Deadlock (2)

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Synchronization

- Project 2 reminder...
  - 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

- **Today's goals (to be on track with P2)**
  - **Coded mutexes and condition variables**
  - **Thoughtful design for thr_create(), maybe thr_join()**
  - **Some code for thr_create(), and some “experience”**
  - **The `startle` test running**
- **Next steps...**
  - **Passing some mutex/cvar tests**
  - **Debugging `cyclone`/`agility_drill`**
  - **Ok if some components are “demo quality” to start out with...**

Outline

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

Deadlock – Alternative Approaches

- Prevention
  - *Pass a law* against one of four ingredients
    - Note: static, absolute ban
  - Every legal application is continuously deadlock-free
- Avoidance
  - Processes *pre-declare usage patterns*
    - Note: more complicated for application, but more flexible
  - Request manager avoids “unsafe states”
- Detection/Recovery
  - Clean up only when trouble really happens

Deadlock Prevention – Satisfactory?

- 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 else I will instead -

     - 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
   - (a) Don't hold onto resources forever
     - Obvious how this helps!
   - (b) 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, ... 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, ...P_i**
- **Claim: P_i's waiting is bounded by the 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**
  - **Solution: follow a safe sequence (run processes serially)**
    - **Slow, but not as slow as a deadlock!**
- **Serial execution is *worst-case*, not typical**
  - **Usually processes execute in parallel**

Request Manager - Naïve

- **Grant a resource 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 a resource 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, tell requesting process to wait**
  - **While holding a smaller set of resources...**
    - ***...which we previously proved other processes don't need to 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 - Has**

“Is it safe?”

“Yes it’s safe; it’s very safe, so safe you wouldn’t believe it.”

(from “Marathon Man”)

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 - Has**

How would we show that this state is safe?

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 ⇒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 acquire more now?

"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 each allowed to ask for >4.

If either does, it must wait, hoping the other frees some up.

If both ask for more than 4, both wait: ***deadlock!***

P1: Complete

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

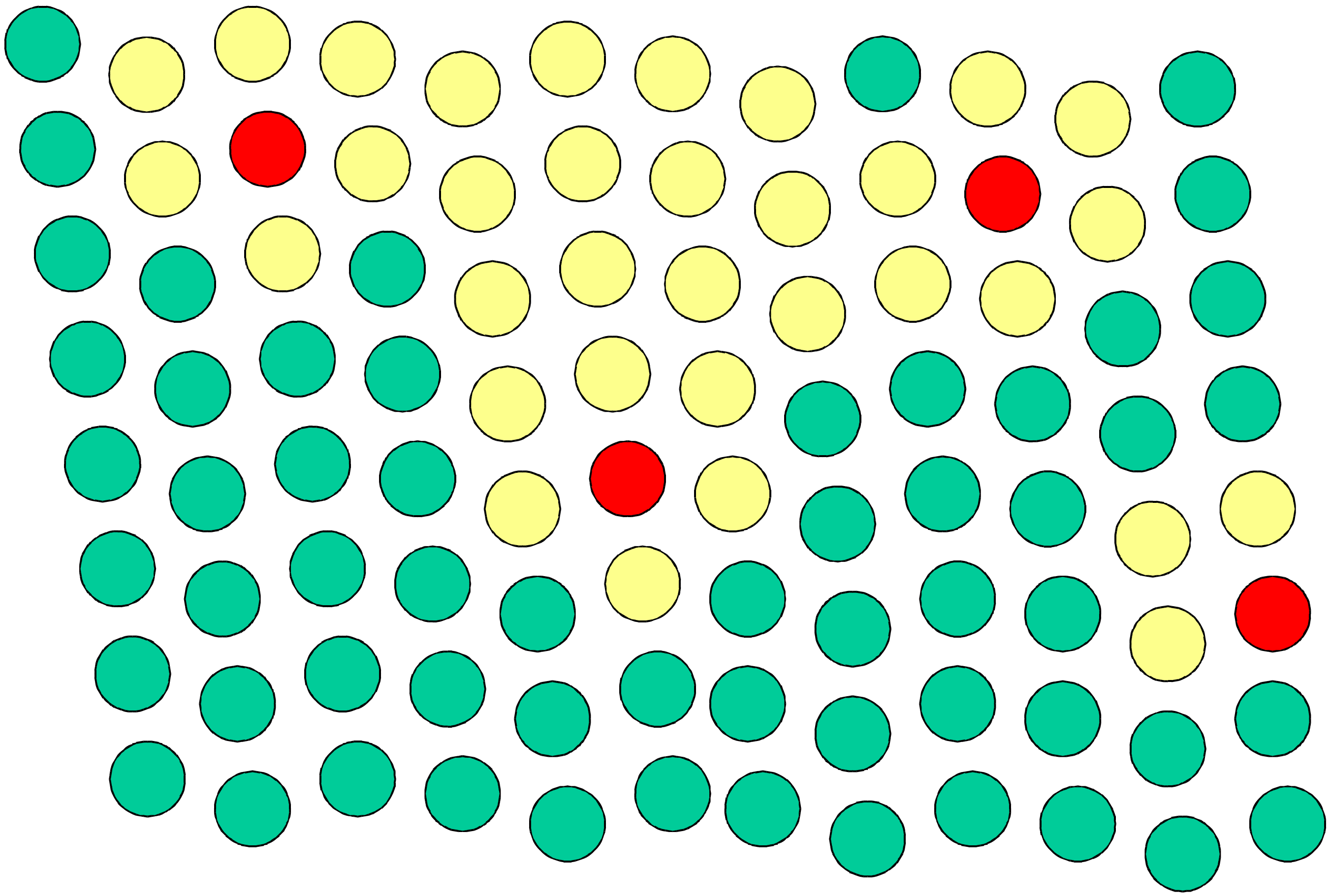
Q1: Is deadlock inevitable?

Q2: Did we miss some possible sequence other than (P1, ...)?

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



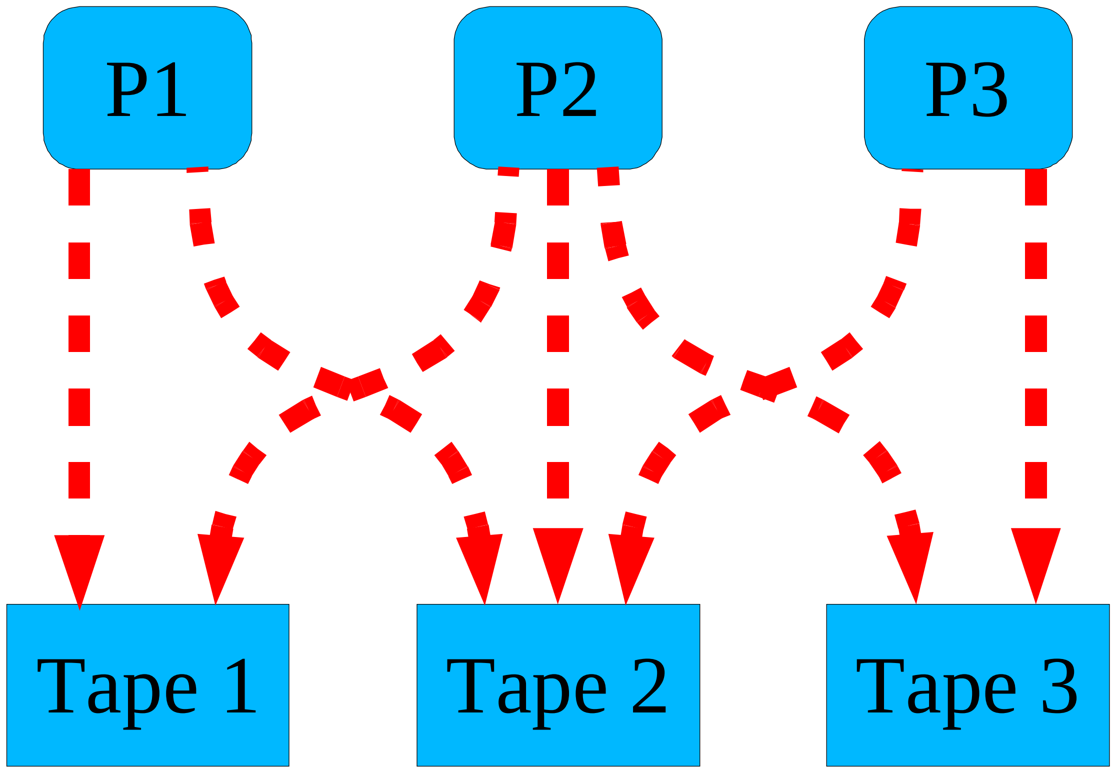
Avoidance – Tradeoff

- Allowing only safe states is more flexible than Prevention
  - Some of the “laws” are inconvenient to follow
- 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...

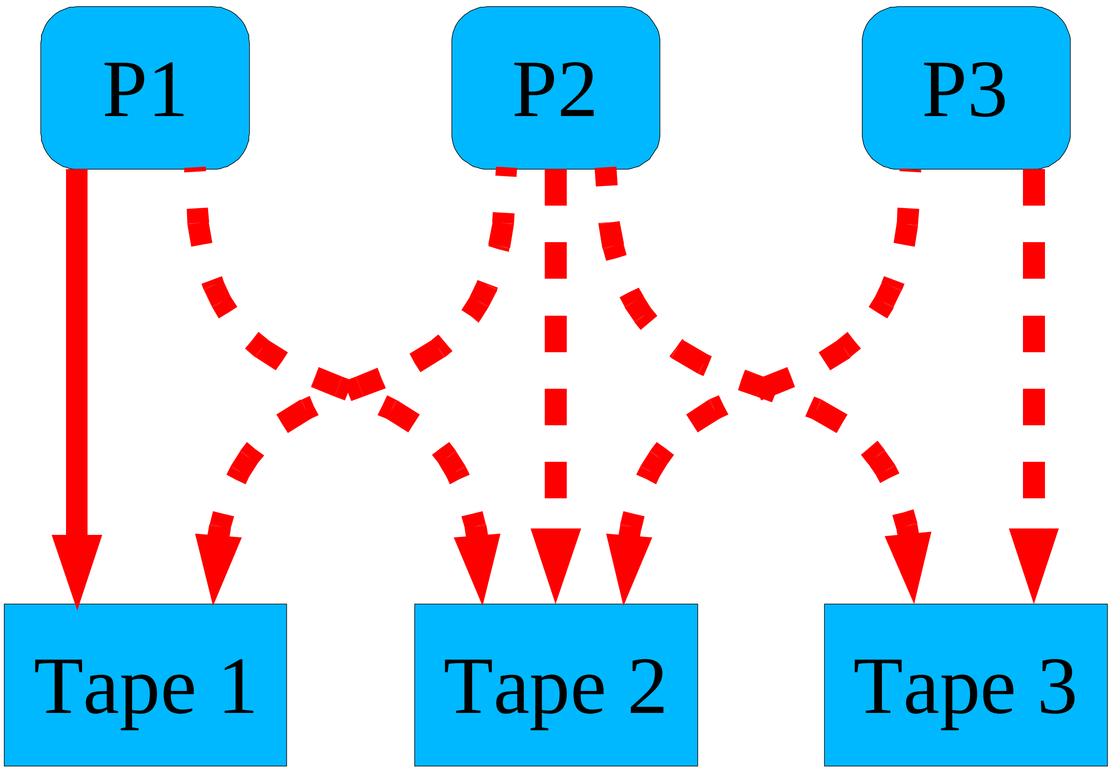
Avoidance - Unique Resources

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

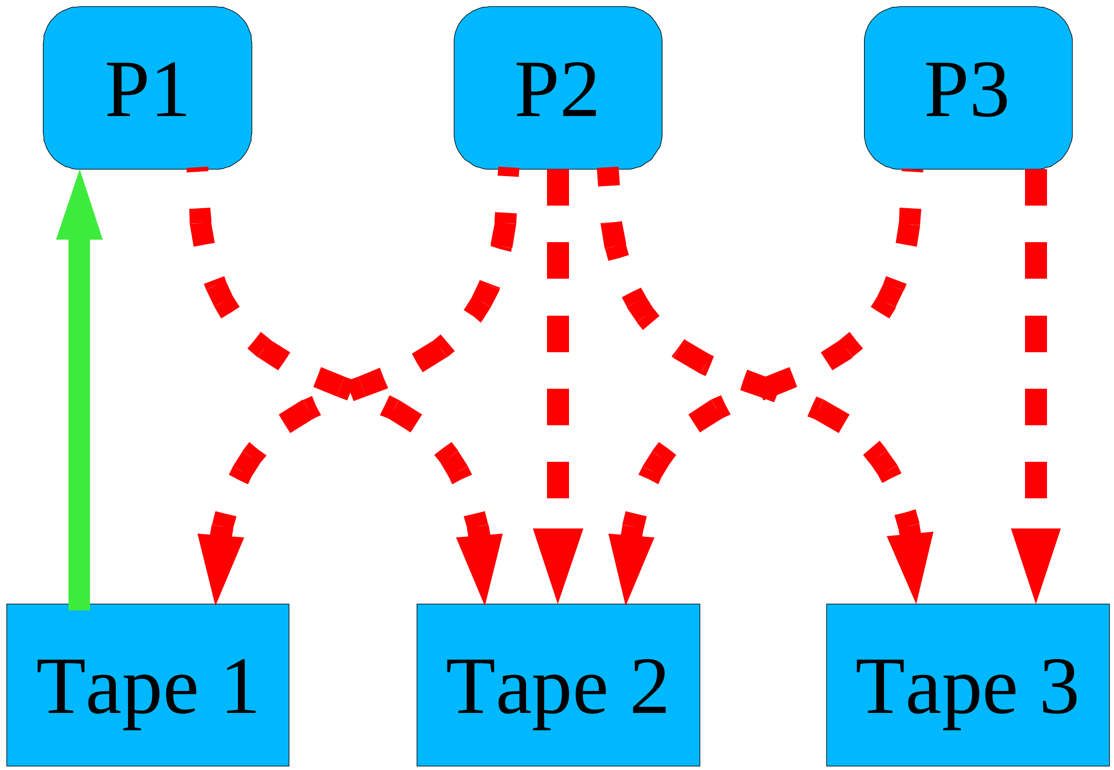
"Claim" (Future-Request) Edges



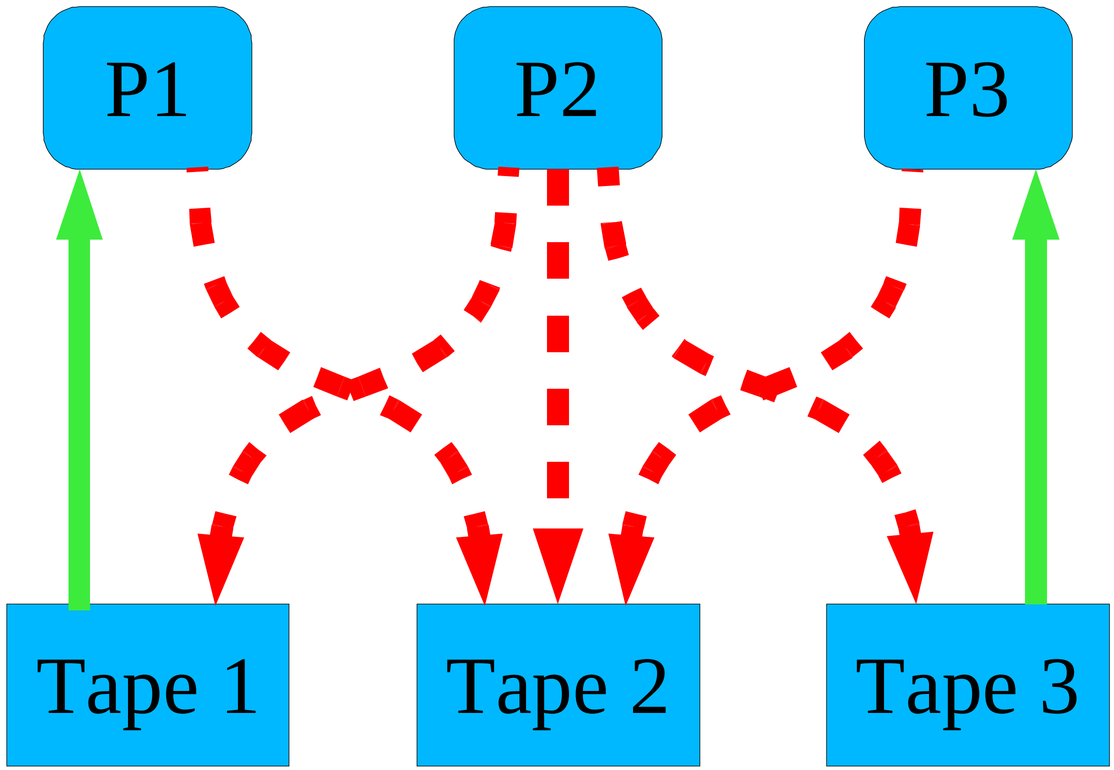
Claim ⇒ Request



Request ⇒ Assignment



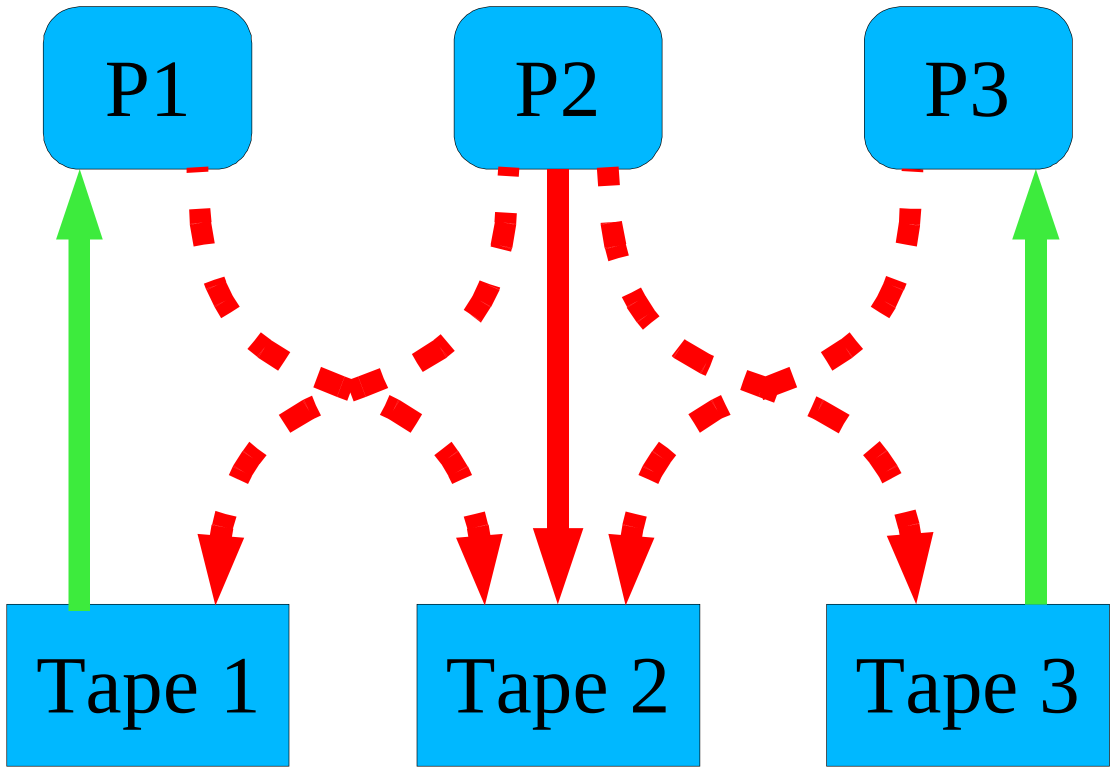
Safe: No Cycle



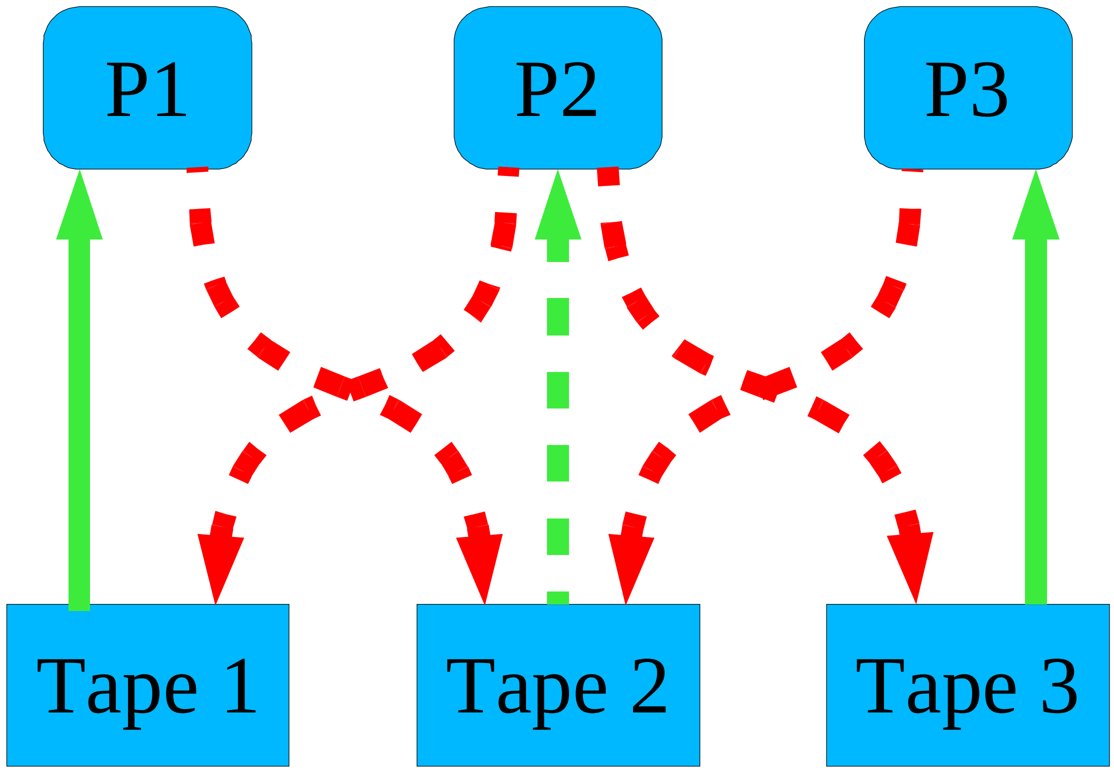
Which Requests Are Safe?

- 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 (block the process** ***now*****,** ***before*** **it gets that tape drive, instead of blocking it later,** ***while*** **it holds it)**

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”

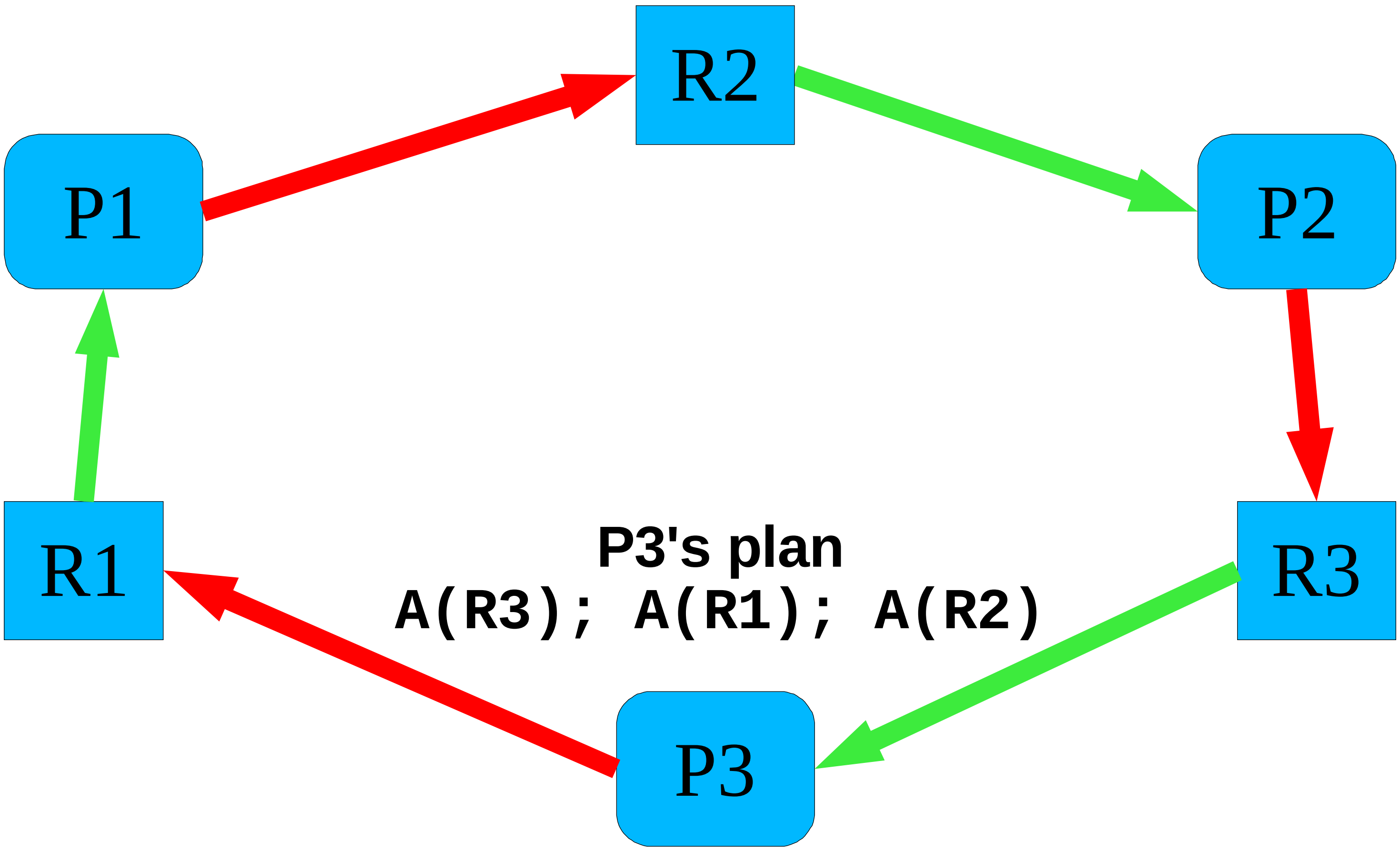
Detection - Algorithms

- 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

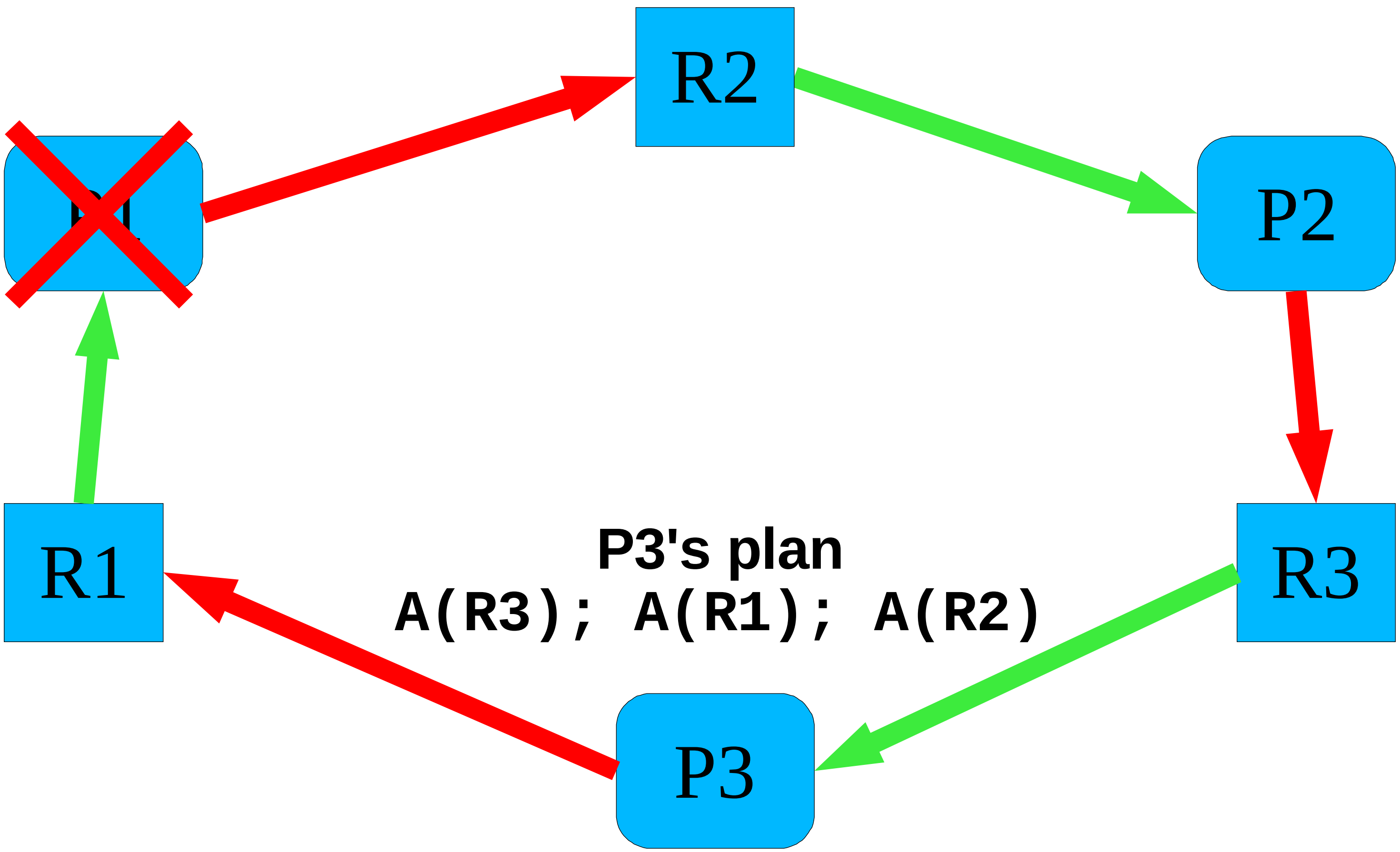
Recovery - Abort

- **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?**

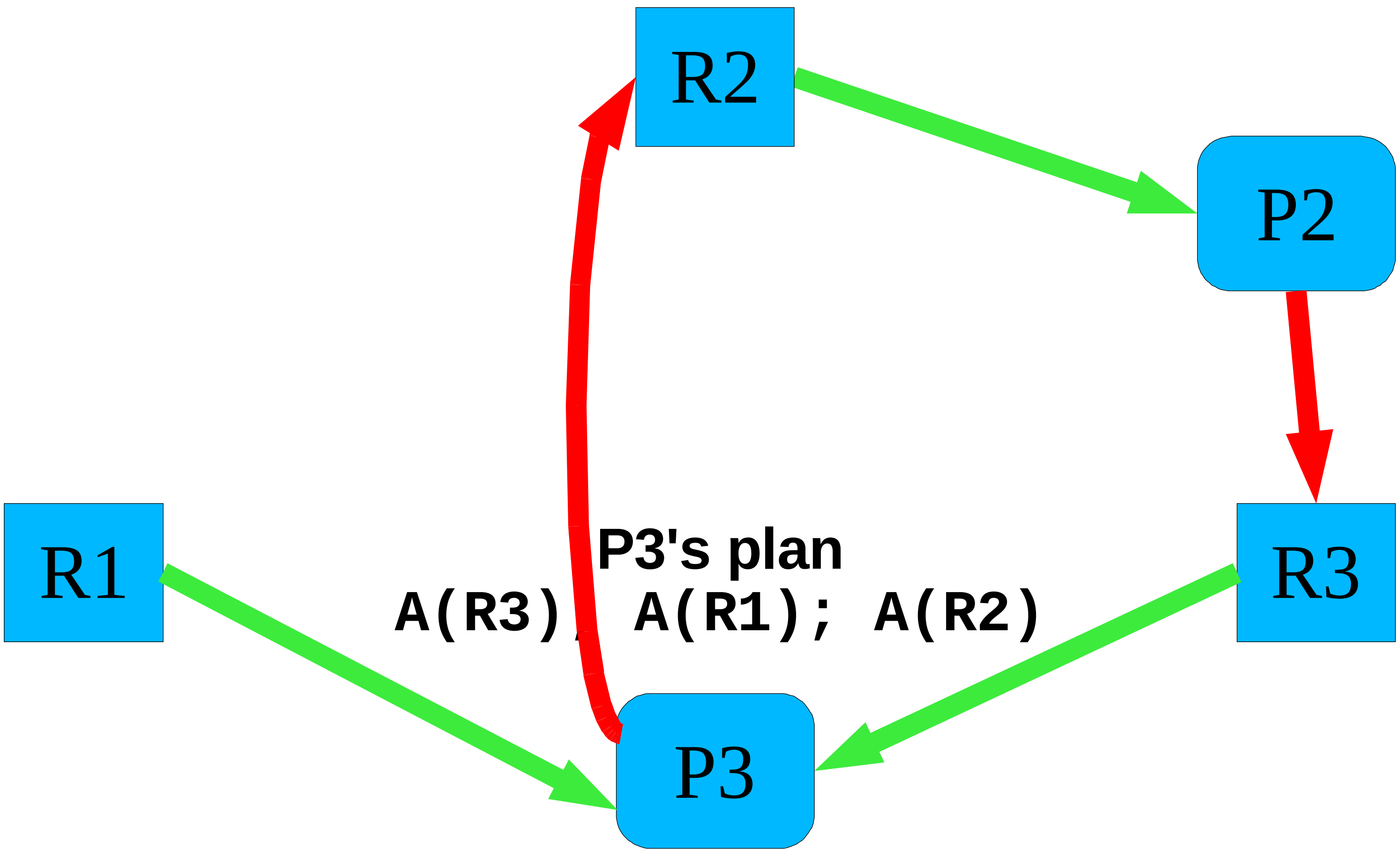
Recovery – Abort Just One?



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): time to give, not take
  - lock(R300) ⇒ “Ok”
  - lock(R346) ⇒ “EDEADLOCK”
- 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)
- Policy question: which process loses?
  - Lowest-numbered? ⇒ ***starvation!***

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 (popular, if feasible; watch out for...)**
- **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.