Deadlock (2)

Roger Dannenberg
Dave Eckhardt

Synchronization

- Project 2 progress
  - Don't split the coding in a bad way
    - One popular bad way: Person A codes list/queue, syscall stubs
    - Person B codes everything else
    - Person A will probably be in big trouble on the exam

Synchronization

- Project 2 progress
  - Should have created a thread
  - Should have passed `startle`
  - Should be close to passing some mutex/cvar tests

Outline

- Review
  - Prevention/Avoidance/Detection
- Today
  - Avoidance
  - Detection/Recovery

Deadlock - What to do?

- Prevention
  - ***Pass a law*** against one of four ingredients
- Avoidance
  - Processes ***pre-declare usage patterns***
  - Request manager avoids “unsafe states”
- Detection/Recovery
  - Clean up only when trouble really happens

Deadlock Avoidance – Motivation

- Deadlock prevention ***passes laws***
  - Unenforceable: shared CD-writers???
  - Annoying
    - Mandatory lock-acquisition order may induce starvation
      - Locked 23, 24, 25, ... 88, 89, now must lock 0...
    - ***Lots*** of starvation opportunities
- Do we really need such strict laws?
  - Couldn't we be more "situational"?

Deadlock *Avoidance* Assumptions

1. Processes pre-declare usage patterns
   - Could enumerate all paths through allocation space
     - Request R1, Request R2, Release R1, Request R3, ...

       \- or -
     - Request R1, Request R3, Release R3, Request R1, ...
   - Easier: declare ***maximal resource usage***
     - I will never need more than 7 tape drives and 1 printer

Deadlock Avoidance Assumptions

2. Processes proceed to completion
   - Don't hold onto resources forever
     - Obvious how this helps!
   - Complete in “reasonable” time
     - So it is ok, if necessary, to stall P2 until P1 completes
     - We will try to avoid this

Safe Execution Sequence

- $(P_1, P_2, P_3, \ldots P_n)$ is a ***safe sequence*** if
  - Every process P_i can be satisfied using
    - currently-free resources F plus
    - resources currently held by $P_1, P_2, \ldots P_i$
- P_i's waiting is bounded by this sequence
  - P_1 will run to completion, release resources
  - P_2 can complete with F + P_1's + P_2's
  - P_3 can complete with F + P_1's + P_2's + P_3's
  - P_i won't wait forever, so no wait cycle, no deadlock □

Safe State

- System in a ***safe state*** iff...
  - there exists at least one safe sequence
- Worst-case situation
  - Every process asks for every resource at once
  - Follow the safe sequence (run processes serially)
    - Slow, but not as slow as a deadlock!
- Serial execution is ***worst-case***, not typical
  - Usually execute in parallel

Request Manager - Naïve

- Grant request if
  - Enough resources are free now
- Otherwise, tell requesting process to ***wait***
  - While ***holding*** resources
    - Which are ***non-preemptible, ...***
- Easily leads to deadlock

Request Manager – Avoidance

- Grant request if
  - Enough resources are free now, ***and***
  - Enough resources would ***still*** be free
    - For some process to complete and release resources
    - And then another one
    - And then you
- Otherwise, wait
  - While holding a smaller set of resources...
    - ***...which we previously proved other processes can complete***

Example (from text)

Who	Max	Has	Room
P0	10	5	5
P1	4	2	2
P2	9	2	7
System	12	3	-

Max=declared

Has=allocated

Room=**Max**−**Ha**

"Is it safe?"

"Yes it's safe; it's very safe, so safe you wouldn't believe it

(from "Marathon M

P1: 2 ⇒ 4

Who	Max	Has	Room
P0	10	5	5
P1	4	2	2
P2	9	2	7
System	12	3	-

Who	Max	Has	Room
P0	10	5	5
P1	4	4	0
P2	9	2	7
System	12	1	-

P1: Complete

Who	Max	Has	Room
P0	10	5	5
P1	4	4	0
P2	9	2	7
System	12	1	-

Who	Max	Has	Room
P0	10	5	5
P2	9	2	7
System	12	5	-

P0: 5 $\Rightarrow$ 10

Who	Max	Has	Room
P0	10	5	5
P2	9	2	7
System	12	5	-

Who	Max	Has	Room
P0	10	10	0
P2	9	2	7
System	12	0	-

P0: Complete

Who	Max	Has	Room
P0	10	10	0
P2	9	2	7
System	12	0	-

Who	Max	Has	Room
P2	9	2	7
System	12	10	-

"Run P1, P0, P2" is a ***safe sequence***.

So the system was in a ***safe state***.

Example (from text)

Who	Max	Has	Room
P0	10	5	5
P1	4	2	2
P2	9	2	7
System	12	3	-

"Can P2 ask for more?"

"Is it safe?"

"No, it's not safe; it's very dangerous, be careful.

P2: 2 ⇒ 3?

Who	Max	Has	Room
P0	10	5	5
P1	4	2	2
P2	9	2	7
System	12	3	-

Who	Max	Has	Room
P0	10	5	5
P1	4	2	2
P2	9	3	6
System	12	2	-

Now, only P1 can be satisfied without waiting.

P1: 2 ⇒ 4?

Who	Max	Has	Room
P0	10	5	5
P1	4	2	2
P2	9	3	6
System	12	2	-

Who	Max	Has	Room
P0	10	5	5
P1	4	4	0
P2	9	3	6
System	12	0	-

P1: Complete

Who	Max	Has	Room
P0	10	5	5
P1	4	4	0
P2	9	3	6
System	12	0	-

Who	Max	Has	Room
P0	10	5	5
P2	9	3	6
System	12	4	-

P1: Complete

Who	Max	Has	Room
P0	10	5	5
P2	9	3	6
System	12	4	-

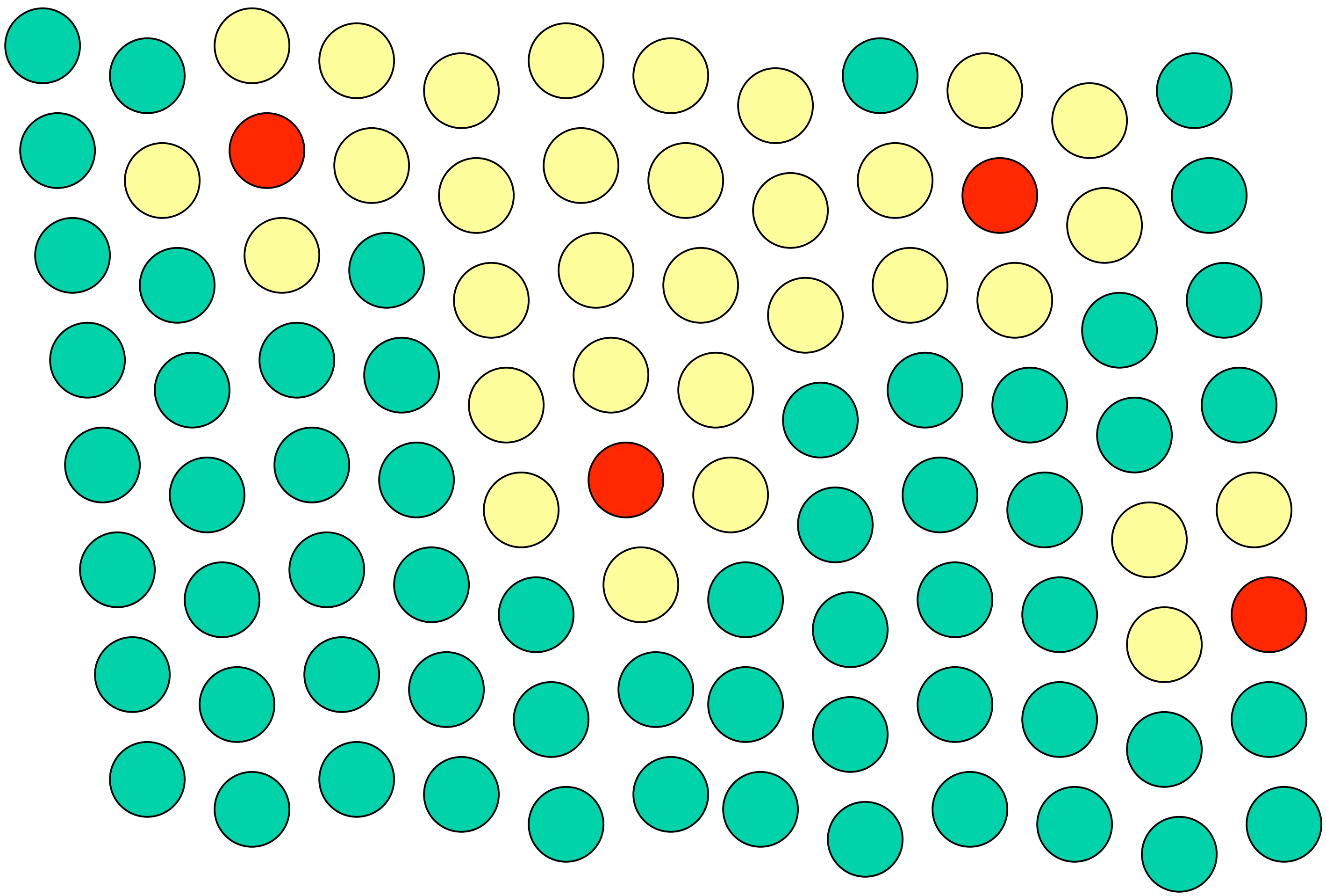
Problem: P0 and P2 are allowed to ask for >4.

If both do, both sleep: ***deadlock***.

Avoidance - Key Ideas

- Safe state
  - Some safe sequence exists
  - Prove it by ***finding one***
- Unsafe state: No safe sequence exists
- Unsafe ***may not be fatal***
  - Processes might exit early
  - Processes might not use max resources today

Safe , Unsafe , Deadlock



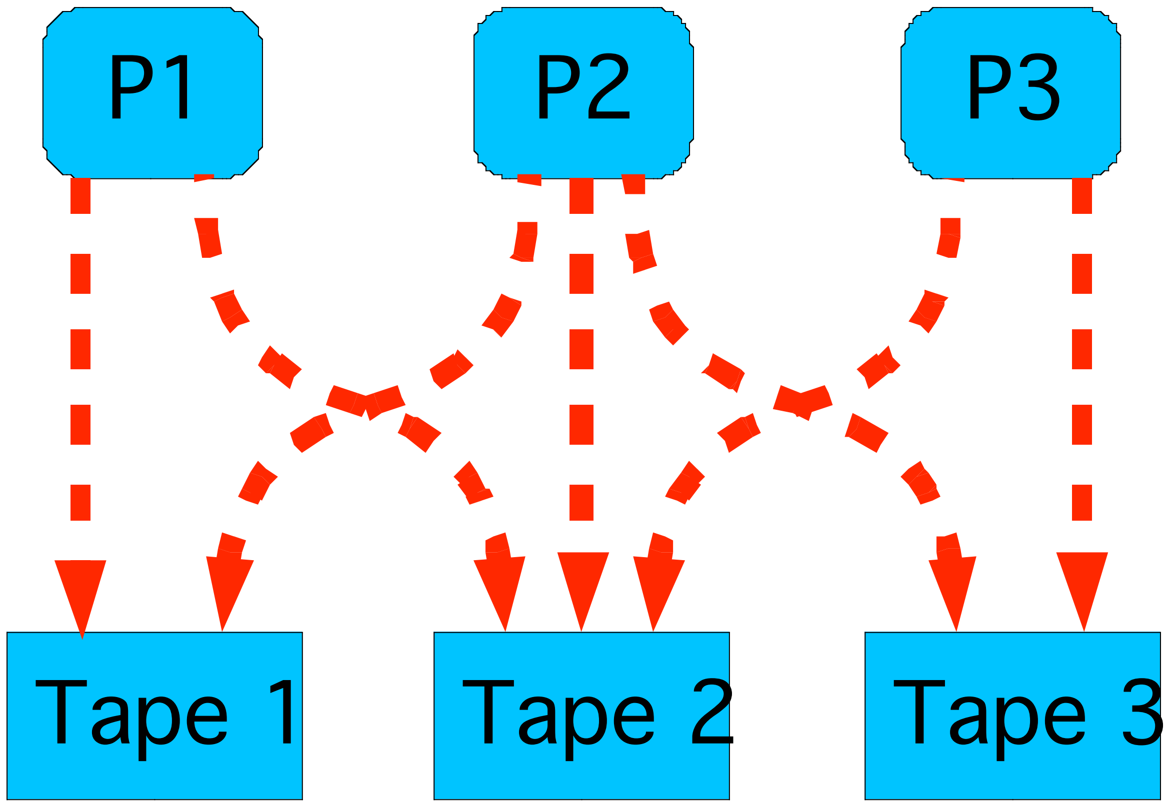
Avoidance – Tradeoff

- Allowing only safe states is more flexible than Prevention
- But rejecting ***all*** unsafe states reduces efficiency
  - System *could* enter unsafe state and then return to safety...
  - How often would the system "retreat from disaster"?
- Hmm...

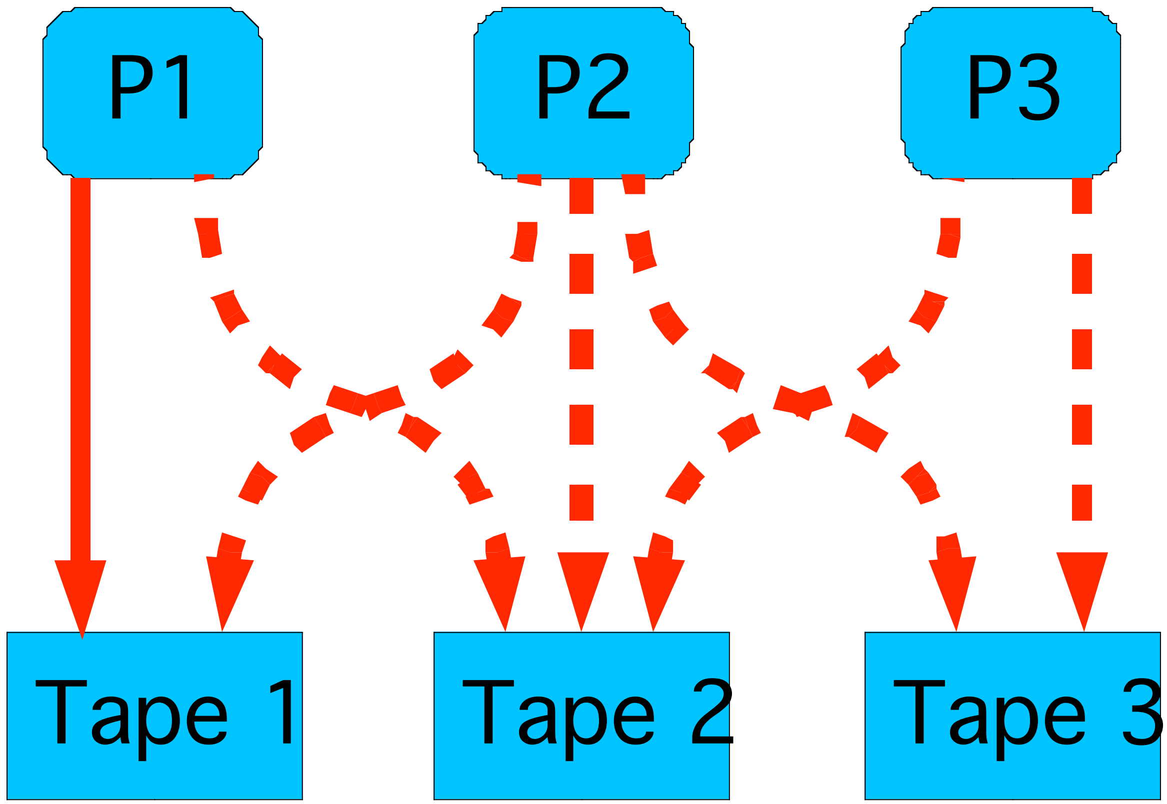
Avoidance - Unique Resources

- Unique resources instead of multi-instance?
  - Graph algorithm
- Three edge types
  - Claim (future request)
  - Request
  - Assign

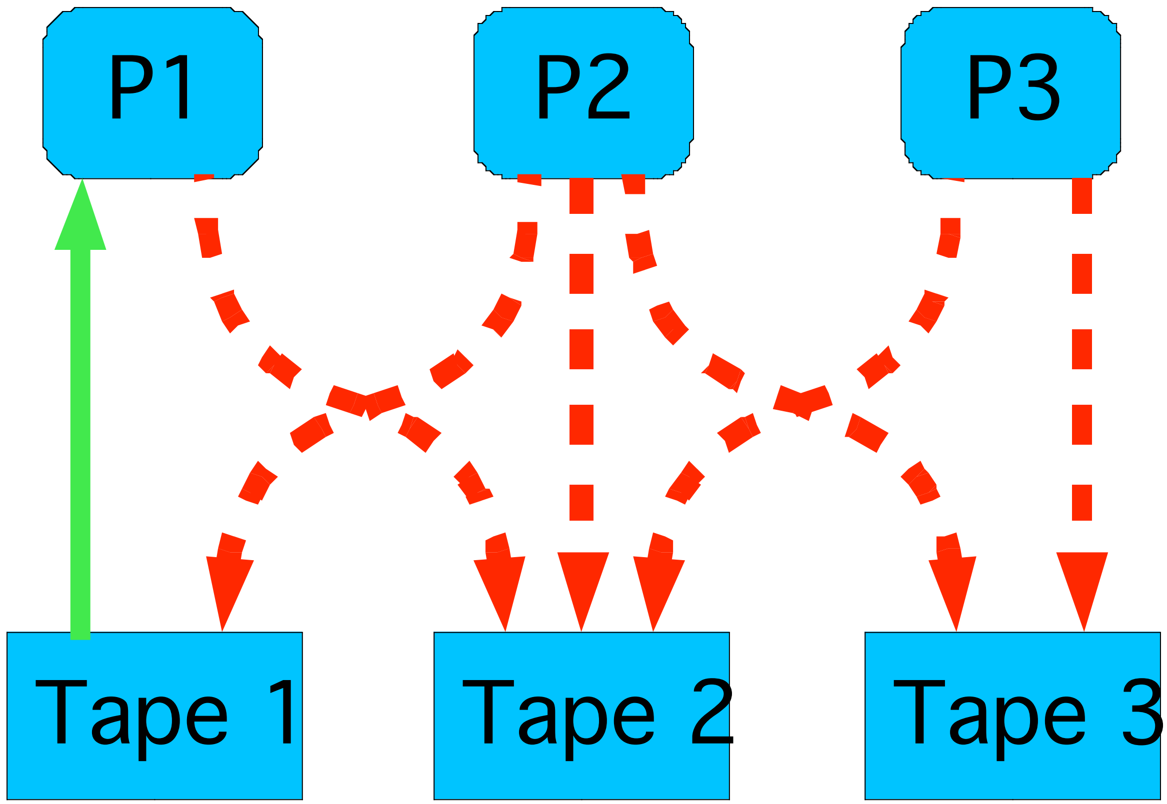
“Claim” (Future-Request) Edges



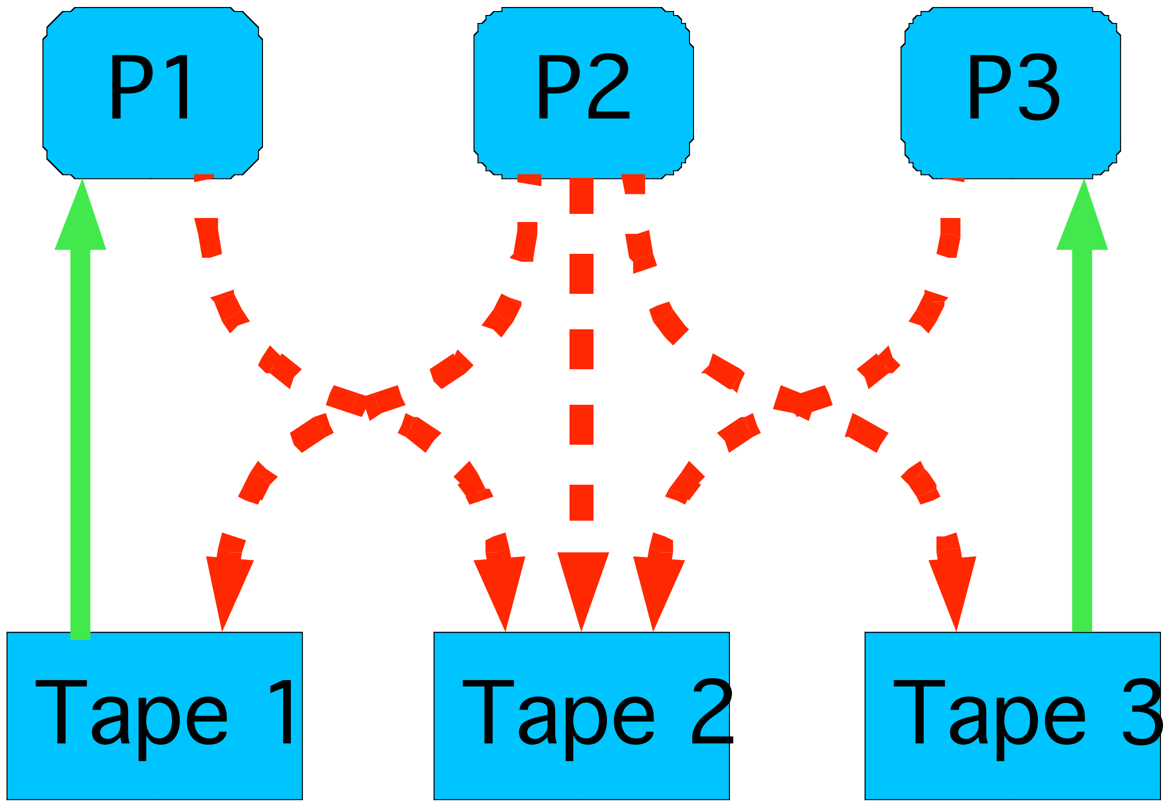
Claim ⇒Request



Request $\Rightarrow$ Assignment



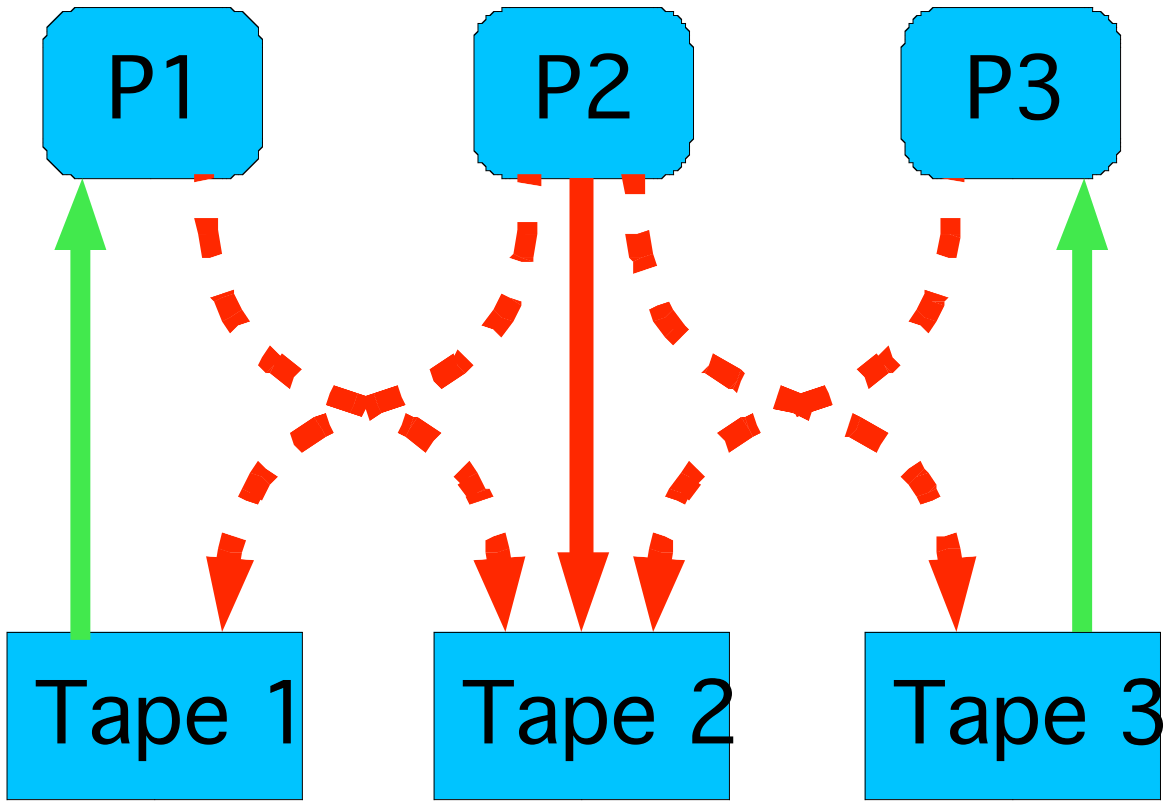
Safe: No Cycle



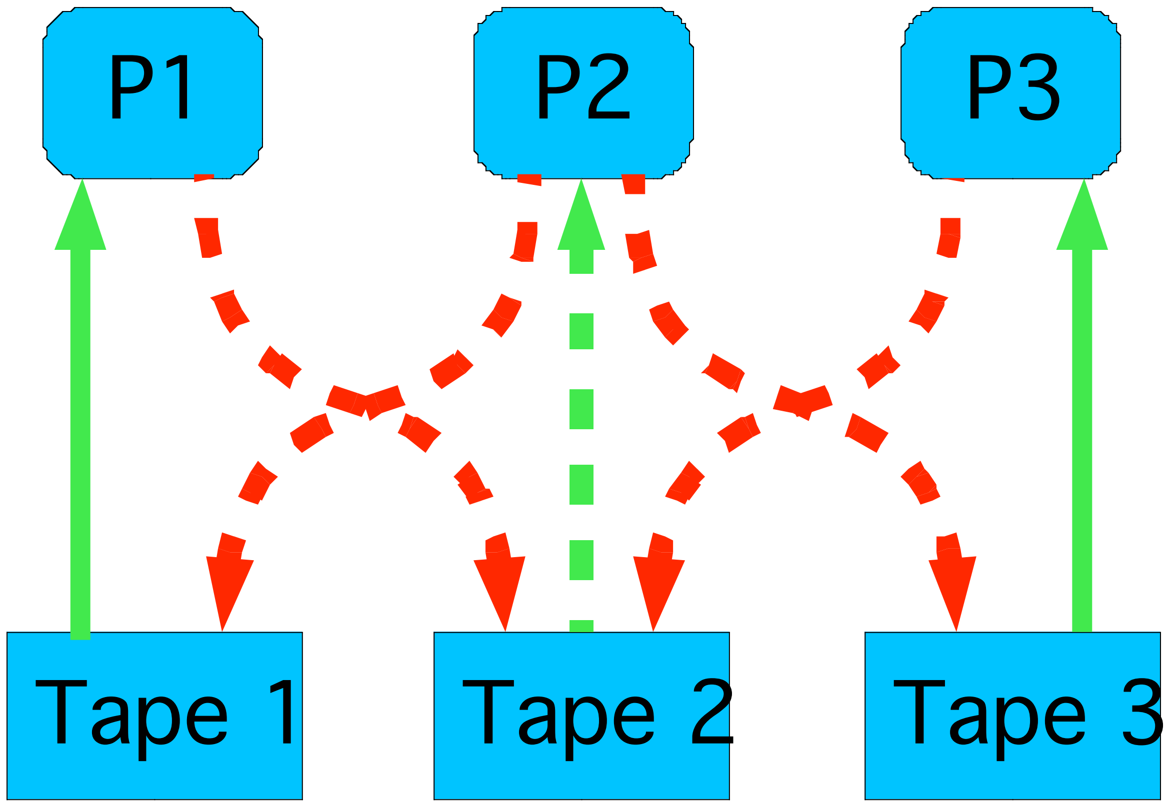
Which Requests Are Safe?

- Pretend to satisfy request
- Look for cycles in resultant graph

A Dangerous Request



See Any Cycles?



Are "Pretend" Cycles Fatal?

- Must we worry about ***all*** cycles?
  - Nobody is waiting on a "pretend" cycle
    - Lots of the edges are only **potential request** edges
  - We don't have a deadlock
- "Is it safe?"

Are “Pretend” Cycles Fatal?

- ***No*** process can, without waiting
  - Acquire maximum-declared resource set
- So ***no process*** can acquire, complete, release
  - (for sure, without maybe waiting)
- Any new request ***could*** form a cycle
  - “No, it's not safe, it's very dangerous, be careful.”
- What to do?
  - Don't grant the request (put the process to sleep ***now***, *before* it gets that resource)

Avoidance - Multi-instance Resources

- Example
  - N interchangeable tape drives
  - Could represent by N tape-drive nodes
  - Needless computational expense
- Business credit-line model
  - Bank assigns maximum loan amount (“credit limit”)
  - Business pays interest on ***current*** borrowing amount

Avoiding “bank failure”

- Bank is “ok” when there is a ***safe sequence***
- One company can
  - Borrow up to its credit limit
  - Do well
  - IPO
  - Pay back its full loan amount
- And then another company, etc.

No safe sequence?

- Company tries to borrow up to limit
  - Bank has no cash
  - Company C1 must wait for money C2 has
  - Maybe C2 must wait for money C1 has
- In real life
  - C1 cannot make payroll
  - C1 goes bankrupt
  - Loan never paid back in full
    - Can model as “infinite sleep”

Banker's Algorithm

```
int cash;
int limit[N]; /* credit limit */
int out[N] /* borrowed */;
boolean done[N]; /* global temp! */
int future; /* global temp! */

int progressor (int cash) {
  for (i = 0; i < N; ++i)
    if (!done[i])
      if (cash >= limit[i] - out[i])
        return (i);
  return(-1);
}
```

Cash on hand is enough so you can borrow entire credit line

Banker's Algorithm

```
boolean is_safe(void) {
  future = cash;
  done[0..N] = false;

  while ((p = progressor(future)) > 0) {
    future += out[p];
    done[p] = true;
  }
  return (done[0..N] == true)
}
```

Banker's Algorithm

```
boolean is_safe(void) {
  future = cash;
  done[0..N] = false;

  while ((p = progressor(future)) > 0) {
    future += out[p];
    done[p] = true;
  }
  return (done[0..N] == true)
}
```

What if progressor chooses processes in the wrong order?

Banker's Algorithm

- Can we loan more money to a company?
  - Pretend we did
    - update cash and out[i]
  - Is it safe?
    - Yes: lend more money
    - No: un-do to pre-pretending state, sleep
- Multi-resource Version
  - Generalizes easily to N independent resource types
  - See text

Avoidance - Summary

- Good news - ***No deadlock***
  - \+ No static “laws” about resource requests
  - \+ Allocations flexible according to system state
- Bad news
  - – Processes must pre-declare maximum usage
  - – Avoidance is ***conservative***
    - ***Many*** “unsafe” states are ***almost*** safe
    - System throughput reduced – extra sleeping
    - 3 processes, can allocate only 2 tape drives!?!?

Deadlock - What to do?

- Prevention
  - ***Pass a law*** against one of four ingredients
- Avoidance
  - Processes ***pre-declare usage patterns***
  - Request manager avoids “unsafe states”
- ***Detection/Recovery***
  - ***Clean up only when trouble really happens***

Detection & Recovery - Approach

- Don't be paranoid
  - Don't refuse requests that ***might*** lead to trouble
    - (someday)
    - Most things work out ok in the end
- Even paranoids have enemies
  - Sometimes a deadlock ***will*** happen
  - Need a plan for noticing
  - Need a policy for reacting
  - Somebody must be told “try again later”

Detection - Key Ideas

- “Occasionally” scan for wait cycles
- Expensive
  - Must lock out all request/allocate/deallocate activity
  - Global mutex is the “global variable” of concurrency
  - Detecting cycles is an N-squared kind of thing

Scanning Policy

- Throughput balance
  - Scan too often - system becomes (very) slow
  - Scan before every sleep? Only in small systems
  - Scan too rarely - system becomes (extremely) slow
- Policy candidates
  - Scan every <interval>
  - Scan when CPU is “too idle”

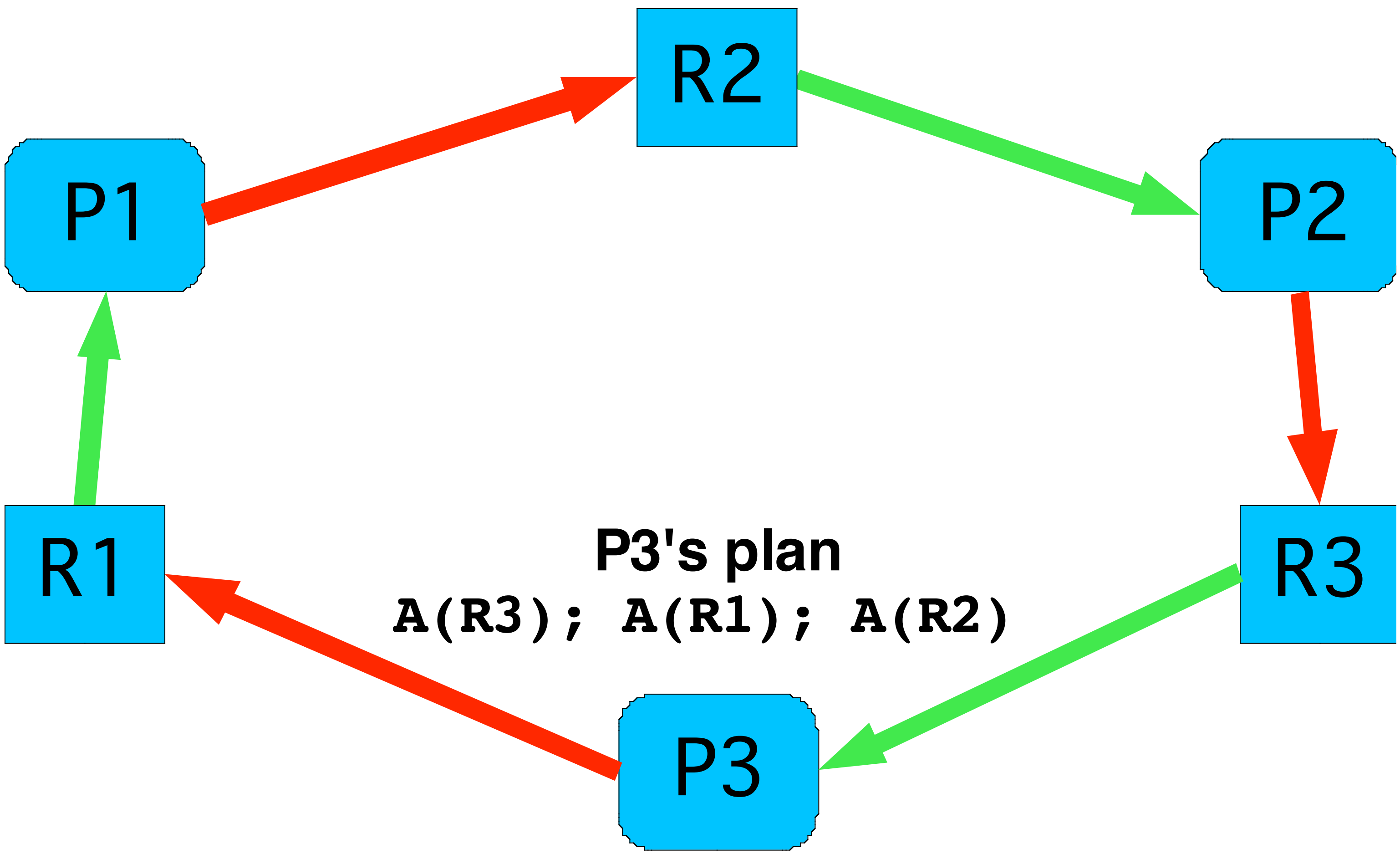
Detection - Algorithms

- Detection: Unique Resources
  - Search for cycles in resource graph
    - (see above)
- Detection: Multi-instance Resources
  - Slight variation on Banker's Algorithm
    - (see text)
- Find a deadlock? Now what?
  - Abort
  - Preempt

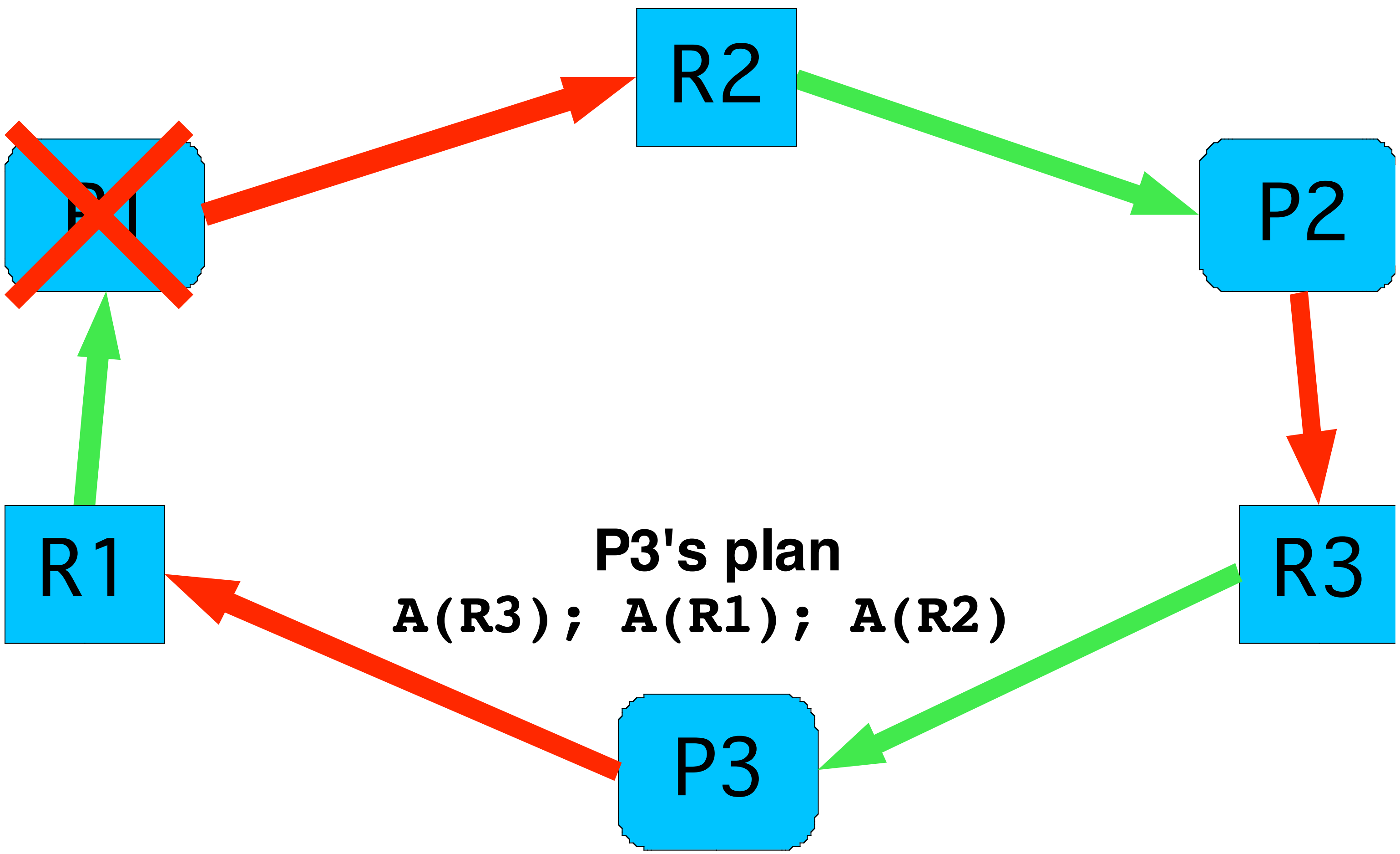
Recovery - Abort

- Evict processes from the system
- All processes in the cycle?
  - Simple & blame-free policy
  - Lots of re-execution work later
- ***Just one*** process in the cycle?
  - ***Which*** one?
    - Priority? Work remaining? Work to clean up?
  - Often immediately creates a smaller cycle – re-scan?

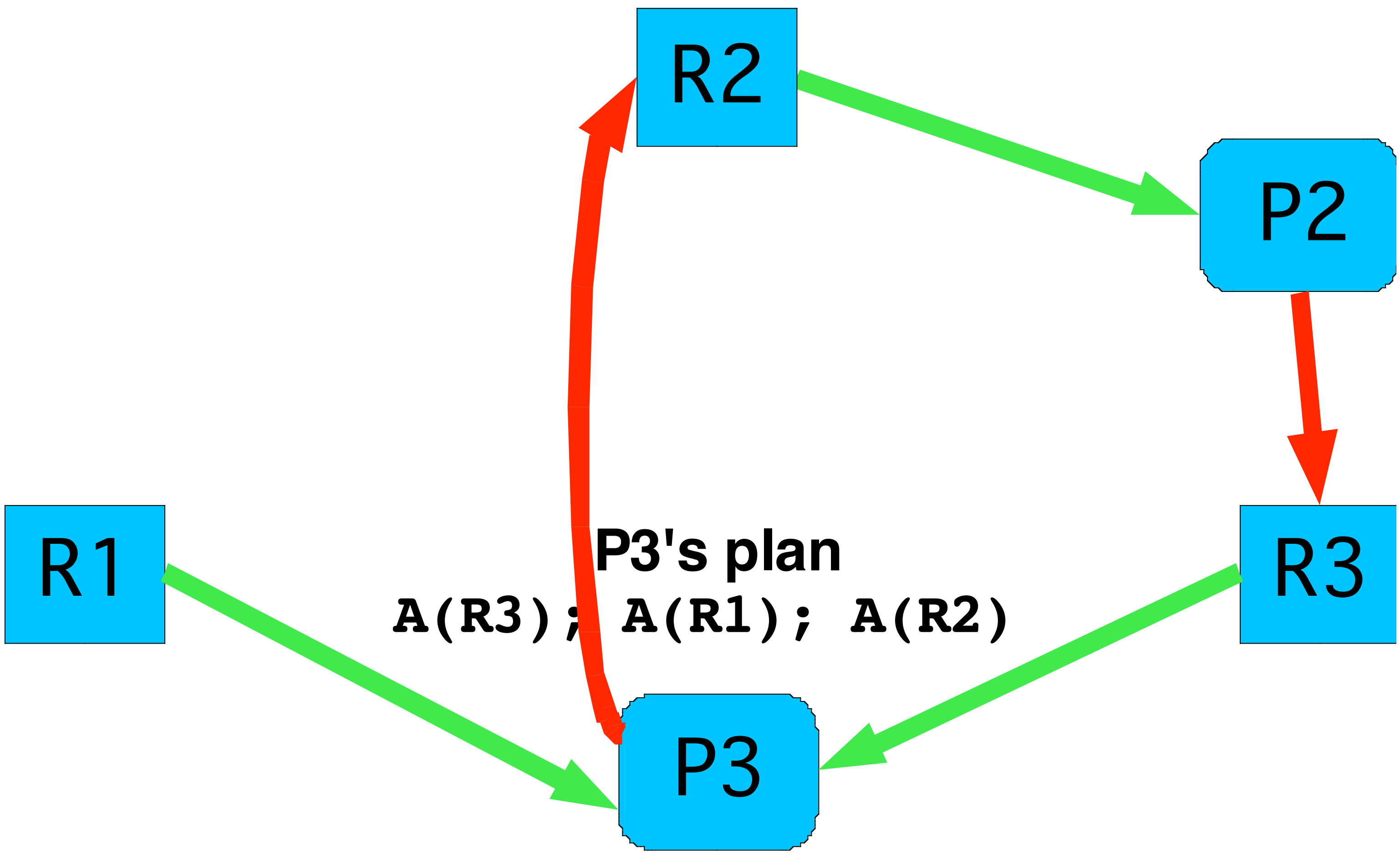
Recovery – Abort Just One?



Recovery – Abort Just One?



Recovery – Abort Just One?



Recovery – Can we do better?

- Aborting processes is undesirable
  - Re-running processes is ***expensive***
  - Long-running tasks may ***never*** complete
  - Starvation

Recovery - Resource Preemption

- Tell some process(es)
- lock(R346) ⇒“EDEADLOCK”
- Policy question: which process loses?
- Lowest-numbered? ⇒ ***starvation!***
- What does “EDEADLOCK” mean?
  - ***Can't*** just retry the request (make sure you see this)
  - Must release ***other*** resources you hold, try later
  - Forced release may require “rollback” (yuck)

Summary - Deadlock

- Deadlock is...
  - Set of processes
  - Each one waiting for something held by another
- Four “ingredients”
- Three approaches
  - (aside from “Hmmm...<reboot>”)

Deadlock - Approaches

- Prevention - Pass a law against one of:
  - Mutual exclusion (unlikely!)
  - Hold & wait (maybe, but...)
  - No preemption (maybe?)
  - Circular wait (sometimes)
- An architectural choice may *preclude* some features, algorithms, …

Deadlock - Approaches

- Avoidance - "Stay out of danger"
  - Requires pre-declaration of usage patterns
  - Not all "danger" turns into ***trouble***
- Detection & Recovery
  - Scan frequency: delicate balance
  - Preemption is hard, messy
- Rebooting
  - Was it ***really*** hung?

Summary - Starvation

- starvation $\neq$ deadlock:
  - Starvation and Deadlock share the property that at least one process is not making progress.
  - With starvation there is a schedule where the process makes progress (but the schedule is not taken).
- Starvation is a ubiquitous danger
- "Solutions" to deadlock leave us vulnerable to starvation.
  - If you're the class of application impacted, you are no better off than if you were deadlocked.