Deadlock (2)

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Synchronization

- **Project 2 progress**
  - **Mutex and condition variable should be "complete"**
    - **Even if they include a temporary shortcut or two**
    - **Should have "tested" them as much as you can with one thread**
    - **How much *can* you test them with one thread?**
  - **Should be able to create threads**
    - **Ok if thr_exit() looks like:** `while(1) continue;`
    - **Not as good if it looks like:** `for(;;);`
  - **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**

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, ...**
     - **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**
- **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-1}**
- **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, no wait cycle, no deadlock**

Safe State

- **System in a *safe state* if**
  - **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 resources...**
    - *...which we already prooved other processes can complete without*

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."

P1: 2 ⇒ 4

Who	Max	Has	Room		Who	Max	Has	Room
P0	10	5	5		P0	10	5	5
P1	4	2	2	⇒	P1	4	4	0
P2	9	2	7		P2	9	2	7
System	12	3	-	⇒	System	12	1	-

P1: Complete

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

P0: 5 ⇒ 10

Who	Max	Has	Room		Who	Max	Has	Room
P0	10	5	5	⇒	P0	10	10	0
P2	9	2	7		P2	9	2	7
System	12	5	-	⇒	System	12	0	-

P0: Complete

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

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		Who	Max	Has	Room
P0	10	5	5		P0	10	5	5
P1	4	2	2		P1	4	2	2
P2	9	2	7	⇒	P2	9	3	6
System	12	3	-	⇒	System	12	2	-

Only P1 can be satisfied without waiting.

P1: 2 ⇒ 4?

Who	Max	Has	Room		Who	Max	Has	Room
P0	10	5	5		P0	10	5	5
P1	4	2	2		P1	4	4	0
P2	9	3	6	⇒	P2	9	3	6
System	12	2	-	⇒	System	12	0	-

P1: Complete?

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

Problem: P0 and P2 are allowed to ask for >4.
If both do, ***deadlock***.

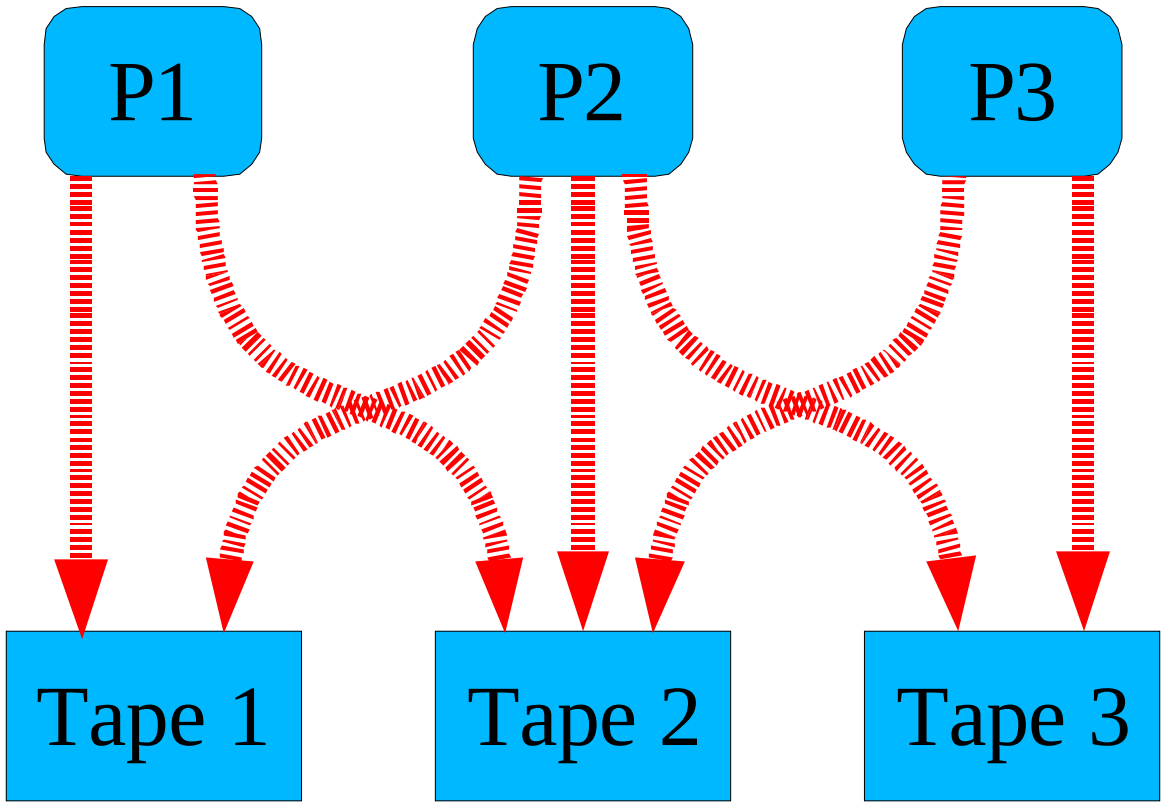
Avoidance - Key Ideas

- **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**
- **Rejecting** *all* **unsafe states reduces efficiency**

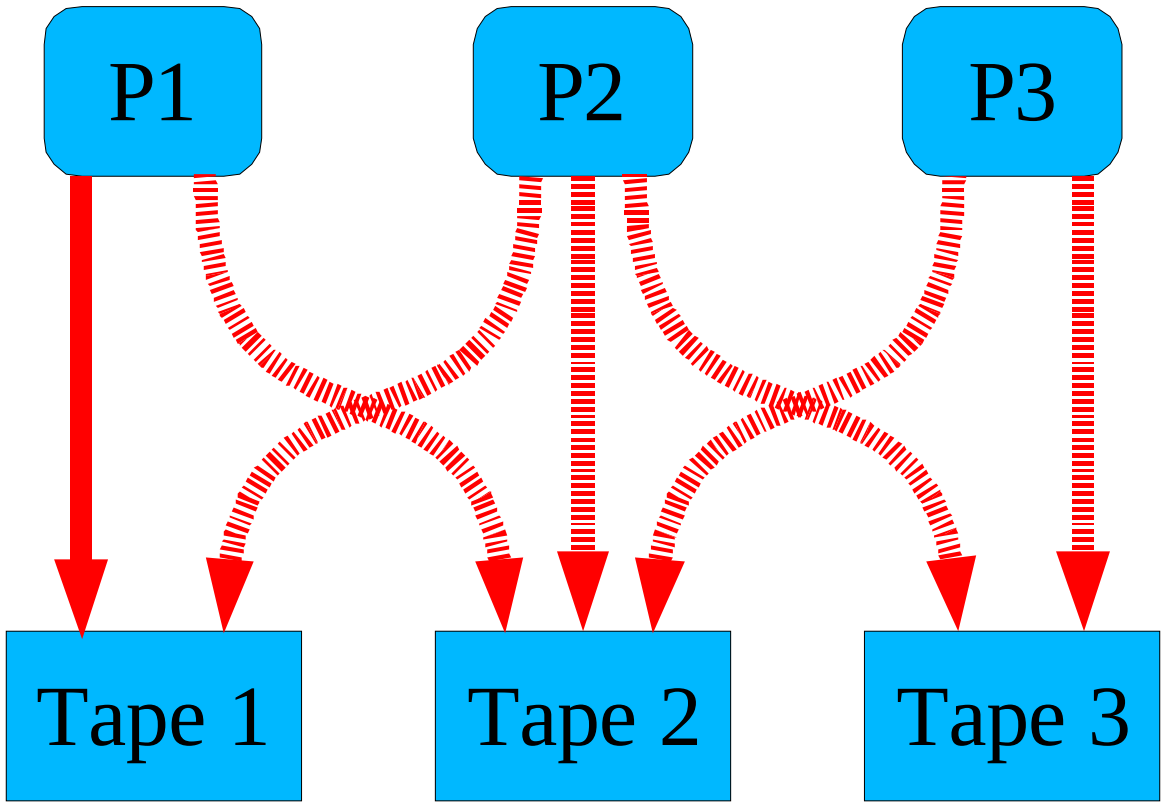
Avoidance - Unique Resources

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

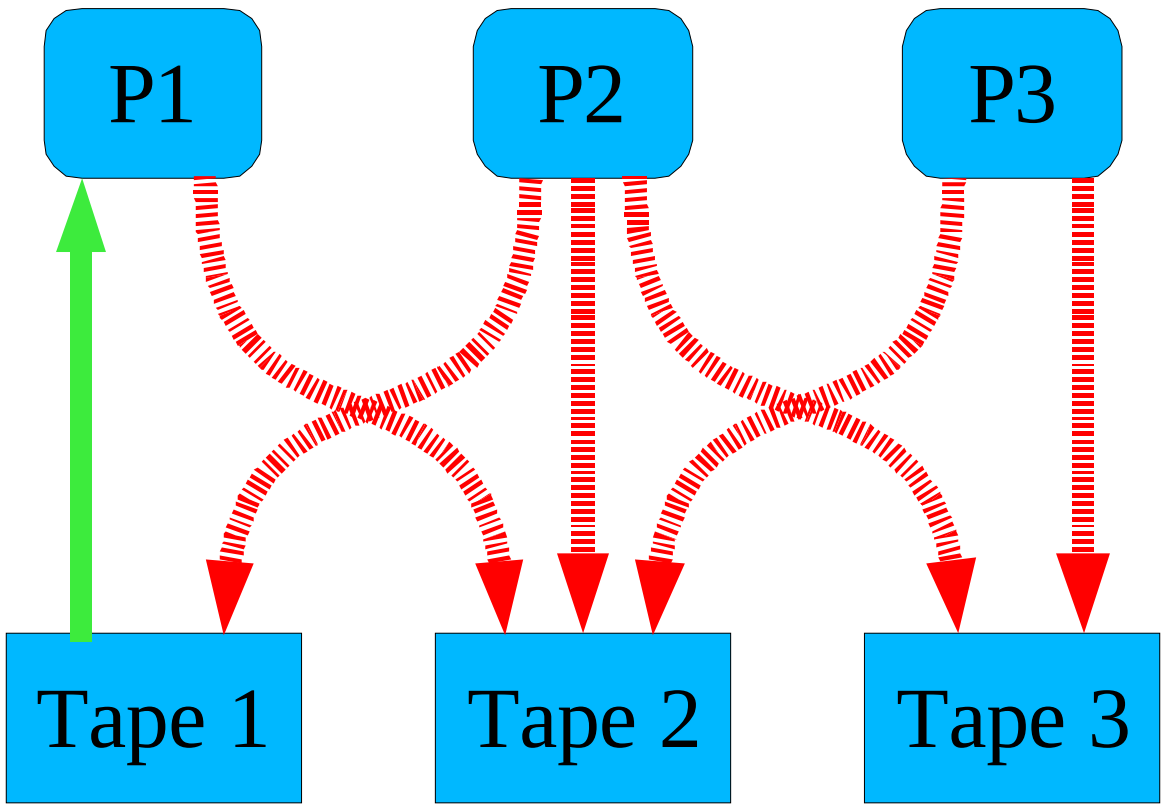
“Claim” (Future-Request) Edges



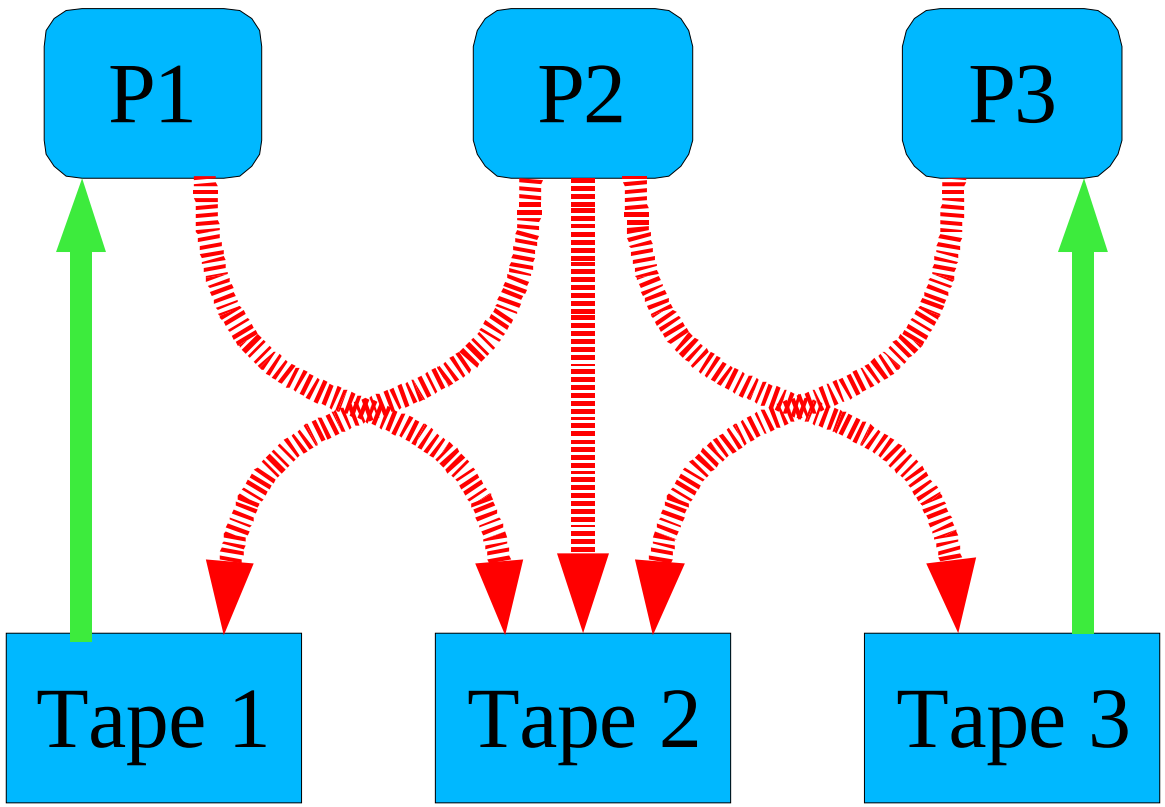
Claim ⇒ Request



Request ⇒ Assignment



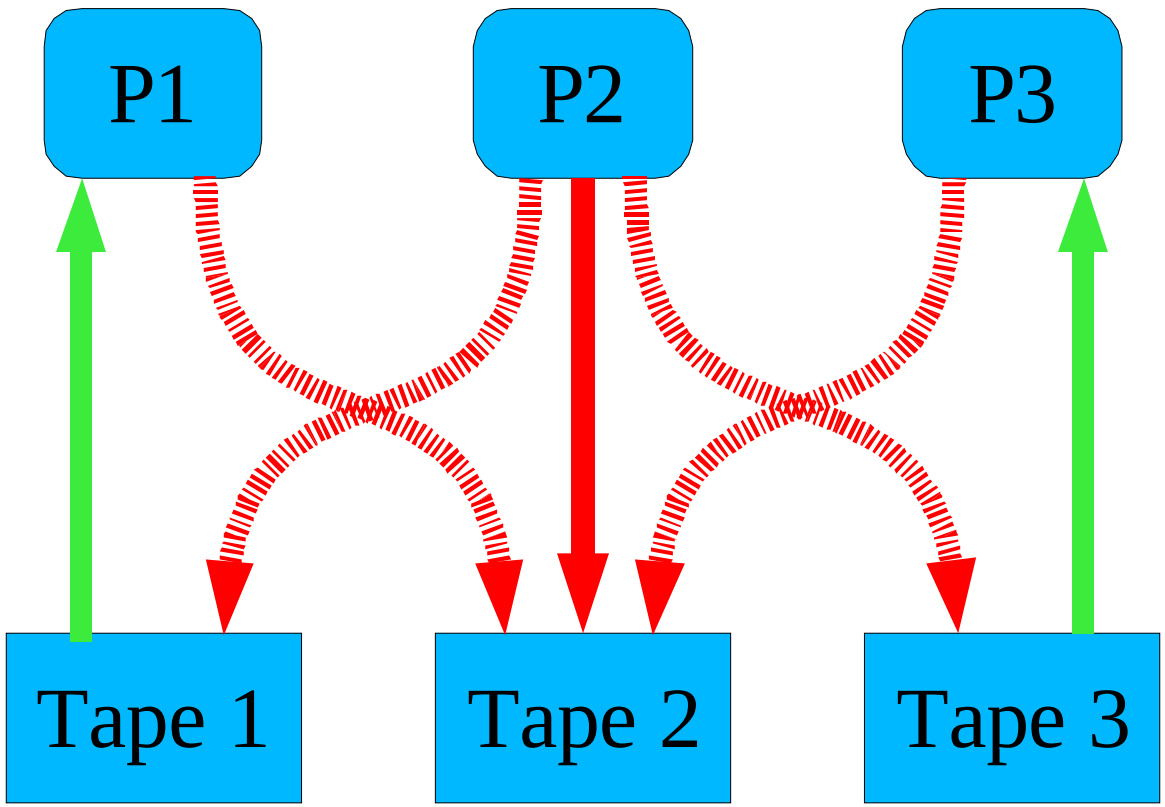
Safe: No Cycle



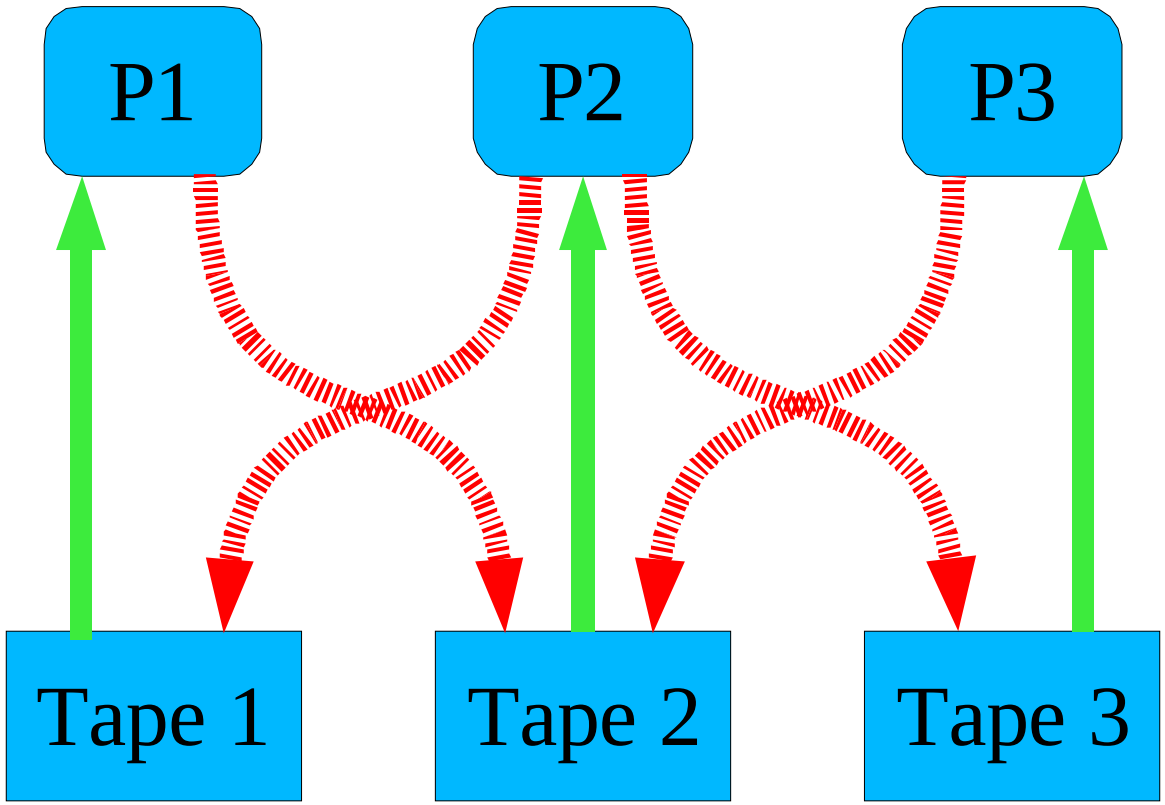
Which Requests Are Safe?

- **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**
  - **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 sleep** *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***)**

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);
}
```

Banker's Algorithm

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

  while (p = progressor(future))
    future += borrowed[p];
    done[p] = true;

  return (done[0..N] == true)
}
```

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**
  - **Too often - system becomes (very) slow**
  - **Before every sleep? Only in small systems**
  - **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 “waits-for” graph**
    - **Derived from “resource graph” in obvious way**
- **Detection: Multi-instance Resources**
  - **Slight variation on Banker's Algorithm**
    - **(see text)**
- **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?**
  - **Often immediately creates a smaller cycle – re-scan?**
  - ***Which*** **one?**
    - **Priority? Work remaining? Work to clean up?**

Recovery – Can we do better?

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

Recovery - Resource Preemption

- **Tell some process(es)**
  - **lock(R347) ⇒"Deadlock!"**
- **Policy question: which one?**
  - **Lowest-numbered? ⇒** *starvation!*
- **What does "Deadlock!" mean?**
  - *Can't* **just retry the request!!**
  - **Must release** *other* **resources, 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 (right!)**
  - **Hold & wait (maybe...)**
  - **No preemption (maybe?)**
  - **Circular wait (sometimes)**

Deadlock - Approaches

- **Avoidance - “Stay out of danger”**
  - **Not all “danger” turns into *trouble***
- **Detection & Recovery**
  - **Frequency: delicate balance**
  - **Preemption is hard**
- **Rebooting**
  - **Was it *really* hung?**

Summary - Starvation

- **Starvation is a ubiquitous danger**
- **Prevention is one extreme**
  - **Need something “illegal”?**
    - **“Illegal” =** ***Eternal*** **starvation!**
- **Detection & Recovery**
  - **Less structural starvation**
  - **Still must make good choices**