Deadlock (2)

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Synchronization

- **Today's goals (to be on track with P2)**
  - **Hopefully you had a fruitful weekend debugging:**
    - `cyclone` **and** `agility_drill`
    - **maybe** `paraguay` **also**

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
    - Inefficient if extra resources must be held
    - 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

- $(P_1, P_2, P_3, \ldots P_n)$ is a *safe sequence* if
  - Every process P_i can be satisfied using
    - currently-free resources F, plus
    - resources currently held by $P_1, P_2, \ldots P_i$
- 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 acquire the rest of its resources, complete, and release all held 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 it's ok to hold, because other processes don't need them 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 total, both wait: ***deadlock!***

P1: Complete

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

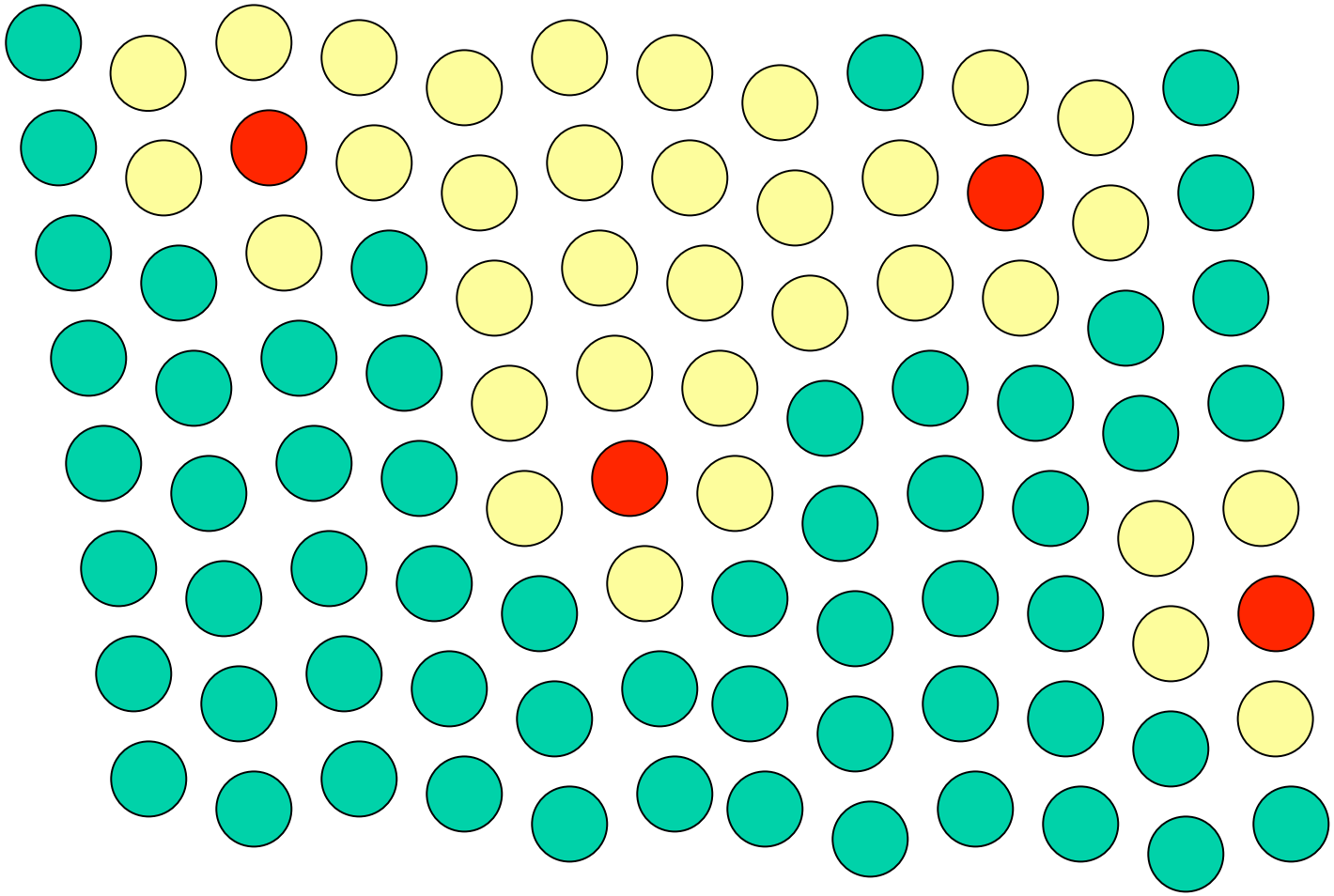
Q1: Is deadlock inevitable?

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



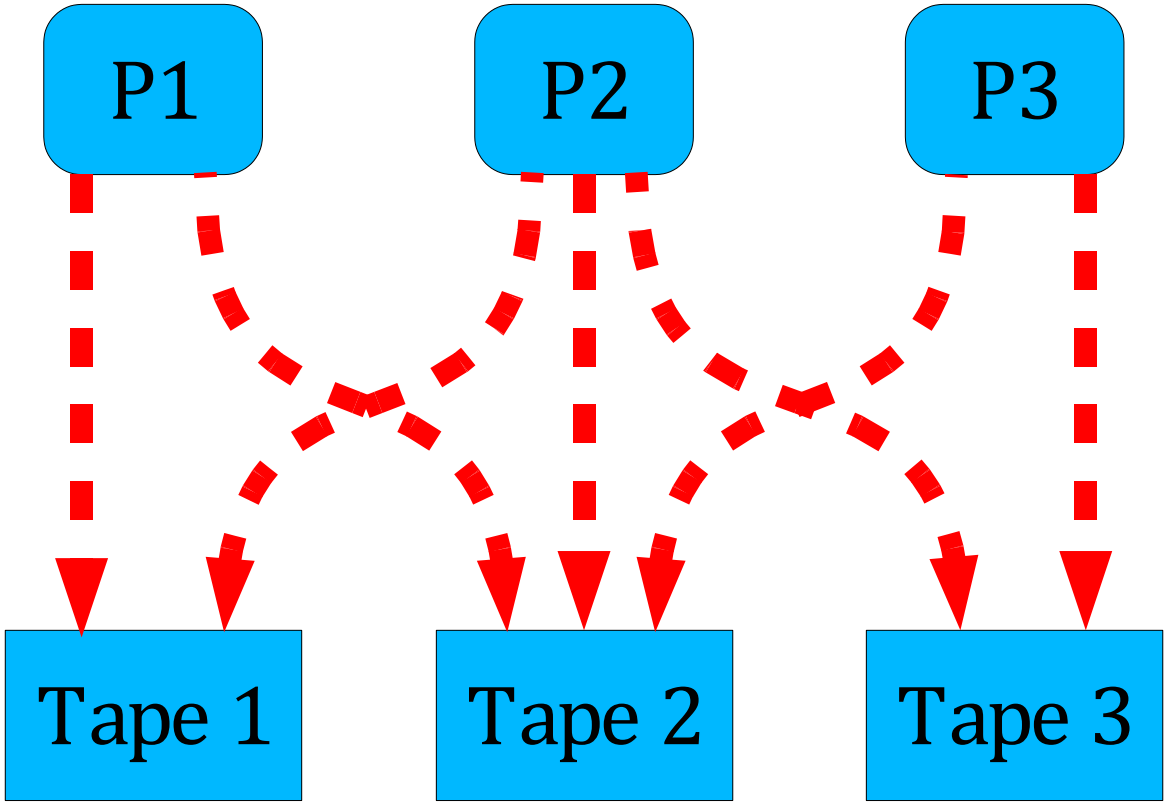
Avoidance – Tradeoff

- 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...

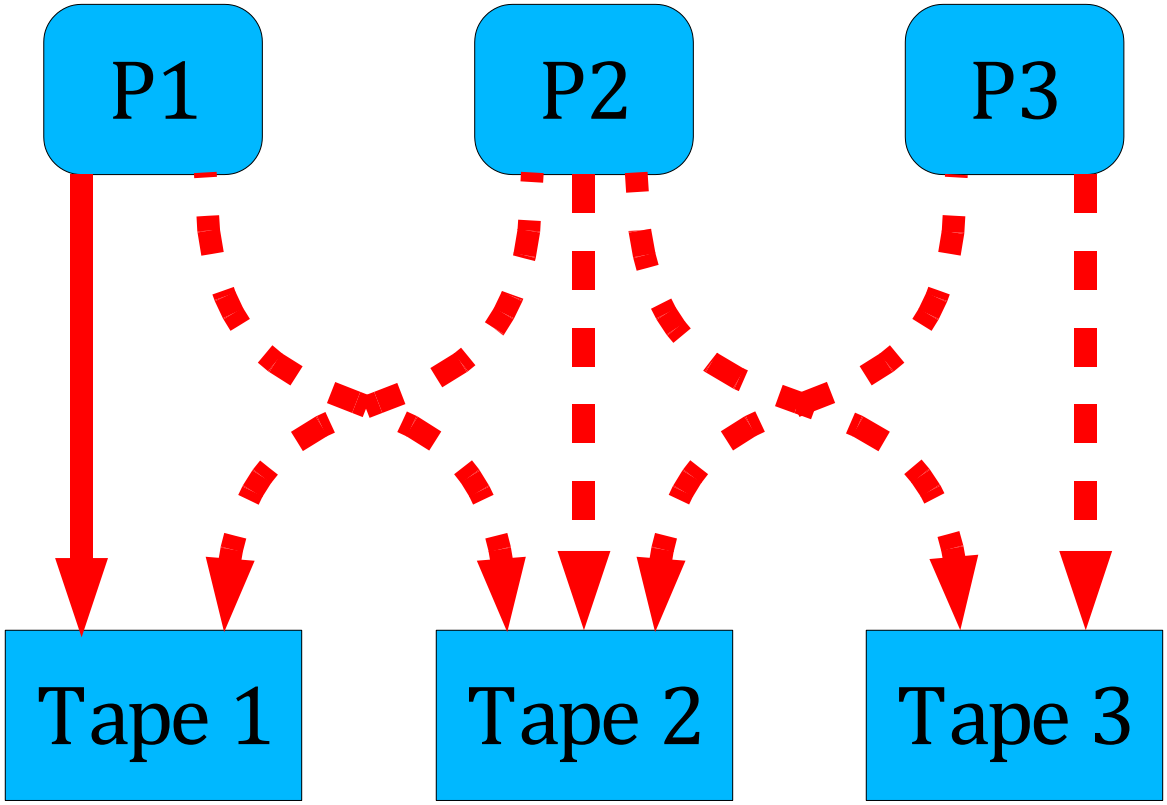
Avoidance - Unique Resources

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

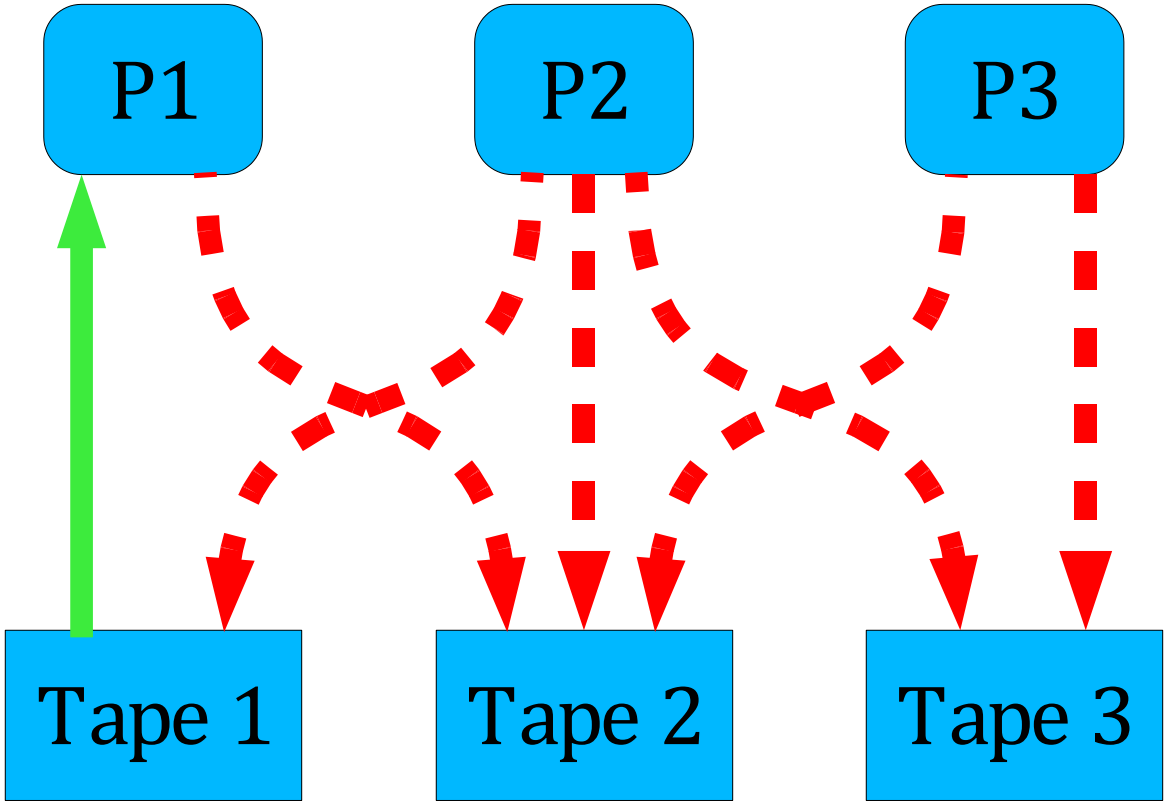
“Claim” (Future-Request) Edges



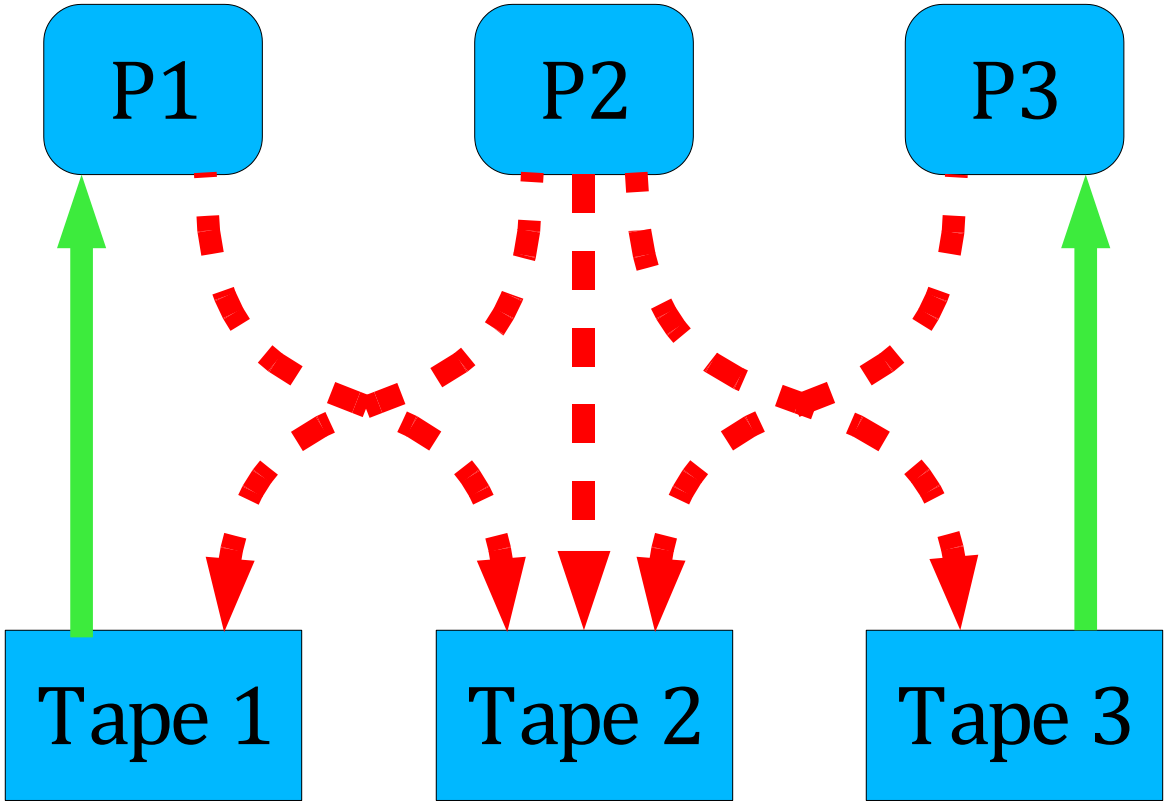
Claim ⇒ Request



Request ⇒ Assignment



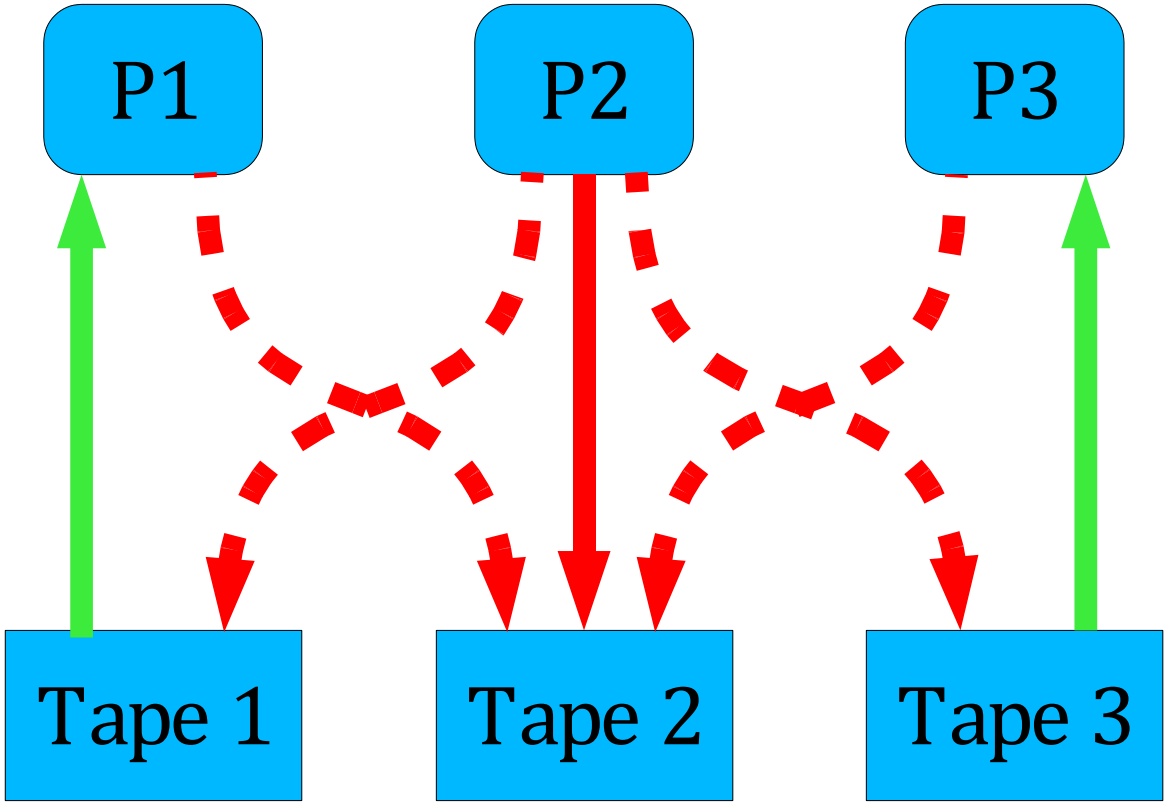
Safe: No Cycle



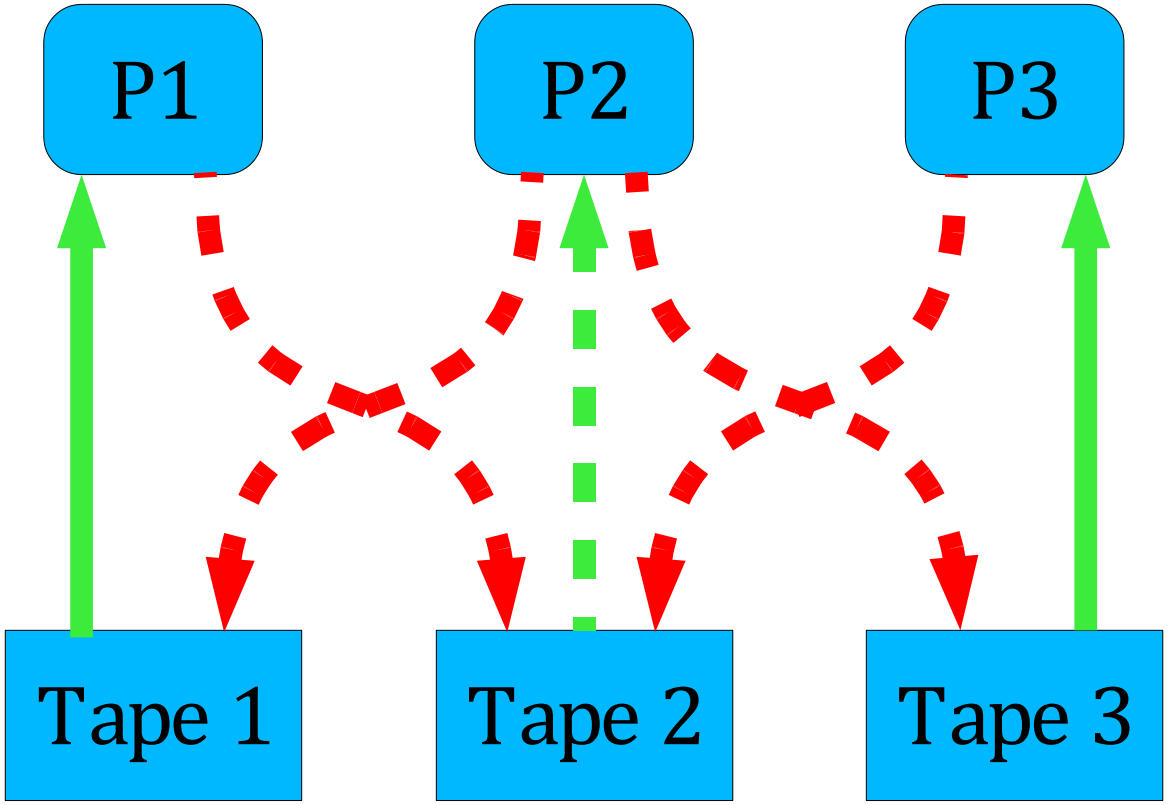
Which Requests Are Safe?

- **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”

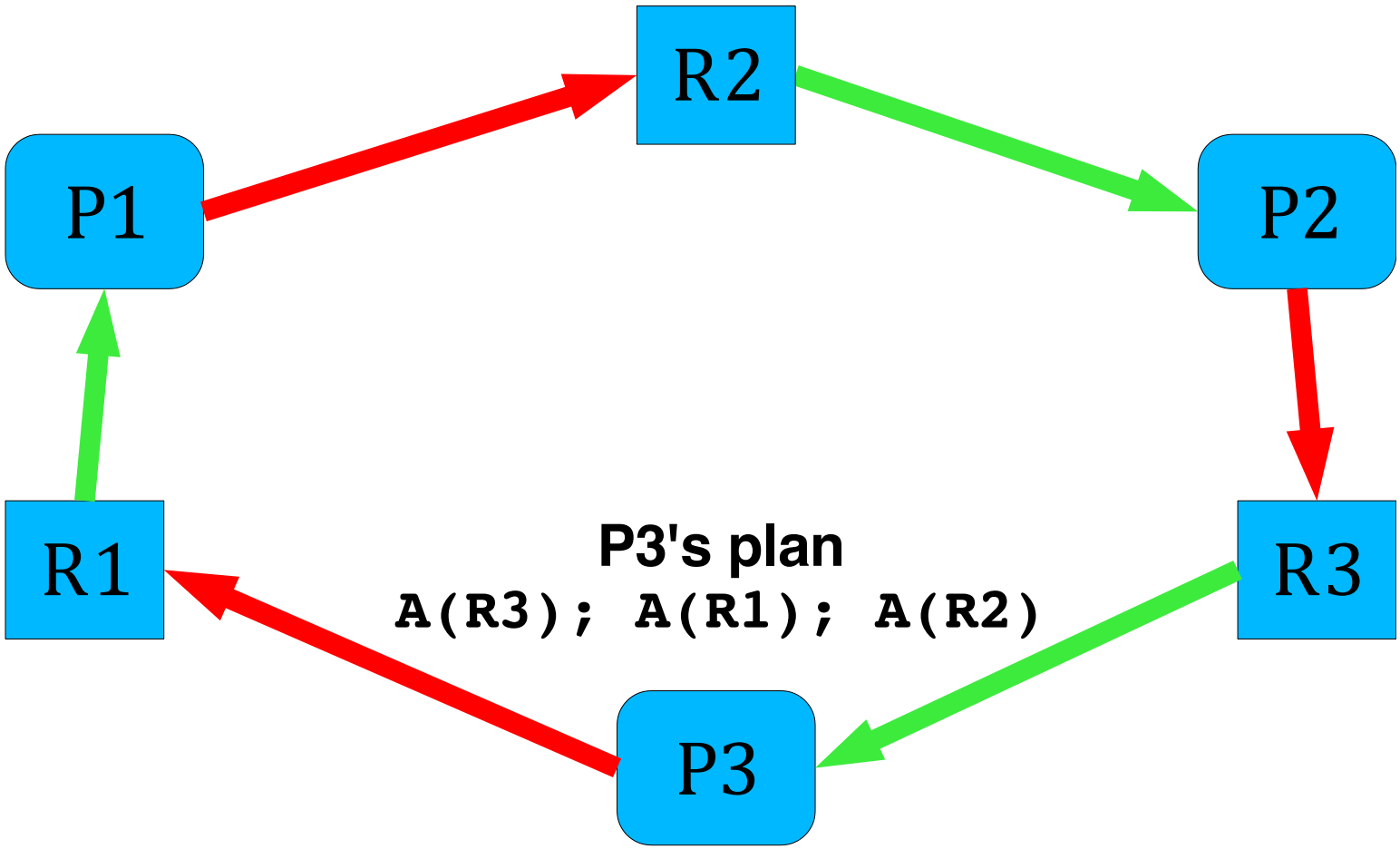
Detection - Algorithms

- 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?



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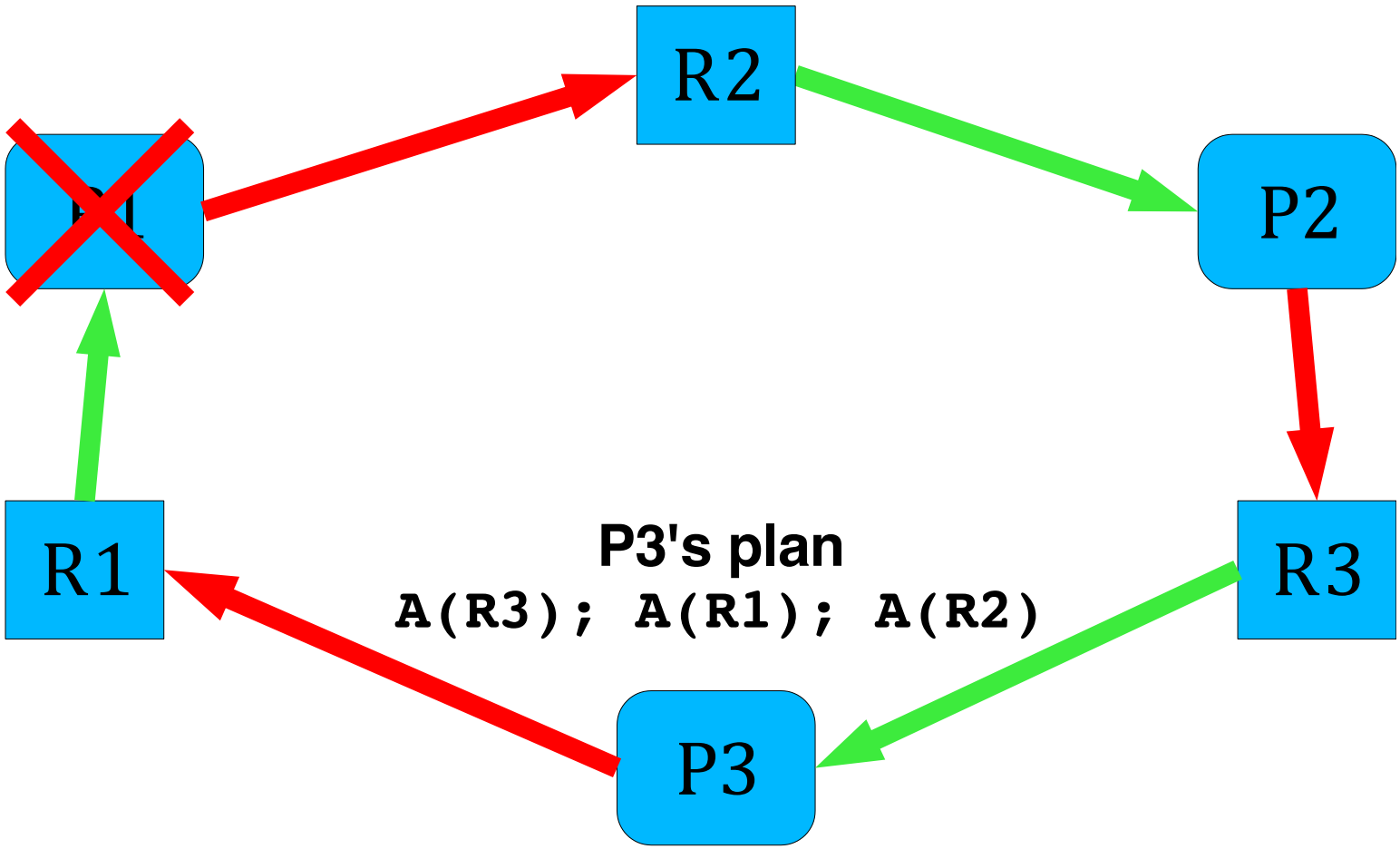
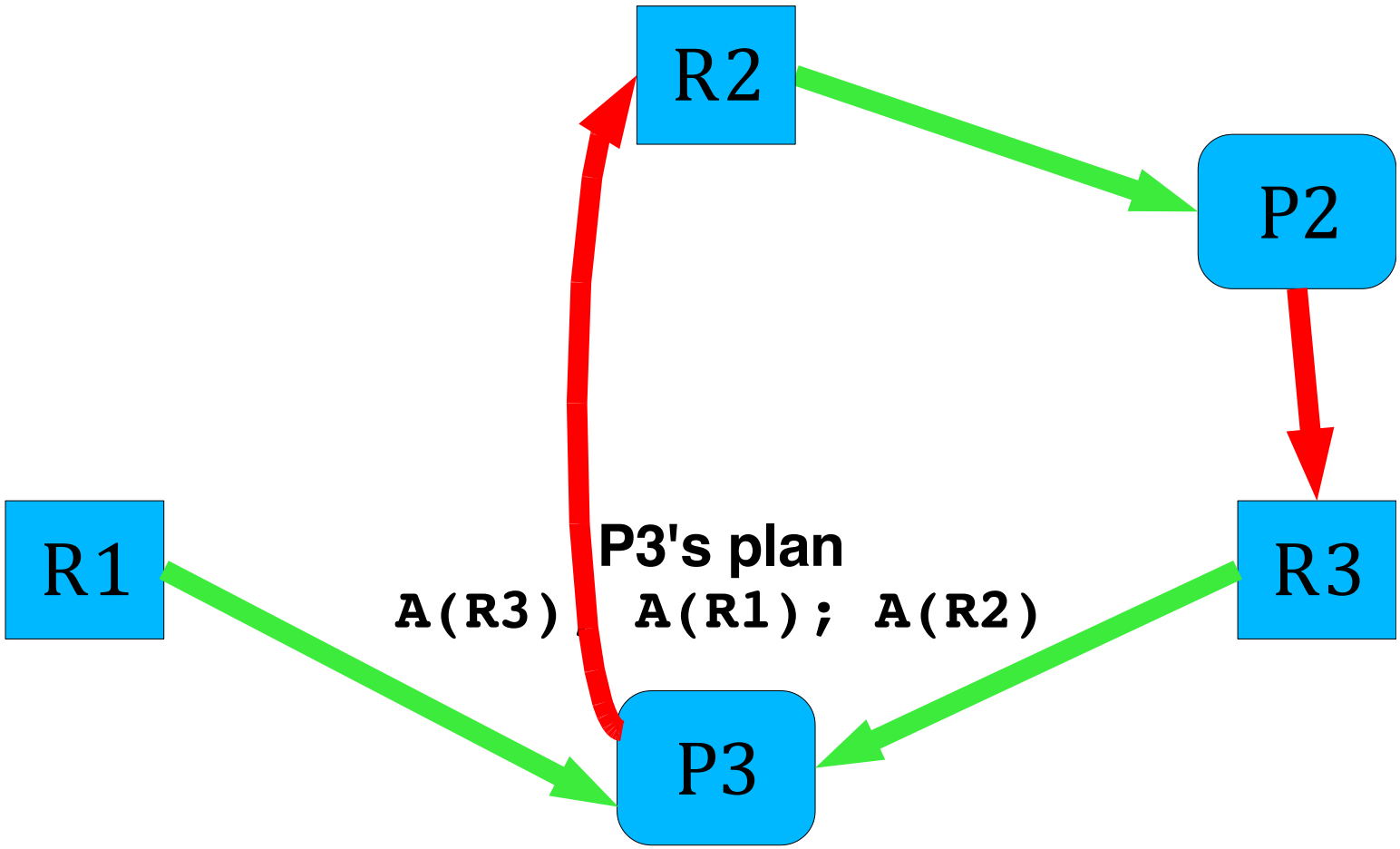


Recovery – Abort Just One?



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 ≠ 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.**

Synchronization

- **Project 2 progress**
  - **Should have created a thread**
  - **Should have passed `startle`**
  - **Should be passing some mutex/cvar tests**
  - **Ok if exiting, cleanup aren't right yet**
    - **Ok if thr_exit() looks like:** `while(1) continue;`
    - **Not as good if it looks like:** `for(;;);`
  - **Ok if some components are "demo quality"**

Synchronization

- **Project 2 progress**
  - **Should have created a thread**
  - **Should have passed `startle`**
  - **Should be passing some mutex/cvar tests**
  - **Should be debugging `cyclone`/`agility_drill`**
  - **Ok if some components are "demo quality"**