CSE 153
Design of Operating Systems

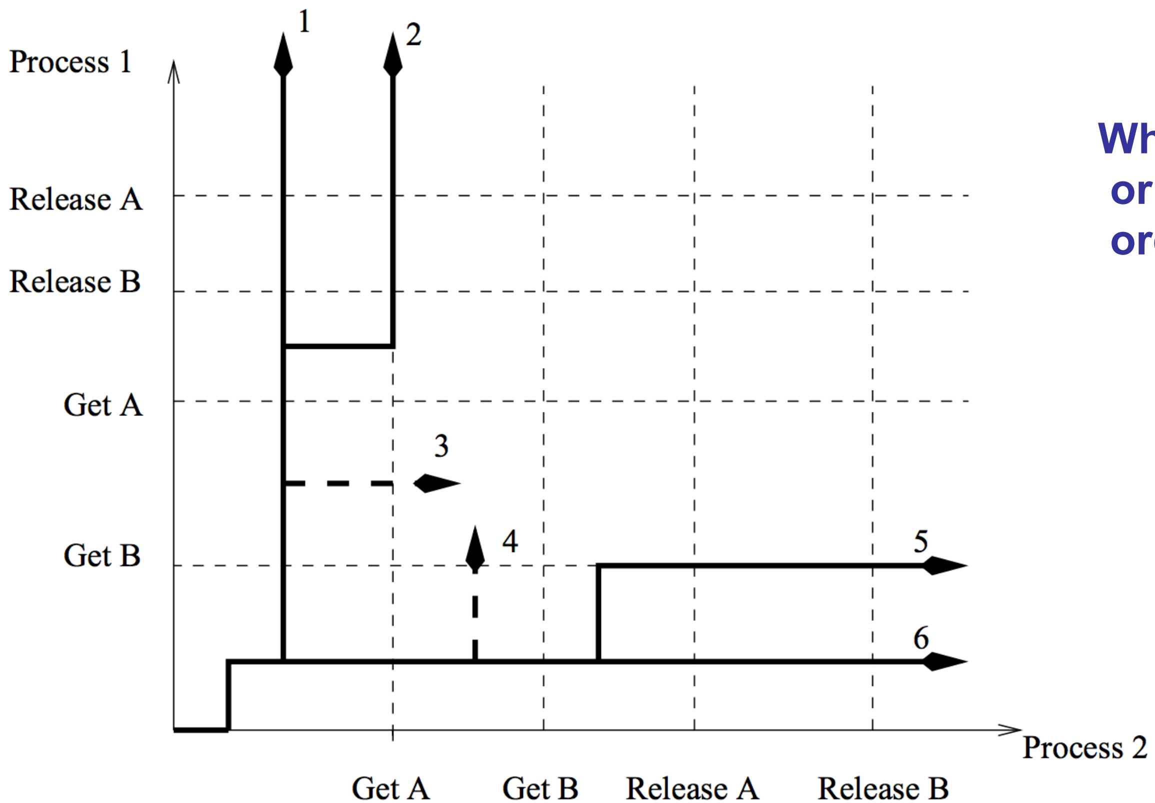
Winter 2023

Lecture 12: Deadlock

Today: Deadlock—the deadly embrace!

- Synchronization– 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
- Consider: processes that use multiple critical sections/need different resources
  - 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 Example (2)

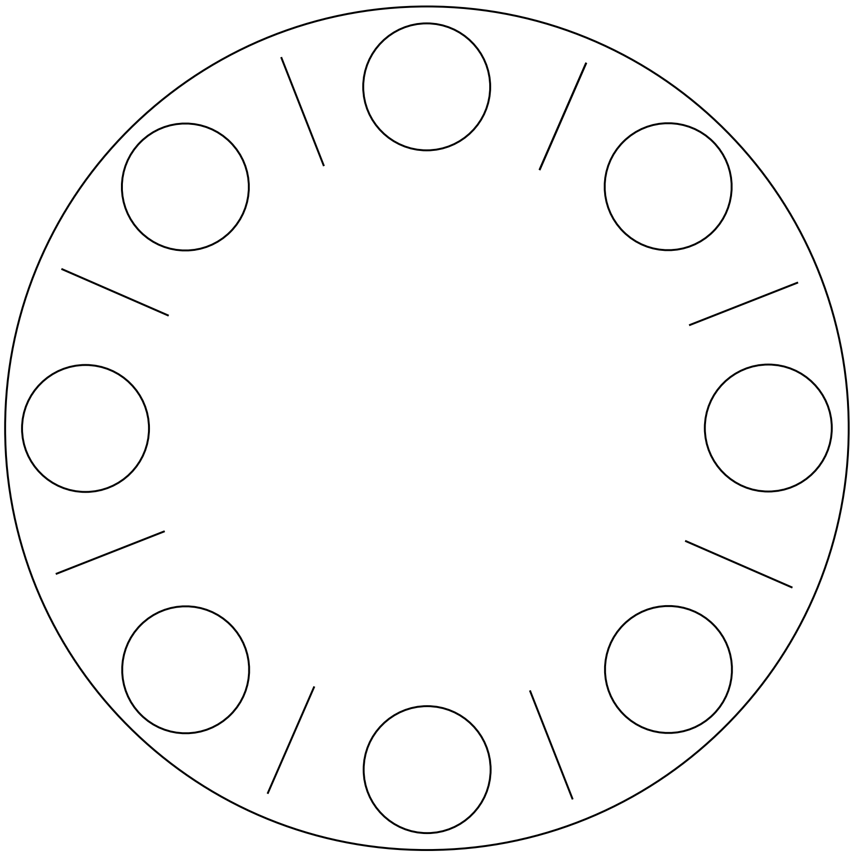


Whether deadlock occurs or not depends on the order of operations!

Conditions for Deadlock

- Deadlock can exist if and only if the following four conditions hold simultaneously:
  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.

Dining Lawyers

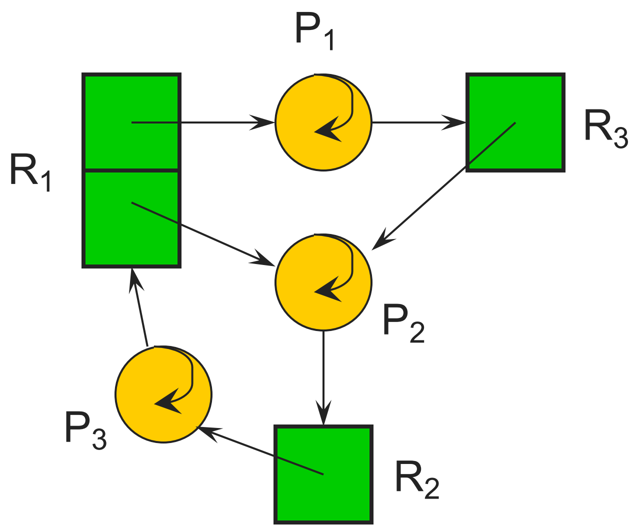


Each lawyer needs two chopsticks to eat.
Each grabs chopstick on the right first.

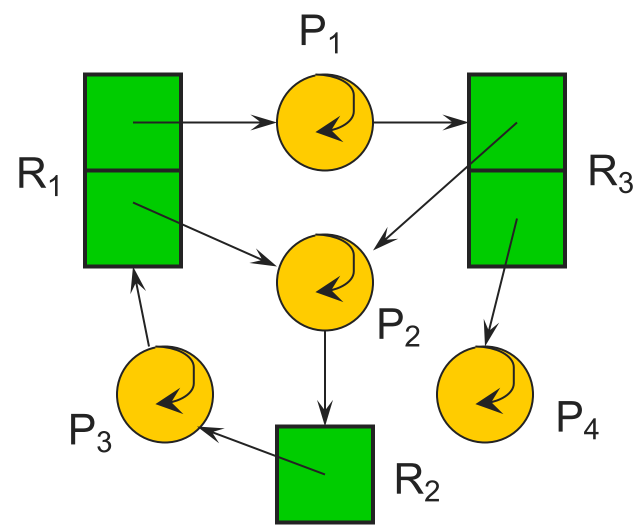
Lets get formal for a minute

- Deadlock can be described using a resource allocation graph (RAG)
- The RAG consists of a set of vertices $P=\{P_1, P_2, \ldots, P_n\}$ of processes and $R=\{R_1, R_2, \ldots, R_m\}$ of resources
  - A directed edge from a process to a resource, $P_i \rightarrow R_i$, means that P_i has requested R_j
  - A directed edge from a resource to a process, $R_i \rightarrow P_i$, means that R_j has been allocated to P_i
  - Each resource has a fixed number of units
- If the graph has no cycles, deadlock cannot exist
- If the graph has a cycle, deadlock may exist

RAG Example



A cycle…and deadlock!



Same cycle…but no deadlock. Why?

A Simpler Case

- If all resources are single unit and all processes make single requests, then we can represent the resource state with a simpler waits-for graph (WFG)
- The WFG consists of a set of vertices $P=\{P_1, P_2, \ldots, P_n\}$ of processes
  - A directed edge $P_i \rightarrow P_j$ means that P_i has requested a resource that P_j currently holds
- If the graph has no cycles, deadlock cannot exist
- If the graph has a cycle, deadlock exists

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 Prevention

- Prevention – Ensure that at least one of the necessary conditions cannot happen
  - Mutual exclusion
    - » Make resources sharable (not generally practical)
  - Hold and wait
    - » Process cannot hold one resource when requesting another
  - Preemption
    - » OS can preempt resource (costly)
  - Circular wait
    - » Impose an ordering (numbering) on the resources and request them in order (popular implementation technique)

Deadlock prevention

- One shot allocation: ask for all your resources in one shot; no more resources can be requested
  - What ingredient does this prevent?
  - Comments?
- Preemption
  - Nice: Give up a resource if what you want is not available
  - Aggressive: steal a resource if what you want is not available
- Hierarchical allocation:
  - Assign resources to classes
  - Can only ask for resources from a higher number class than what you hold now

Deadlock Avoidance

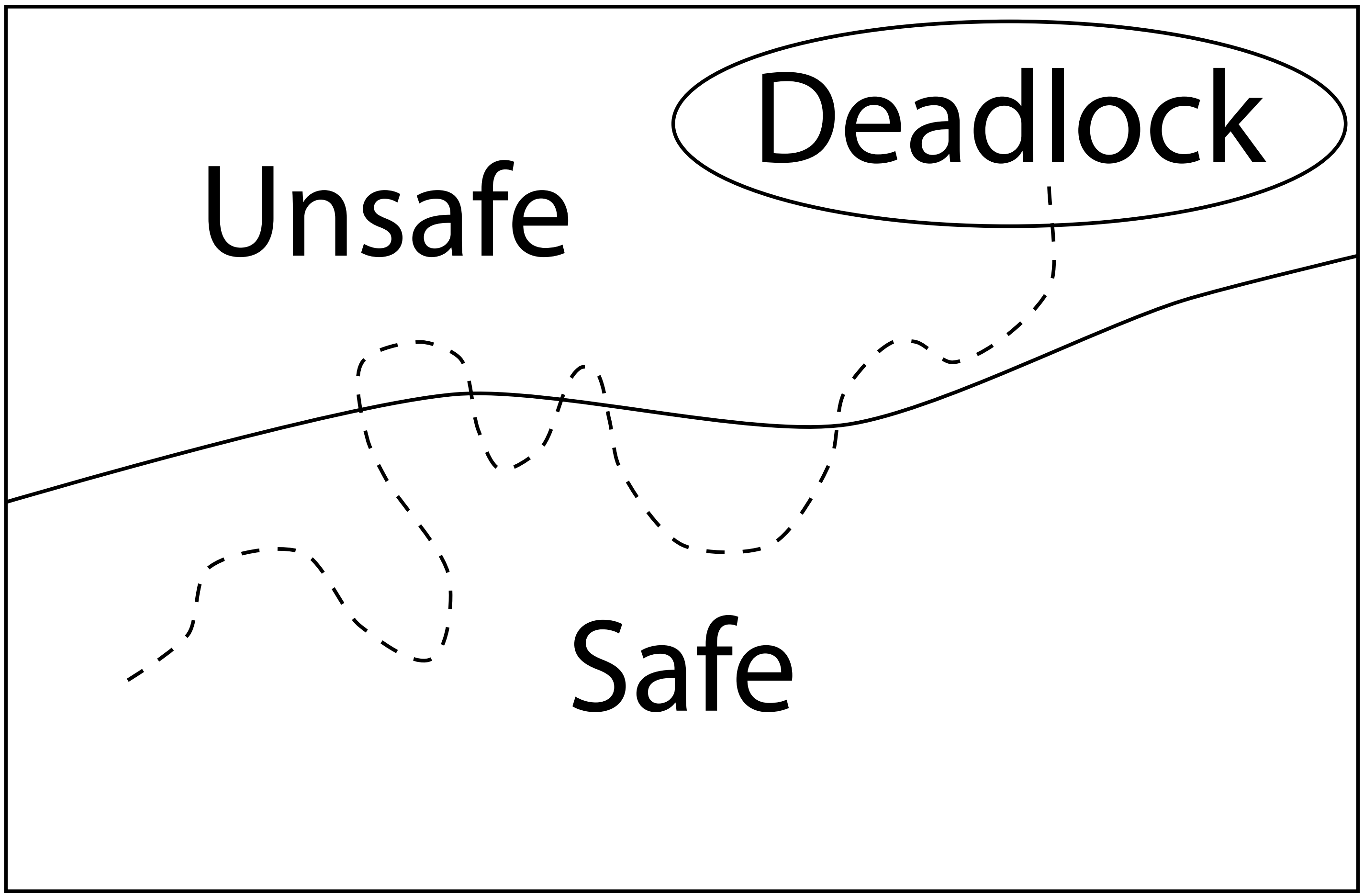
- Prevention can be too conservative – can we do better?
- Avoidance
  - Provide information in advance about what resources will be needed by processes
  - System only grants resource requests if it knows that deadlock cannot happen
  - Avoids circular dependencies
- Tough
  - Hard to determine all resources needed in advance
  - Good theoretical problem, not as practical to use

Banker's Algorithm

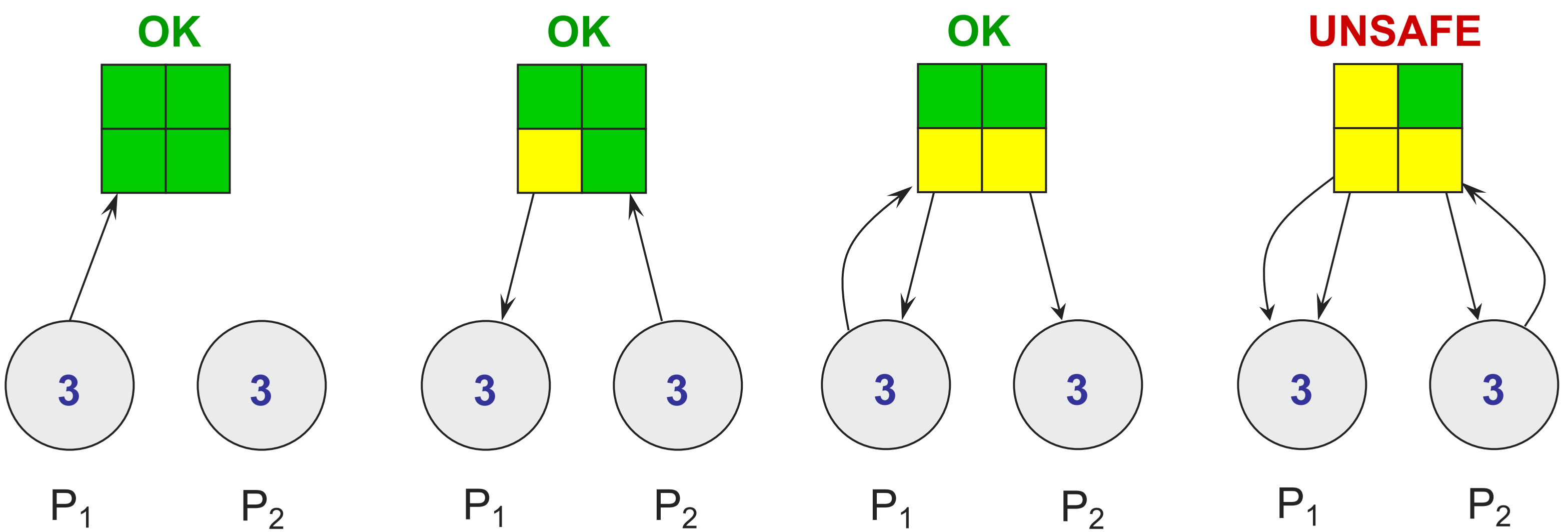
- The Banker's Algorithm is the classic approach to deadlock avoidance for resources with multiple units

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

Possible System States



Banker's Algorithm Simplified



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