource for each thread
- Allow thread i to proceed if

(available resources - request_i) ≥ max remaining required resources by any thread

- Really conservative!

Banker's Algorithm (cont.)

- Less conservative invariant
  At all times, there exists some order of requests that would succeed
- How to implement this?
  - Allocate resources dynamically
  - Evaluate each request and grant it if some ordering of threads is deadlock free
  - Use deadlock detection algorithm presented earlier
    - BUT: Assume each process needs "max" resources to finish

```
[Avail] = [FreeResources]
Add all nodes to UNFINISHED
do {
       done = true
       foreach node in UNFINISHED {
          if ([Max_node]-[Alloc_node]<= [Avail]) {
             remove node from UNFINISHED
             [Avail] = [Avail] + [Alloc_node]
             done = false
          }
       }
} until(done)
```

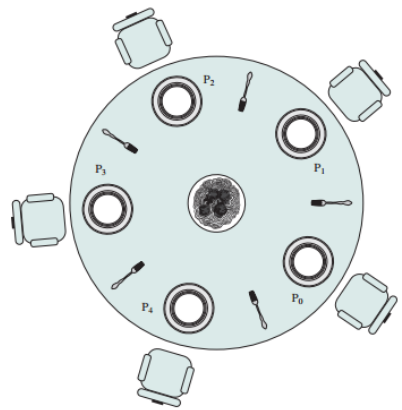
Each process might need "max" resources in order to finish

Banker's Algorithm: Key Properties

- Keeps system in "SAFE" state
  - There exists a sequence $\{T_1, \ldots, T_n\}$ with T_1 requesting all its remaining resources and finishing, then T2 requesting all remaining resources, etc.

- Algorithm allows sum of maximum resource needs of all current threads to be greater than total resources

Banker's Algorithm Example



- Banker's algorithm with dining politicians
  - "Safe" (won't cause deadlock) if when try to grab chopstick either
    - Not last chopstick
    - Is last chopstick but someone will have two afterwards
  - What if k-handed politician? Don't allow if:
    - It's the last one, no one would have k
    - It's 2nd to last, and no one would have k-1
    - It's 3rd to last, and no one would have k-2
    - …

Deadlock Prevention – The Reality

- Deadlock Prevention is HARD
  - How many resources will each thread need?
  - How many total resources are there?

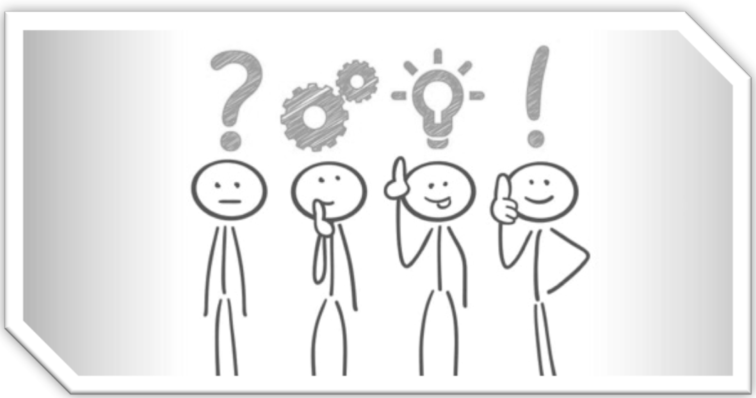
- Also Slow/Impractical
  - Matrix of resources/requirements could be big and dynamic
  - Re-evaluate on every request (even for small/non-contended)
  - Banker's algorithm assumes everyone asks for max

- REALITY
  - Most OSs don't bother
  - Programmers job to write deadlock-free programs (e.g. by ordering all resource requests).

Summary

- Starvation (wait indefinitely) versus deadlock (circular waiting)
- Four conditions for deadlocks
  - Mutual exclusion
    - Only limited number of thread at a time can use resources
  - Hold and wait
    - Thread hold at least one resource while waiting to acquire additional ones
  - No preemption
    - Resources are released only voluntarily by threads
  - Circular wait
    - $\exists$ set $\{T_1, \ldots, T_n\}$ of threads with a cyclic waiting pattern
- Techniques for addressing Deadlock
  - Allow system to enter deadlock and then recover
  - Ensure that system will never enter a deadlock
  - Ignore problem and pretend that deadlocks never occur in system

Questions?



Acknowledgment

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