Deadlock Solutions: Avoidance, Detection, and Recovery

CS 241

March 30, 2012

University of Illinois

Deadlock: definition

There exists a cycle of processes such that each process cannot proceed until the next process takes some specific action.

Result: all processes in the cycle are stuck!

Deadlock solutions

Prevention

- Design system so that deadlock is impossible

Avoidance

- Steer around deadlock with smart scheduling

Detection & recovery

- Check for deadlock periodically
- Recover by killing a deadlocked processes and releasing its resources

Do nothing

- Prevention, avoidance and detection/recovery are expensive
- If deadlock is rare, is it worth the overhead?
- Manual intervention (kill processes, reboot) if needed

Last time: Deadlock Prevention

#1: No mutual exclusion

- Thank you, Captain Obvious

#2: Allow preemption

- OS can revoke resources from current owner

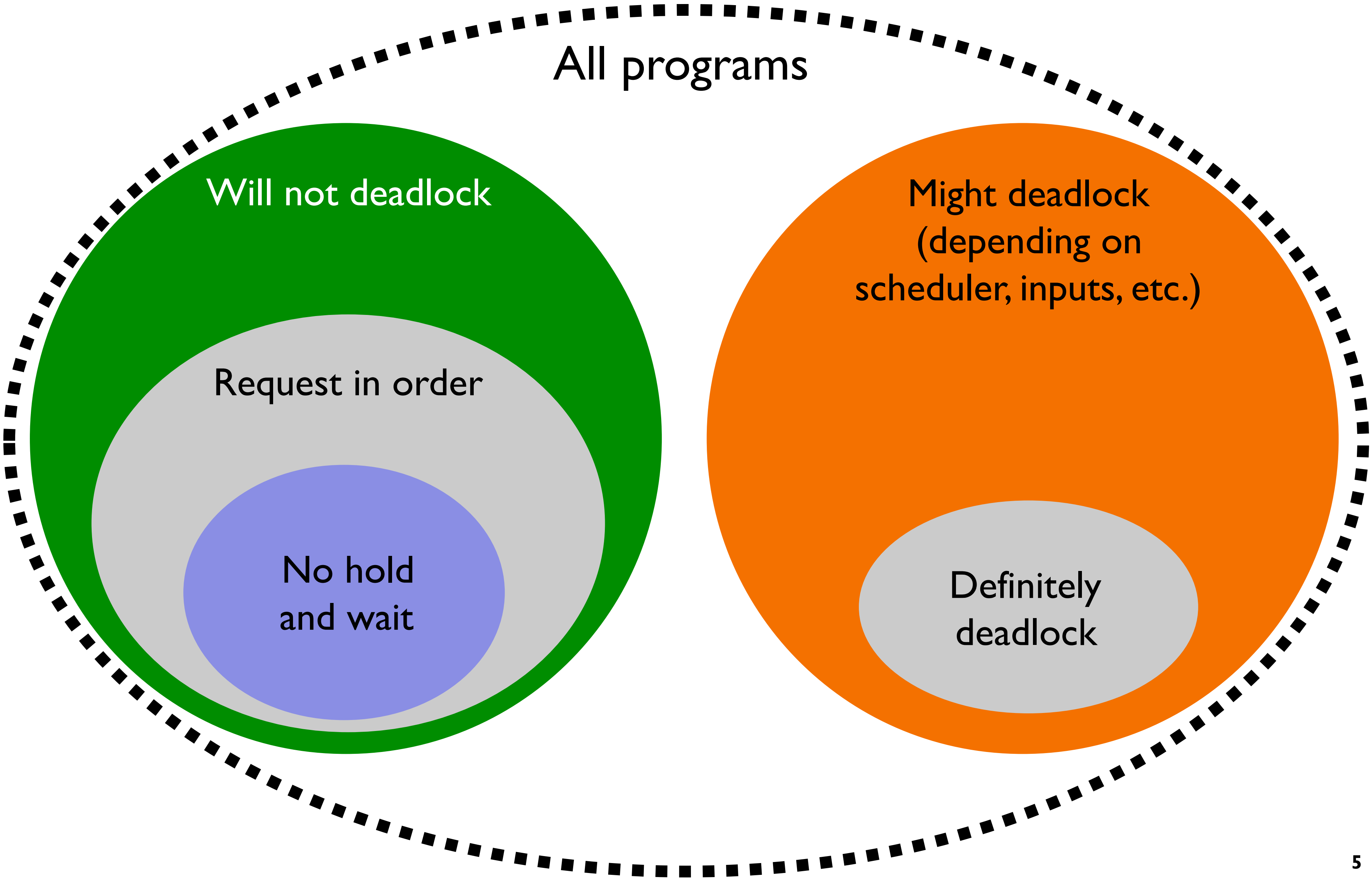
#3: No hold and wait

- When waiting for a resource, must not currently hold any resource

#4: Request resources in order

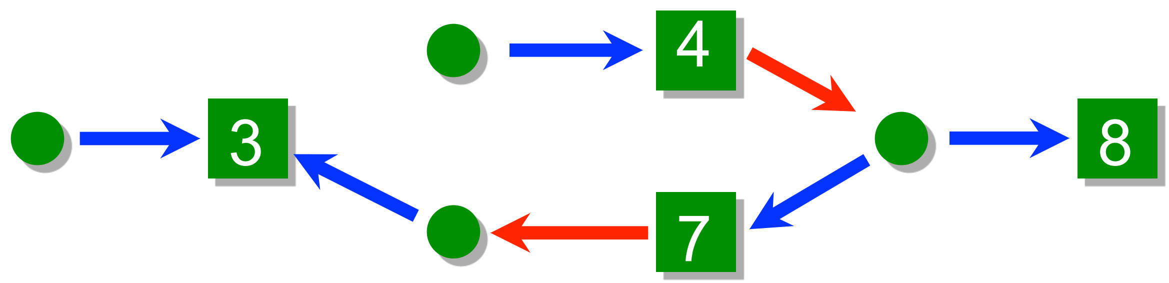
- When waiting for resource *i*, must not currently hold any resource $j > i$
- As you can see: If your program satisfies #3 then it satisfies #4

“Request In Order” is more permissive



Are we always in trouble without ordering resources?

No, not always:

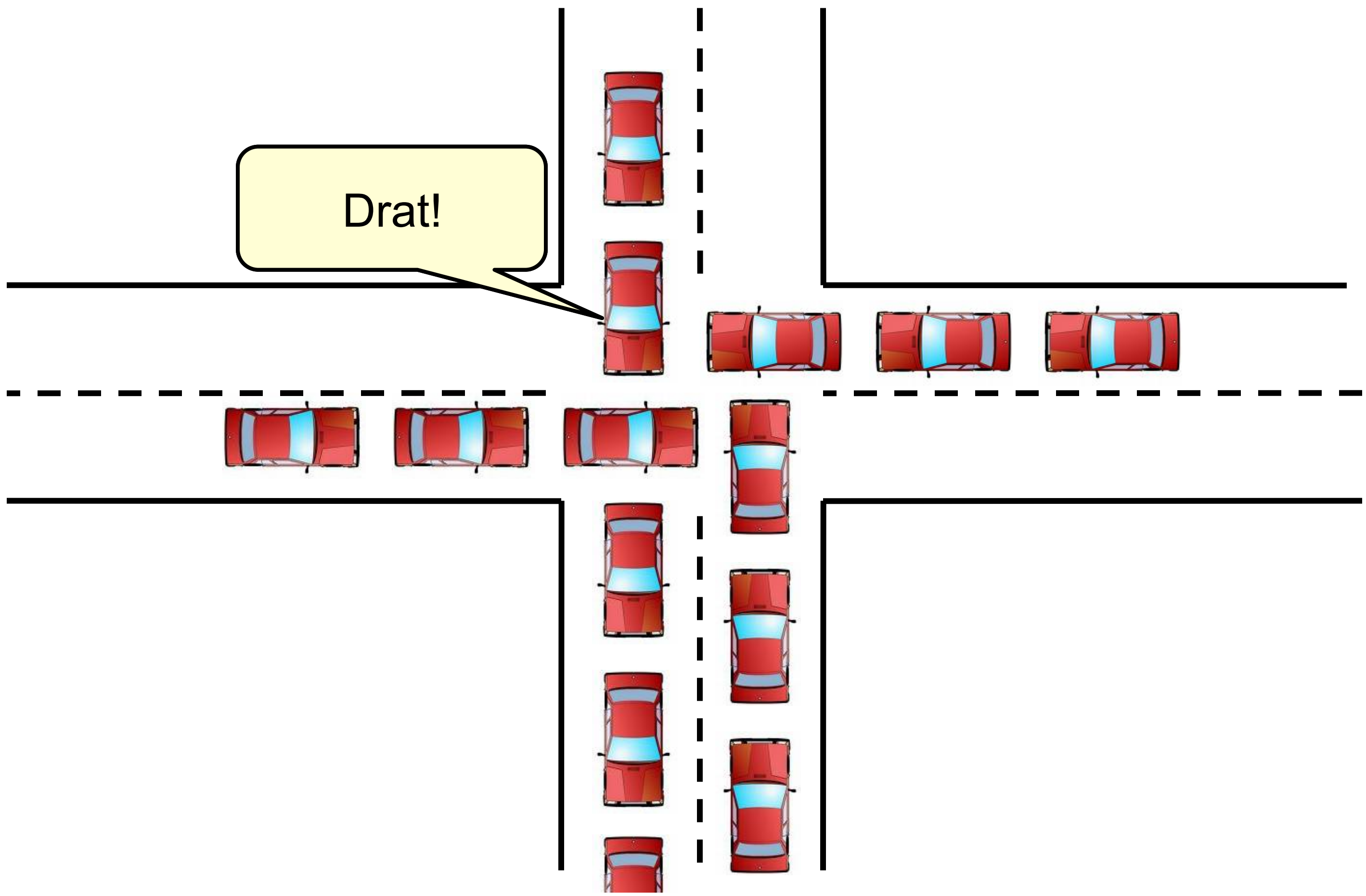


Ordered resource requests are sufficient to avoid deadlock, but not necessary

Convenient, but may be conservative

Q: What's the rule of the road?

What's the law? Does it resemble one of the rules we saw?



Deadlock Avoidance

Deadlock Avoidance

Idea: Steer around deadlock with smart scheduling

Assume OS knows:

- Number of available instances of each resource
  - Each individual mutex lock is a resource with one instance available
  - Each individual semaphore is a resource with possibly multiple "instances" available
- For each process, current amount of each resource it owns
- For each process, maximum amount of each resource it might ever need
  - For a mutex this means: Will the process ever lock the mutex?

Assume processes are independent

- If one blocks, others can finish if they have enough resources

How to guide the system down a safe path of execution

Helper function: is a given state safe?

- Safe = there's definitely a way to finish the processes without deadlock

When a resource allocation request arrives

- Pretend that we approve the request
- Call function: Would we then be safe?
- If safe,
  - Approve request
- Otherwise,
  - Block process until its request can be safely approved
  - Some other process is scheduled in the meantime

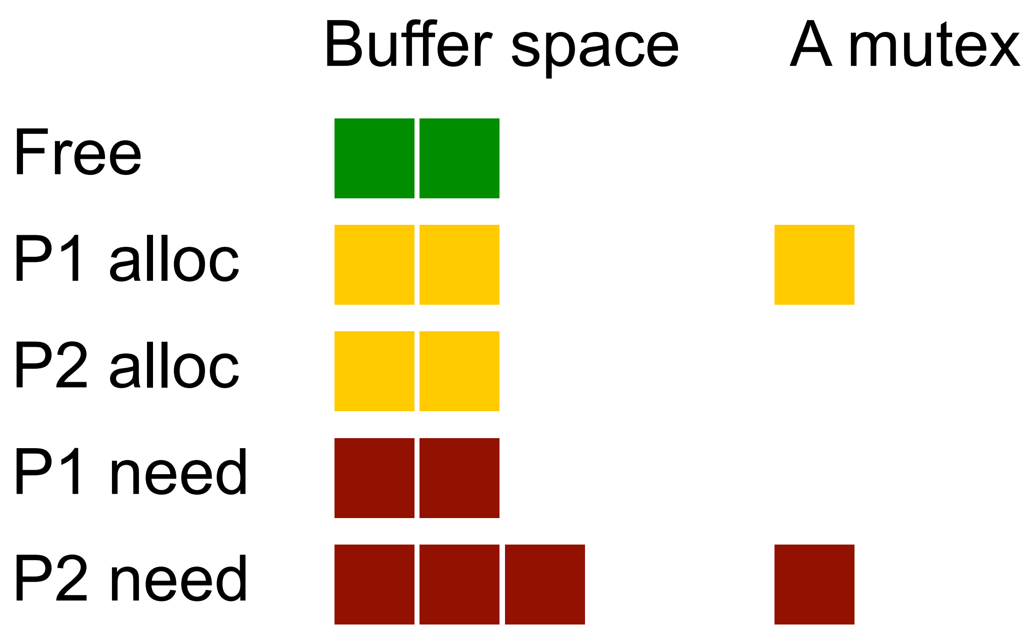
This is called the Banker's Algorithm

- Dijkstra, 1965

What is a state?

For each resource,

- Current amount available
- Current amount allocated to each process
- Future amount needed by each process (maximum)



When is a state safe?

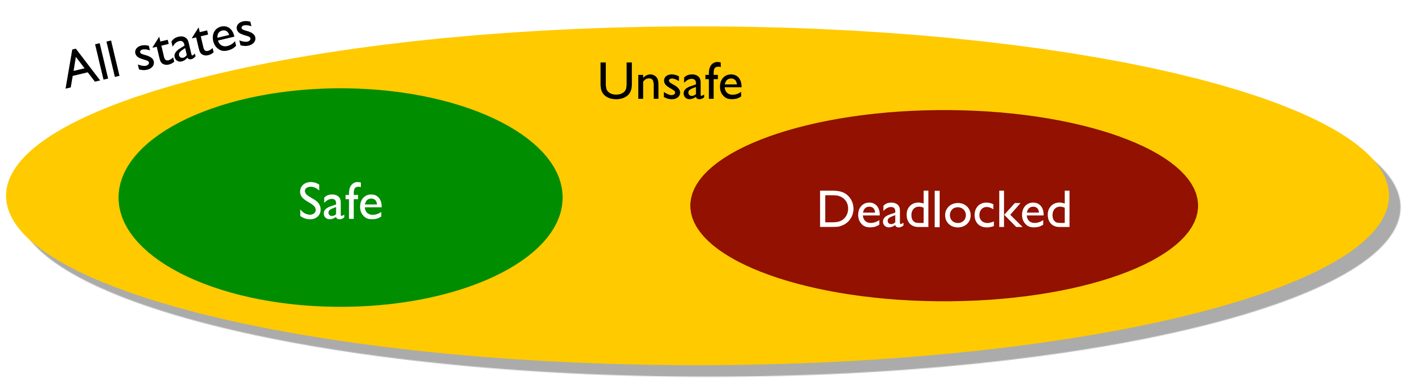
There is an execution order that can finish

In general, that's hard to predict

- So, we're conservative: find sufficient conditions for safety
- i.e., make some pessimistic assumptions

Pessimistic assumptions:

- A process might request its maximum resources at any time
- A process will never release its resources until it's done



Computing safety

"There is an execution order that can finish"

Search for an order P1, P2, P3, ... such that:

- P1 can finish using what it has plus what's free
- P2 can finish using what it has + what's free + what P1 releases when it finishes
- P3 can finish using what it has + what's free + what P1 and P2 will release when they finish
- ...

Computing safety

"There is an execution order that can finish"

More specifically... Search for an order P1, P2, P3, ... such that:

- P1's max resource needs ≤ what it has + what's free
- P2's max resource needs ≤ what it has + what's free + what P1 will release when it finishes
- P3's max resource needs ≤ what it has + what's free + what P1 and P2 will release when they finish
- ...

But how do we find that order?

Inspiration

Playing Pickup Sticks with Processes

Pick up a stick on top

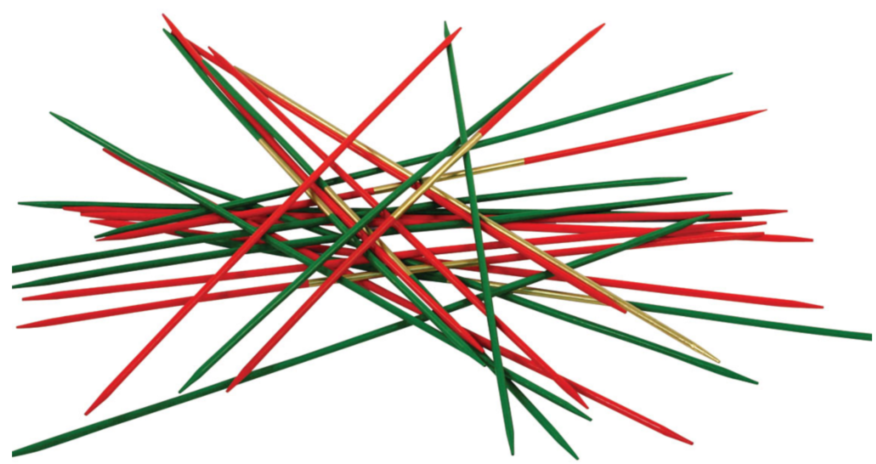
- = Find a process that can finish with what it has plus what's free

Remove stick

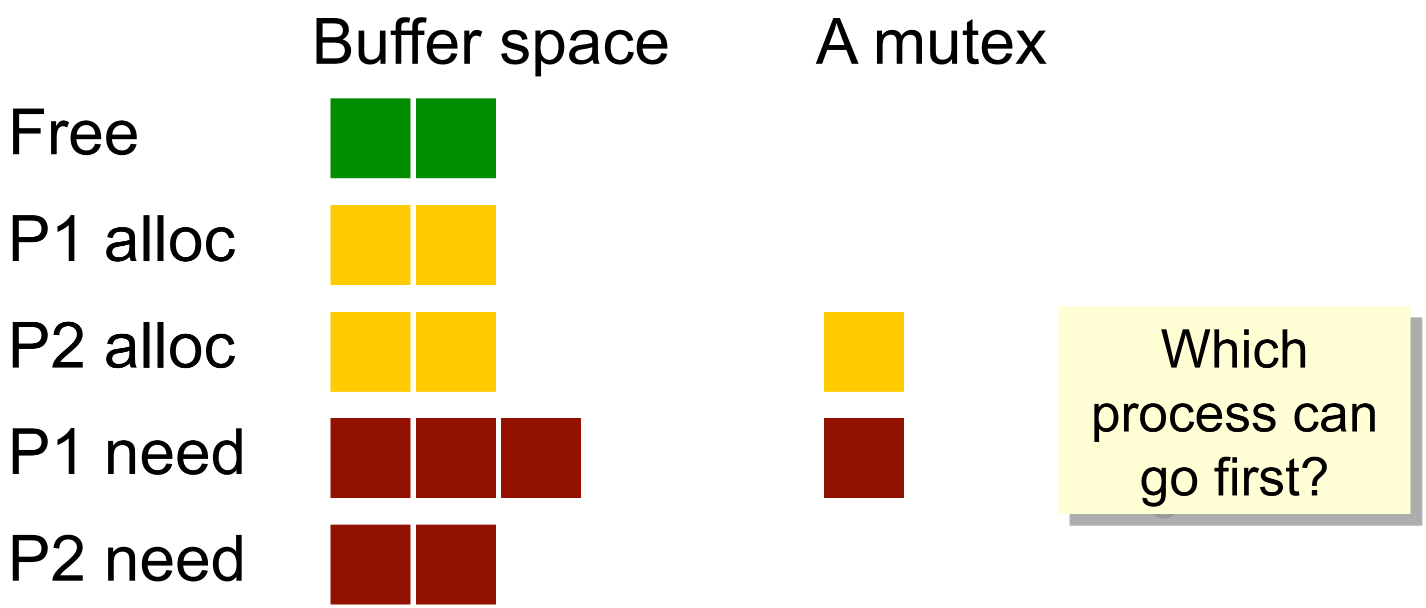
- = Process finshes & releases its resources

Repeat until...

- ...all processes have finished
  - Answer: safe
- ...or we get stuck
  - Answer: unsafe



Try it: is this state safe?



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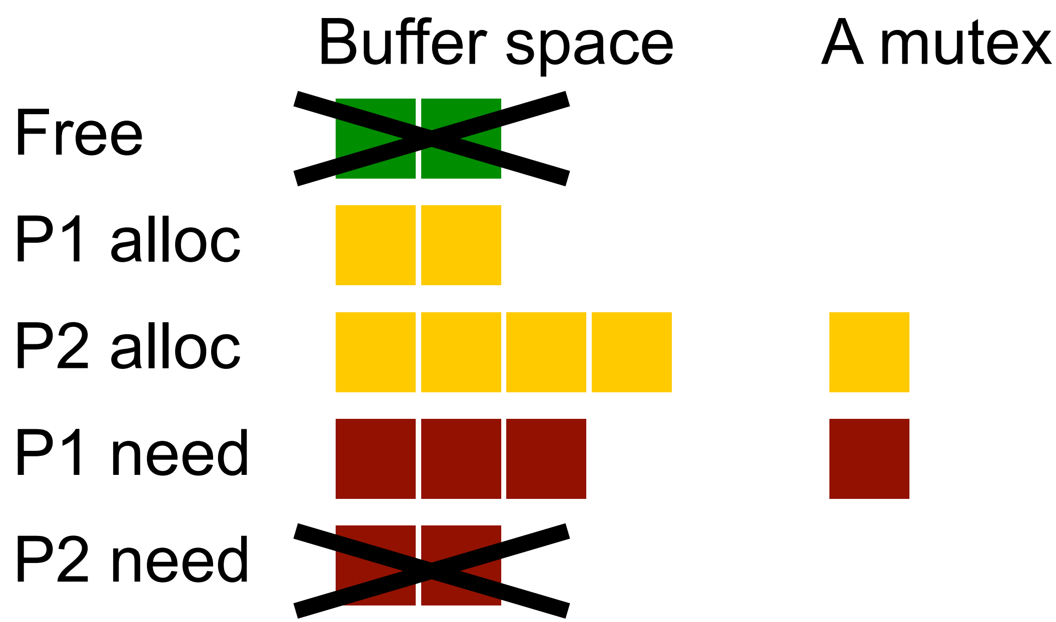
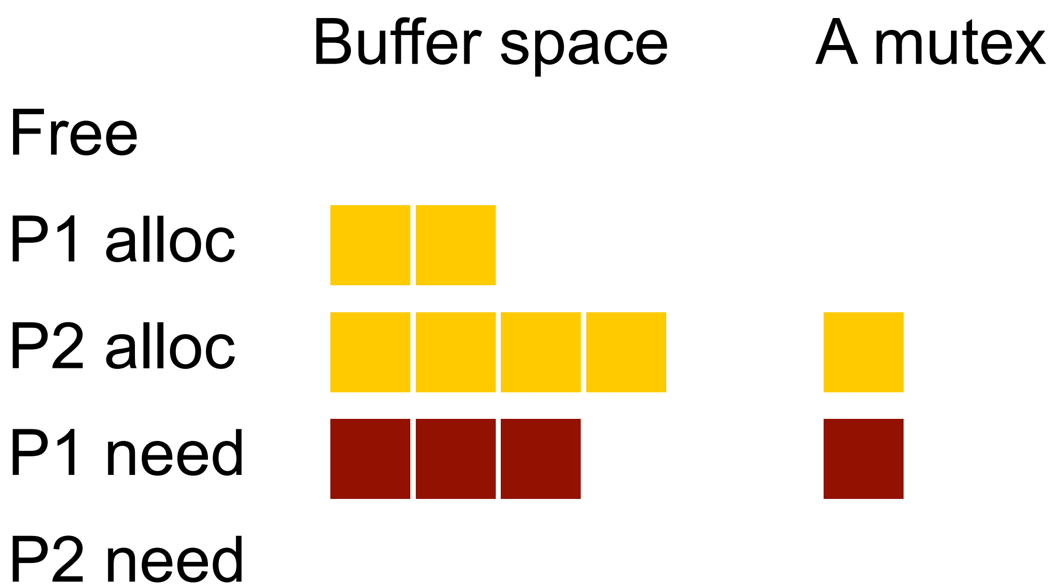


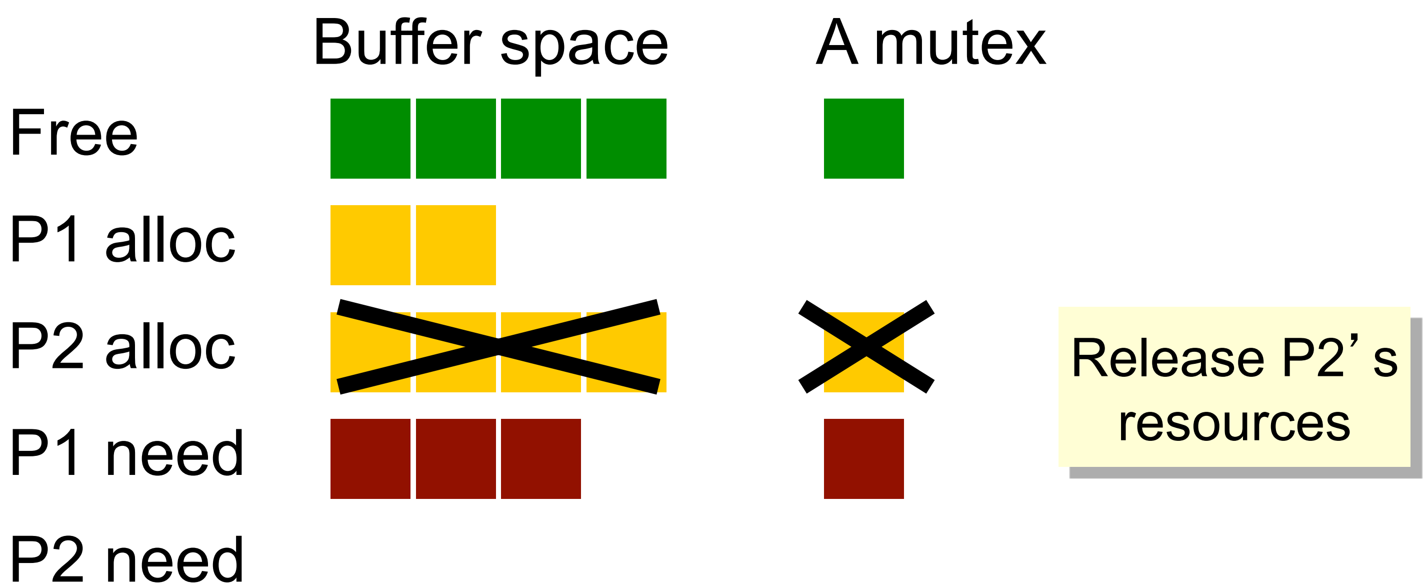
Start with P2

Try it: is this state safe?



Release P2's resources

Try it: is this state safe?



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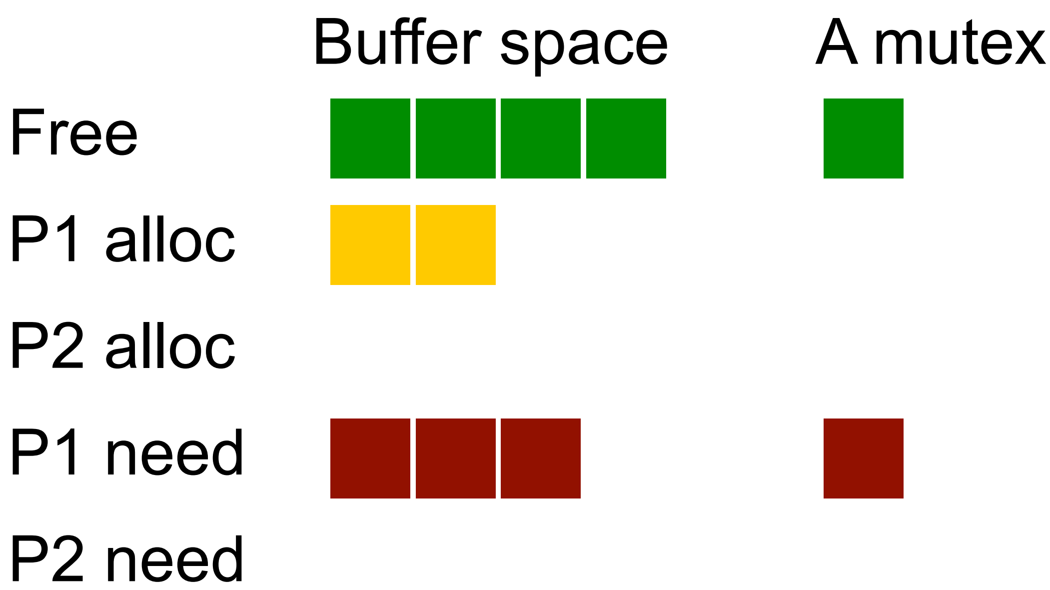
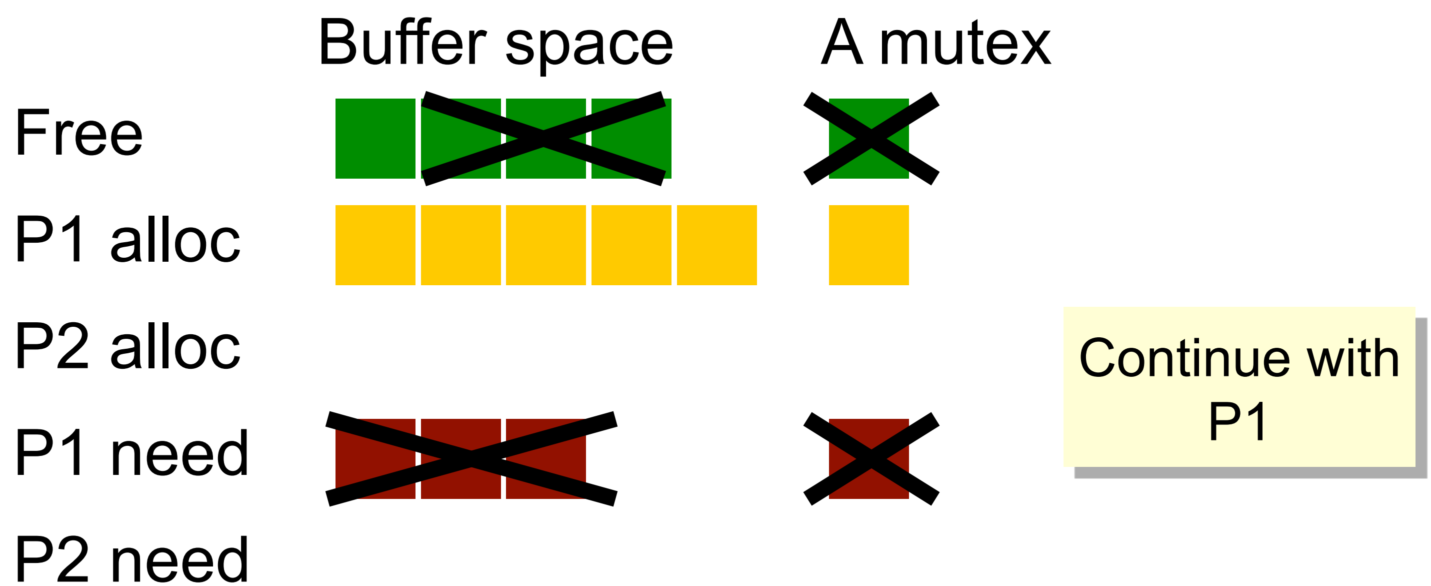


Continue with P1

Try it: is this state safe?



Try it: is this state safe?

Buffer space A mutex

Free

P1 alloc

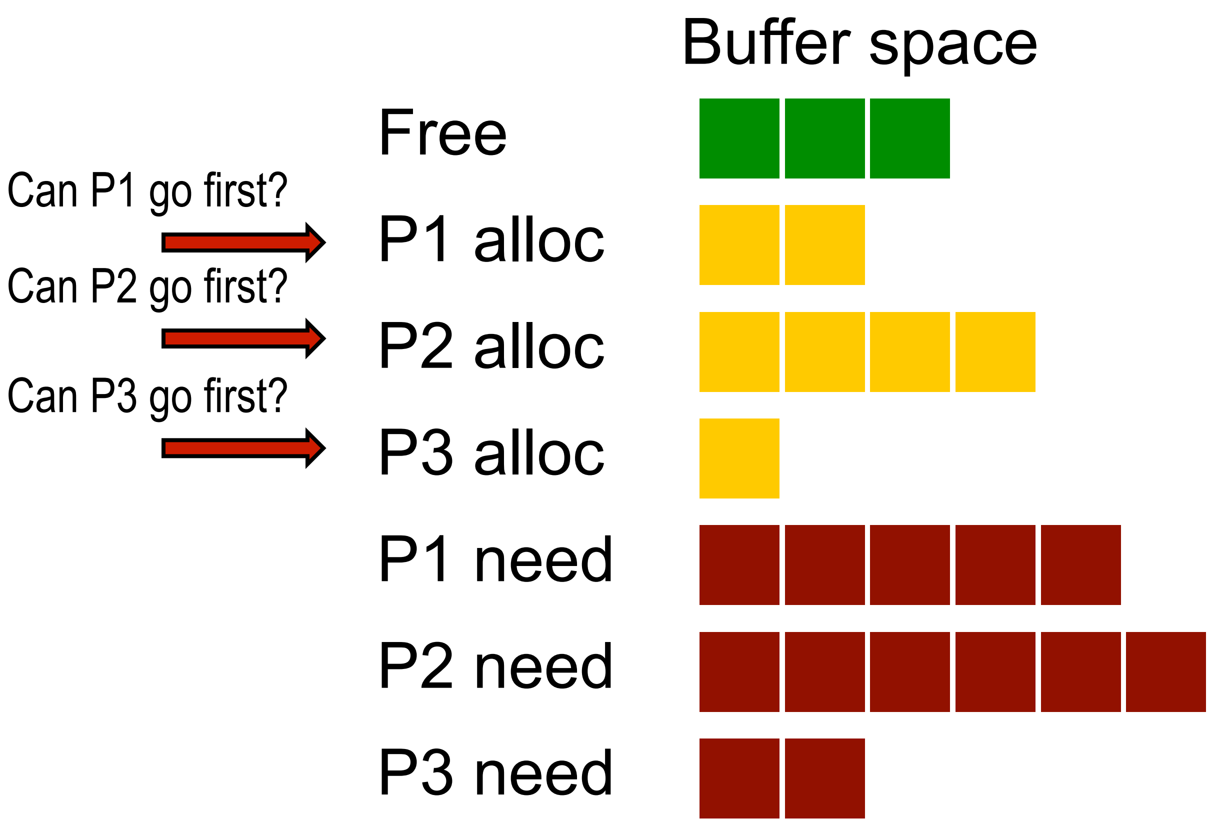
P2 alloc

P1 need

P2 need

Yes, it's safe: Order is P2, P1

Example 2: Is this state safe?



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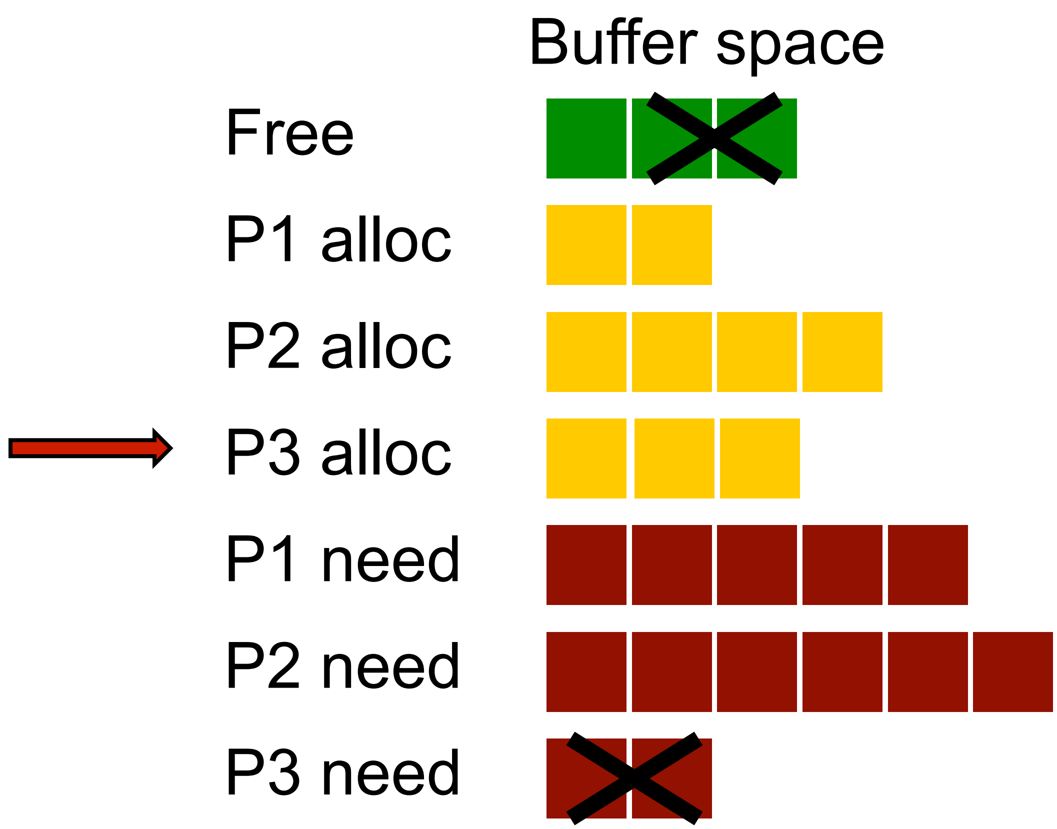

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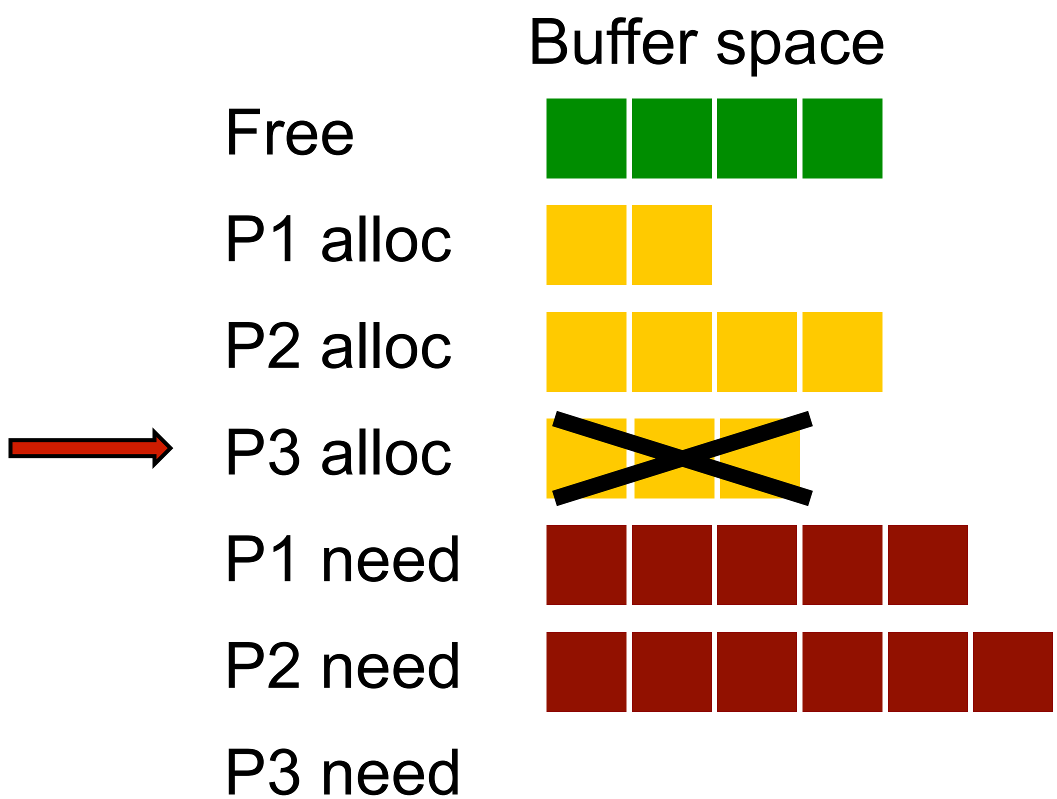

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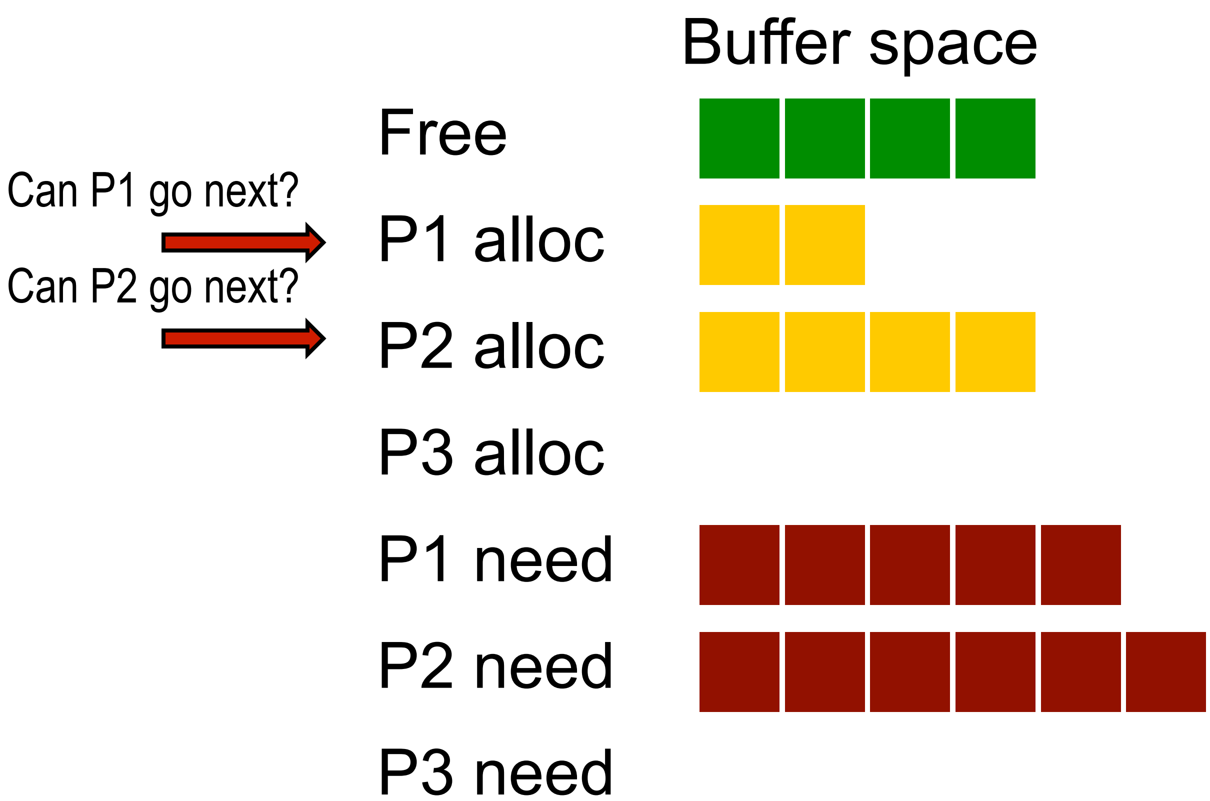


Unsafe!

Deadlock Detection & Recovery

Deadlock Detection

Check to see if a deadlock has occurred!

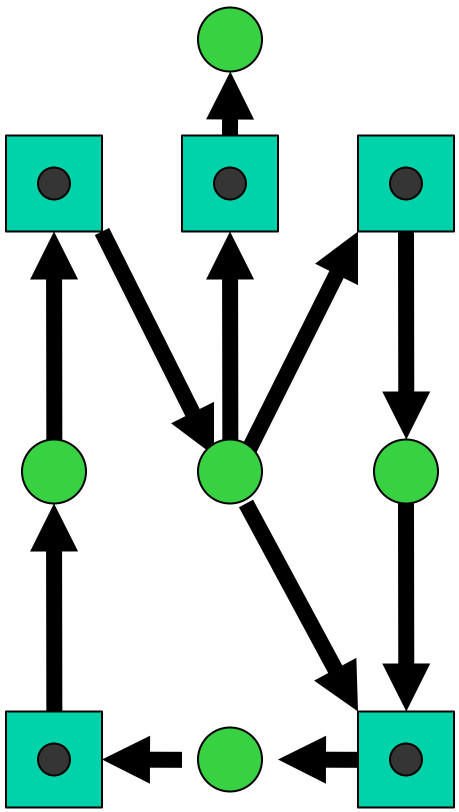
Special case: Single resource per type

- E.g., mutex locks (value is zero or one)
- Check for cycles in the resource allocation graph

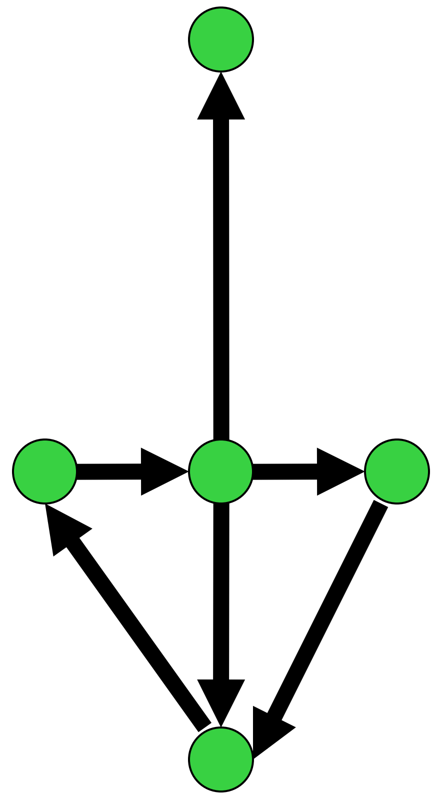
General case

- E.g., semaphores, memory pages, ...
- See book, p. 355 – 358

Dependencies between processes



Resource allocation graph



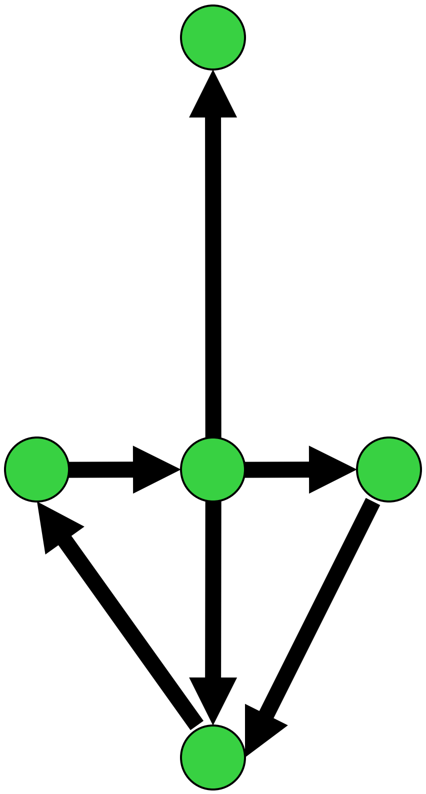
Corresponding process dependency graph

Deadlock Recovery

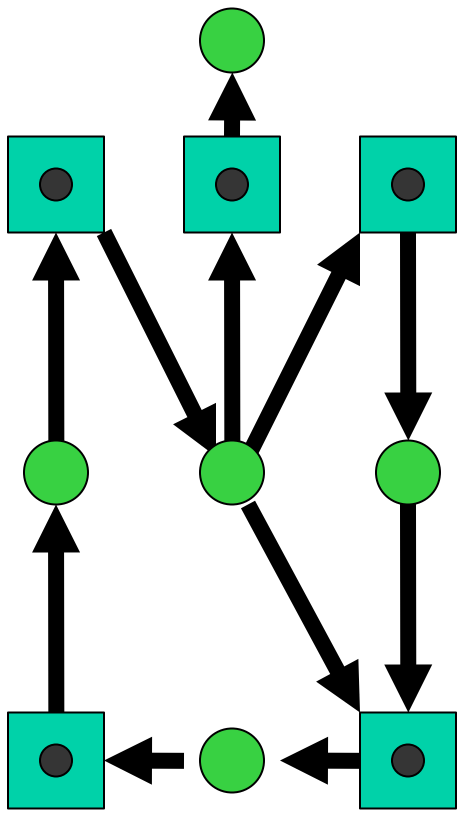
Recovery idea: get rid of the cycles in the process dependency graph

Options:

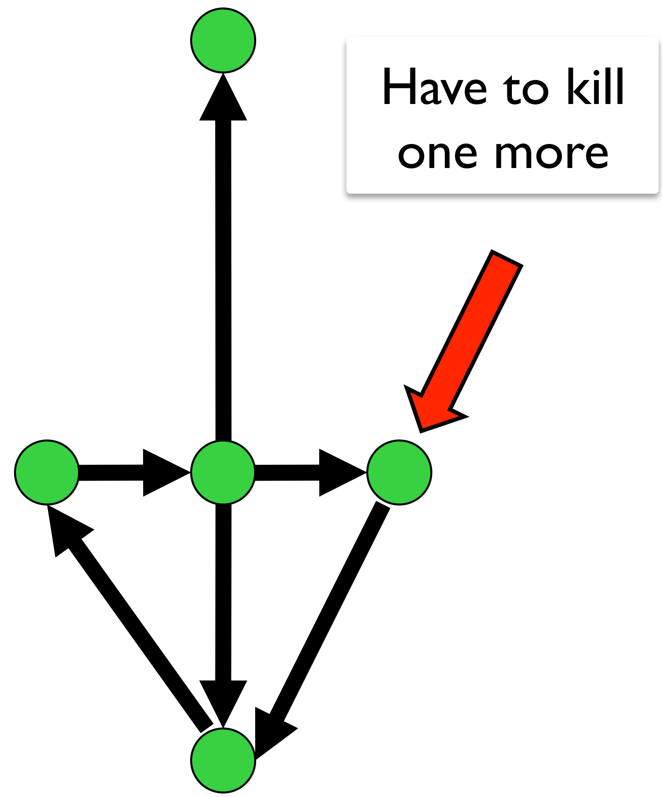
- Kill all deadlocked processes
- Kill one deadlocked process at a time and release its resources
- Steal one resource at a time
- Roll back all or one of the processes to a checkpoint that occurred before they requested any resources, then continue
  - Difficult to prevent indefinite postponement



Deadlock Recovery



Resource allocation graph



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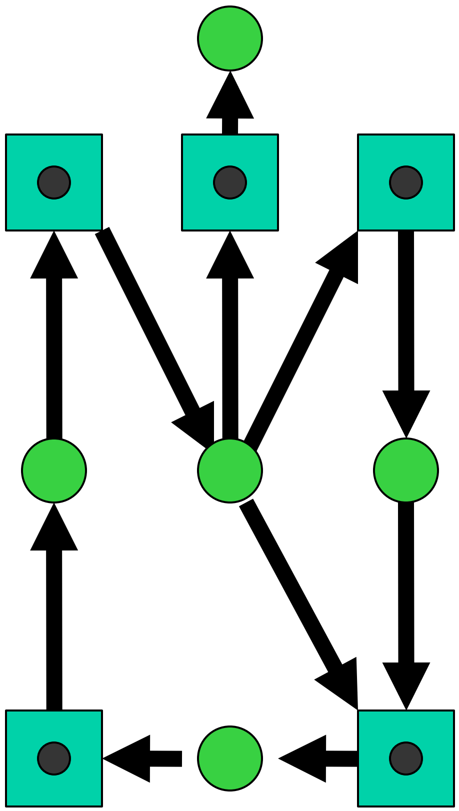

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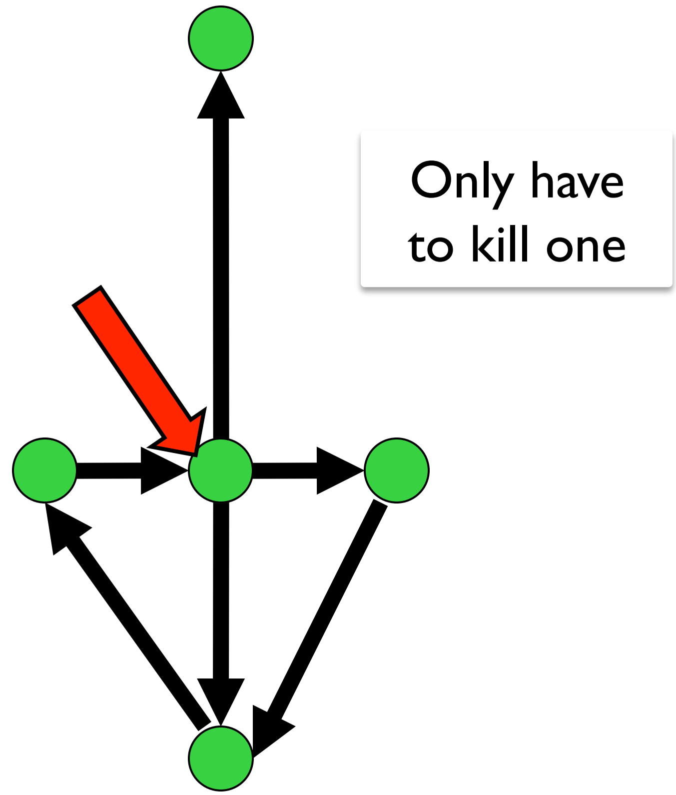

Corresponding process dependency graph

Deadlock Recovery

How should we pick a process to kill?

We might consider...

- process priority
- current computation time and time to completion
- amount of resources used by the process
- amount of resources needed by the process to complete
- the minimal set of processes we need to eliminate to break deadlock
- is process interactive or batch?

Rollback instead of killing processes

Selecting a victim

- Minimize cost of rollback (e.g., size of process's memory)

Rollback

- Return to some safe state
- Restart process for that state
- Note: Large, long computations are sometimes checkpointed for other reasons (reliability) anyway

Challenge: Starvation

- Same process may always be picked as victim
- Fix: Include number of rollbacks in cost factor

Deadlock Summary

Deadlock: cycle of processes/threads each waiting for the next

- Nasty timing-dependent bugs!

Detection & Recovery

- Typically very expensive to kill / checkpoint processes

Avoidance: steer around deadlock

- Requires knowledge of everything an application will request
- Expensive to perform on each scheduling event

Prevention (ordered resources)

- Imposes conservative rules on application that preclude deadlock
- Application can do it; no special OS support

Deadlock Summary

Typical solution:

- OS (Unix/Windows) do nothing (Ostrich Algorithm)
- Application uses general-purpose deadlock prevention

Transaction systems (e.g., credit card processing) may use detection/recovery/avoidance