Deadlock (1)

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Synchronization – P2

- You should *really* have
  - Figured out where wrappers belong, why
  - Made some system calls
  - Designed mutexes, condition variables
  - Drawn pictures of thread stacks
- You should probably have
  - Mutexes and condition variables coded
  - Thoughtful design for thr_create(), thr_join()
  - Some code for thr_create(), and some “experience”

Synchronization – P2

- **A note on debugging**
  - **We have received several "perplexed" queries**
    - **We did x...**
    - **...something happened other than our expectation...**
    - **...can you tell us why?**
  - **Reminder: "not really"**
  - **You need to progress beyond "*something* happened"**
    - **What was it that happened, exactly?**
    - **printf() is probably not the right tool**
      - **captures only what you told it to, only "C-level" stuff**
      - ***changes your code* by its mere presence!!!**

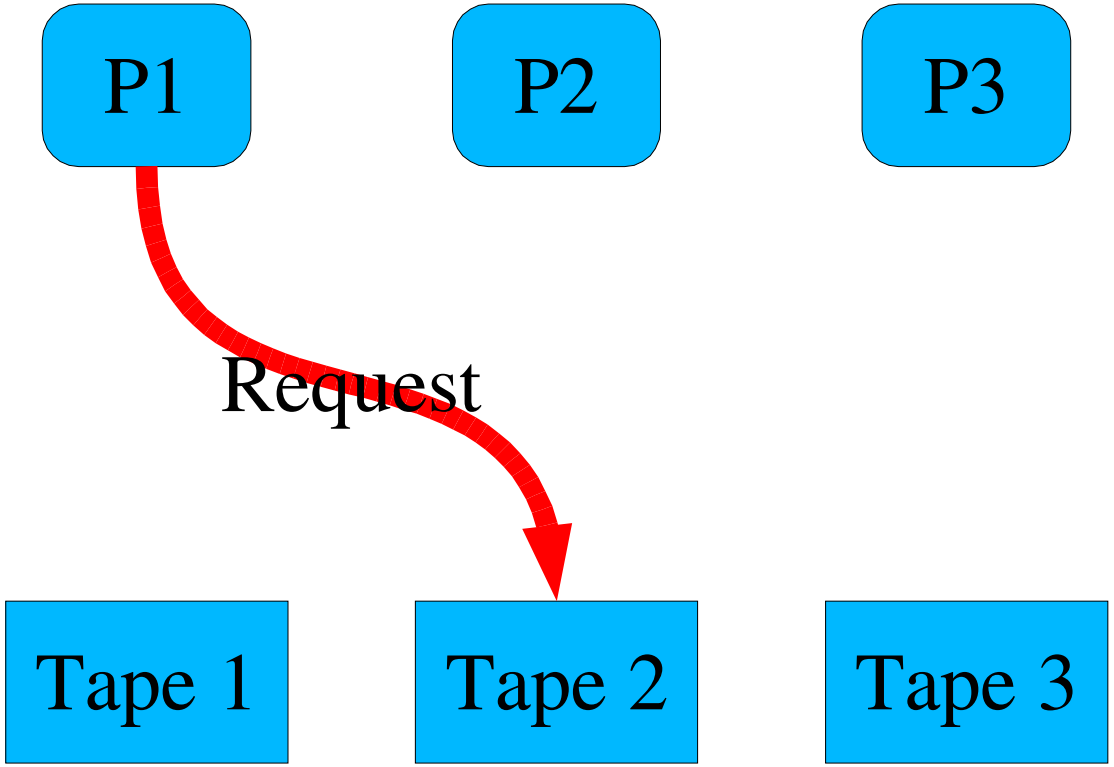
Synchronization – Readings

- **Next three lectures**
  - **Deadlock: 7.4.3, 7.5.3, Chapter 8**
- **Reading ahead**
  - **Scheduling: Chapter 6**
  - **Virtual Memory: Chapter 9, Chapter 10**

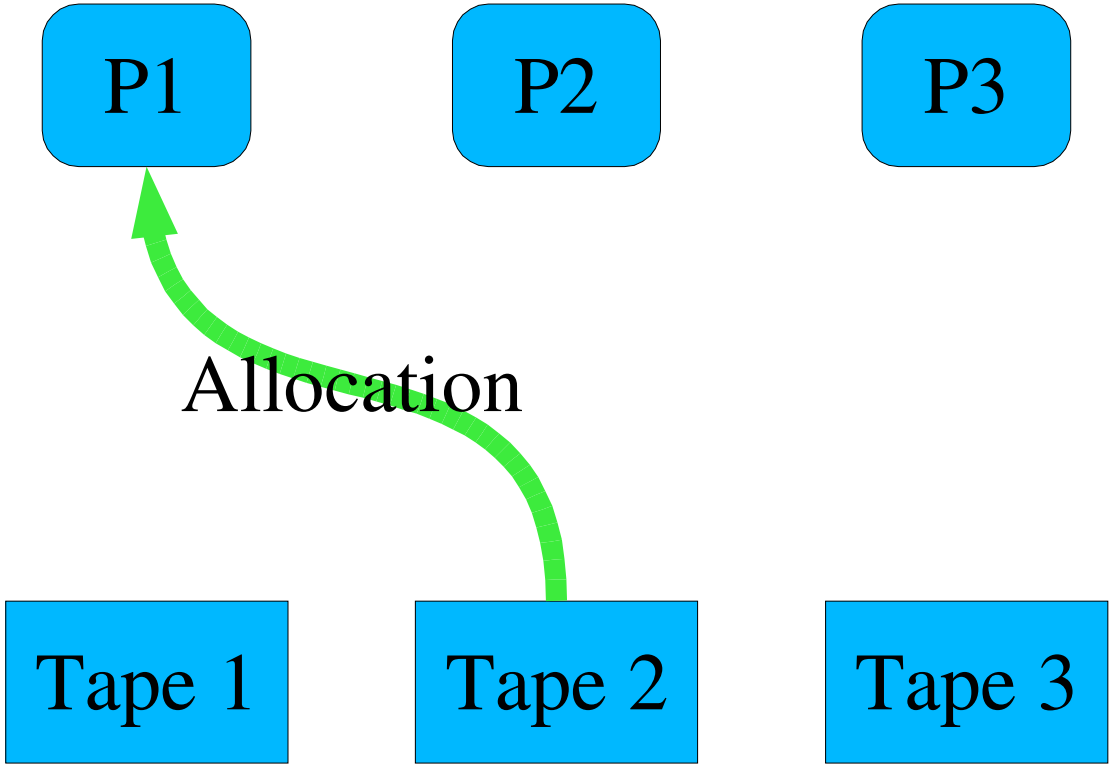
Outline

- **Process resource graph**
- **What is deadlock?**
- **Deadlock *prevention***
- **Next time**
  - **Deadlock *avoidance***
  - **Deadlock *recovery***

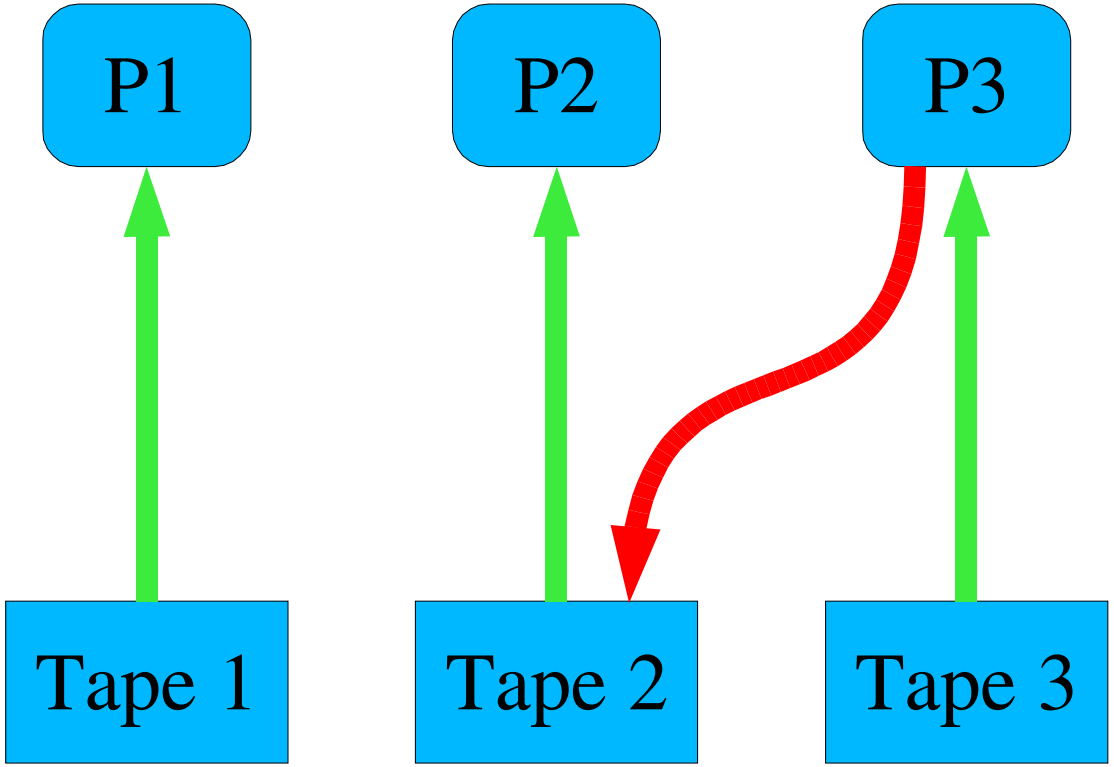
Process/Resource graph



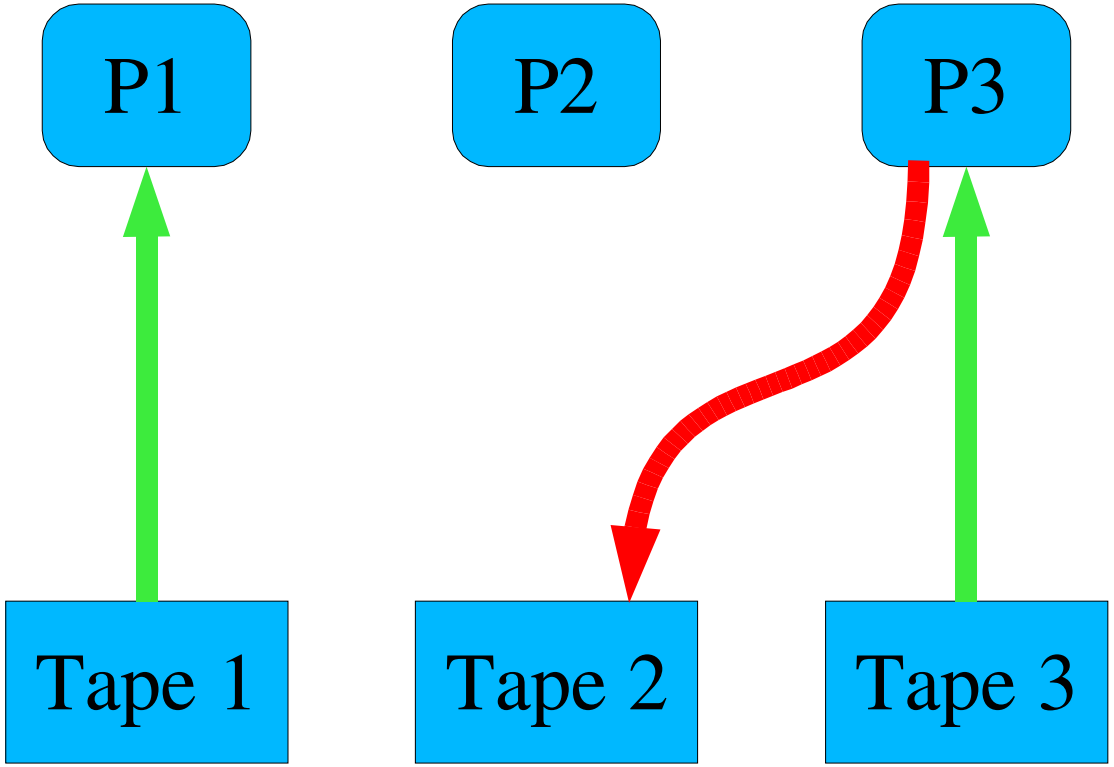
Process/Resource graph



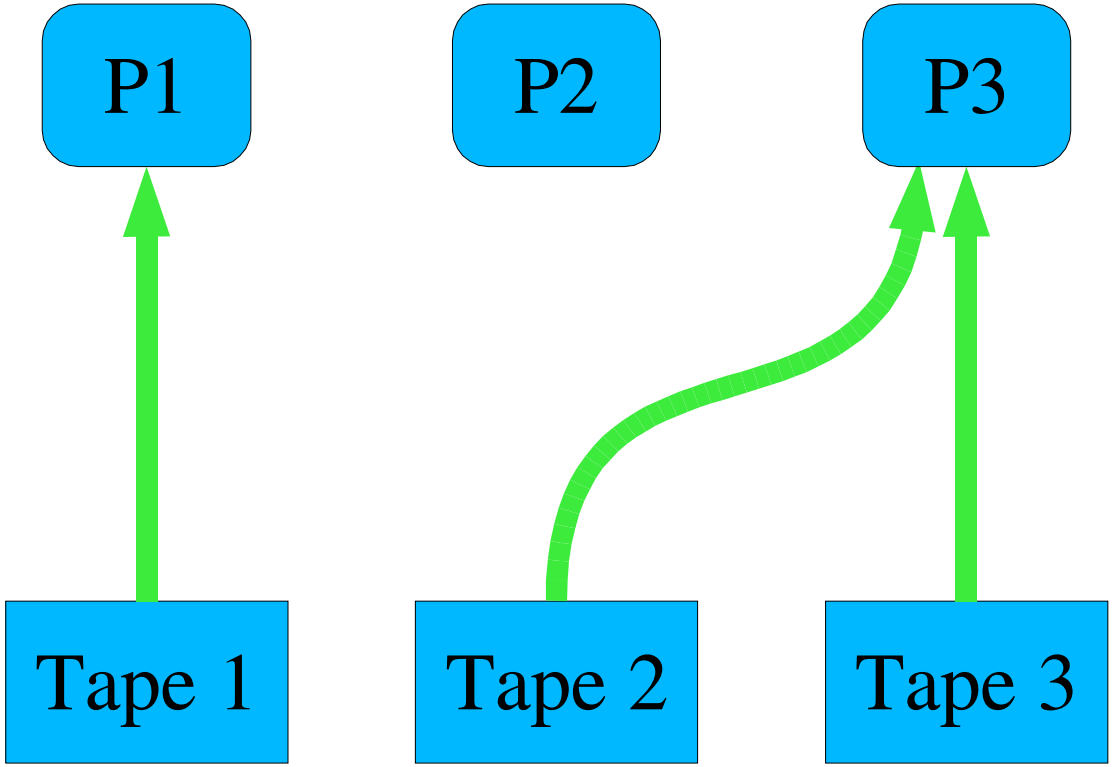
Waiting



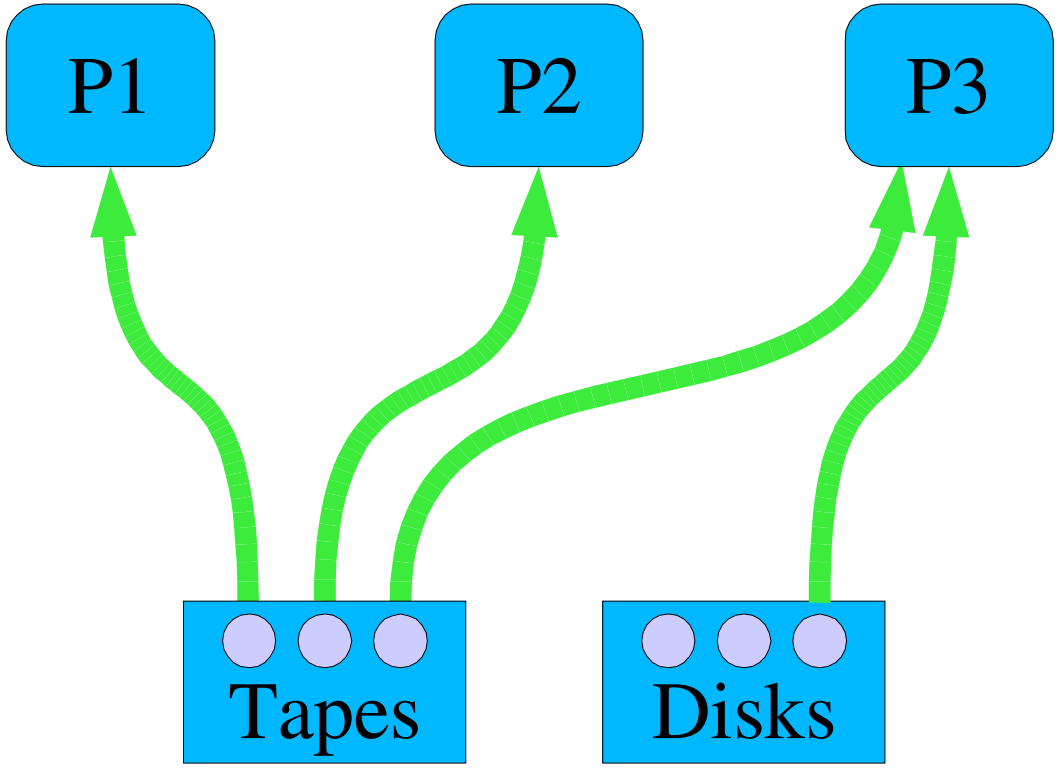
Release



Reallocation



Multi-instance Resources



Definition of Deadlock

- **Deadlock**
  - **Set of N processes**
  - **Each waiting for an event**
    - **...which can be caused *only by another waiting process***
- **Every process will wait forever**

Deadlock Examples

- Simplest form
  - Process 1 owns printer, wants tape drive
  - Process 2 owns tape drive, wants printer
- Less-obvious
  - Three tape drives
  - Three processes
    - Each has one tape drive
    - Each wants “just” one more
  - Can't blame anybody, but problem is still there

Deadlock Requirements

- **Mutual Exclusion**
- **Hold & Wait**
- **No Preemption**
- **Circular Wait**

Mutual Exclusion

- Resources aren't “thread-safe” (“reentrant”)
- Must be allocated to one process/thread at a time
- Can't be shared
  - Programmable Interrupt Timer
    - Can't have a different reload value for each process

Hold & Wait

- **Process holds resources while waiting for more**

```
mutex_lock(&m1);
mutex_lock(&m2);
mutex_lock(&m3);
```

- **This locking behavior is *typical***

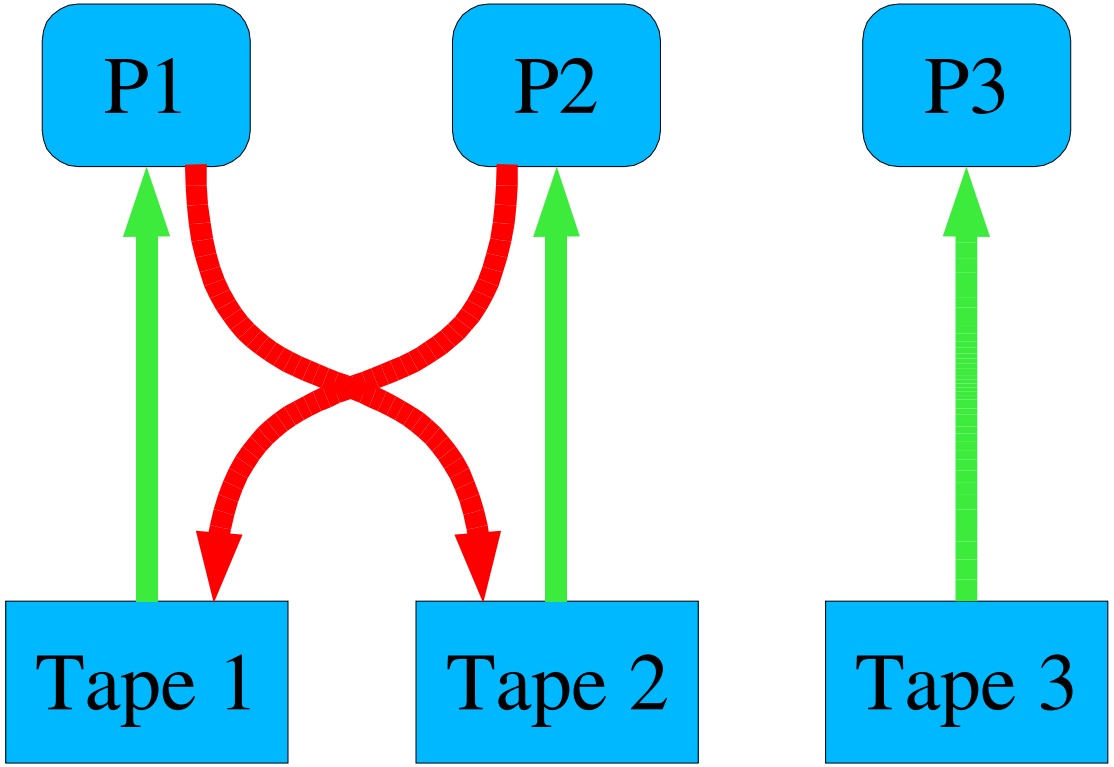
No Preemption

- Can't force a process to give up a resource
- Interrupting a CD-R burn creates a “coaster”
- Obvious solution
  - CD-R device driver forbids second open()
  - If you can't open it, you can't pre-empt it...

Circular Wait

- **Process 0 needs something process 4 has**
  - **Process 4 needs something process N has**
  - **Process N needs something process M has**
  - **Process M needs something process 0 has**
- **Described as “cycle in the resource graph”**

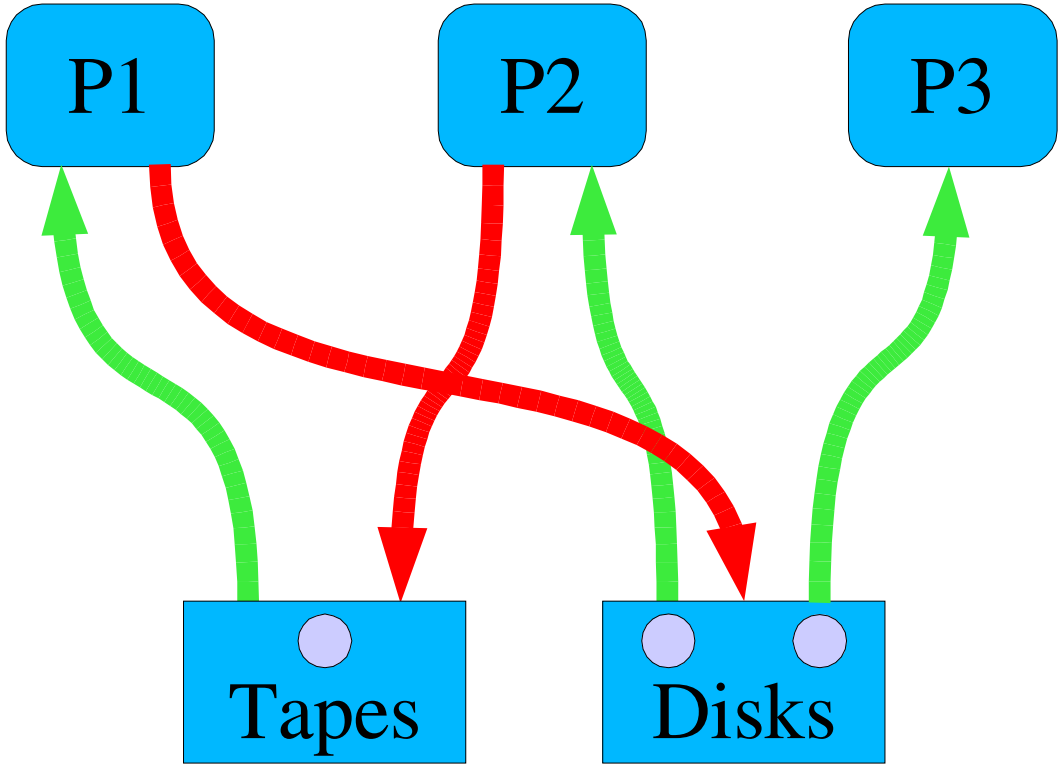
Cycle in Resource Graph



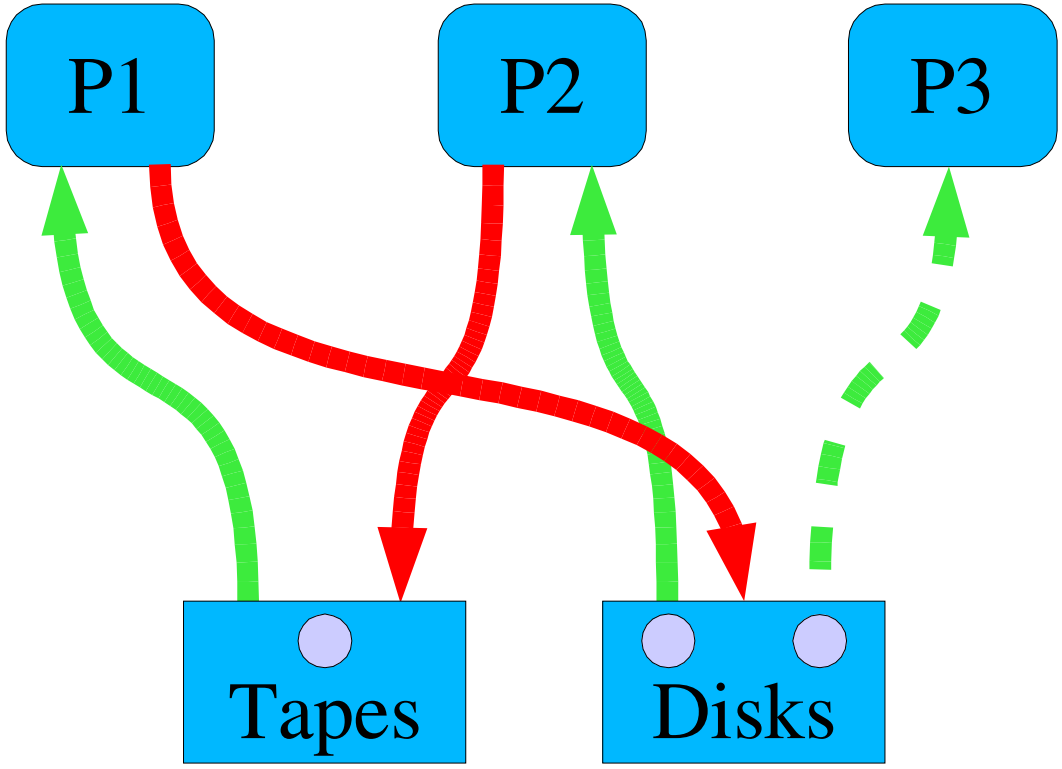
Deadlock Requirements

- **Mutual Exclusion**
- **Hold & Wait**
- **No Preemption**
- **Circular Wait**
- ***Each deadlock*** **requires** ***all four***

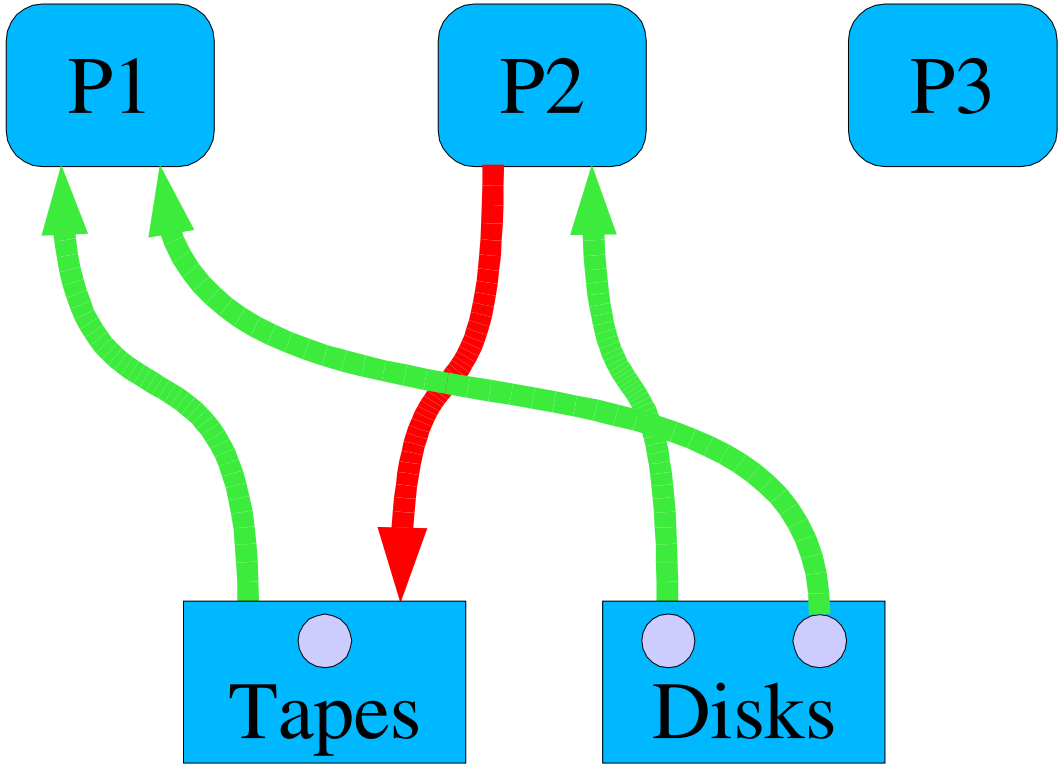
Multi-Instance Cycle



Multi-Instance Cycle *(With Rescuer!)*



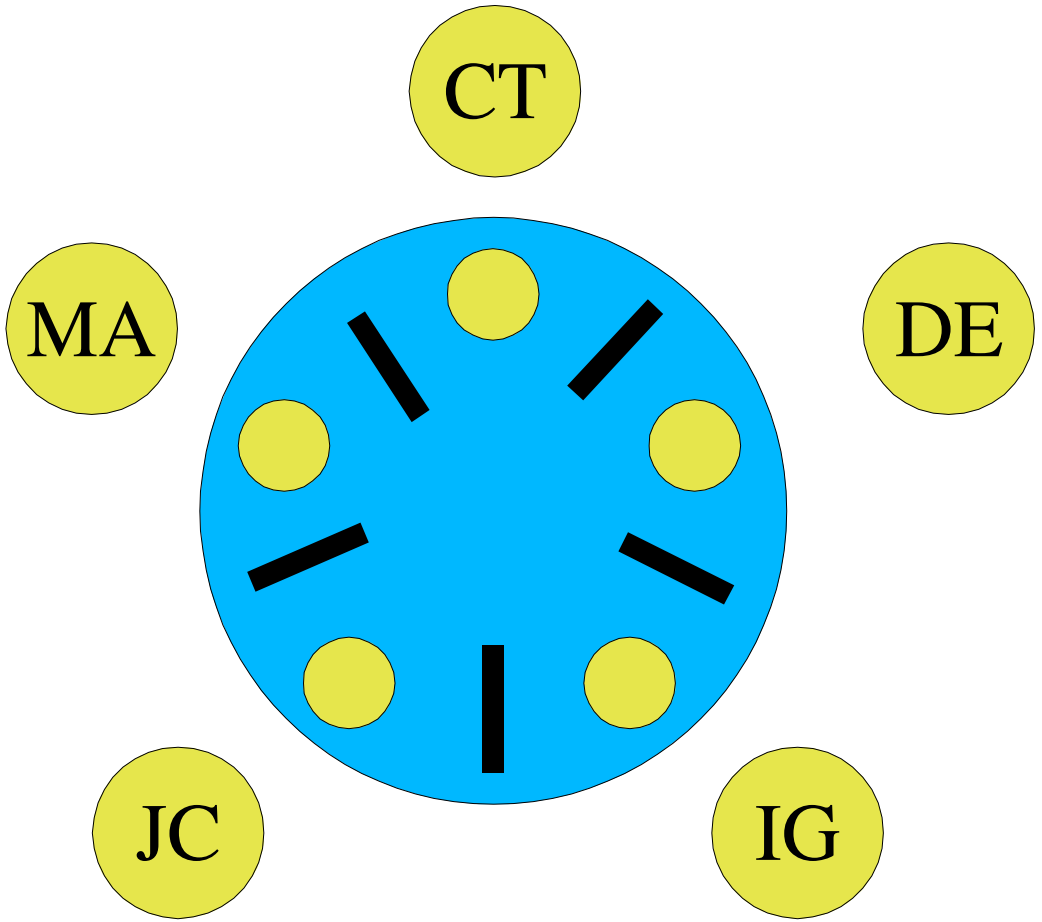
Cycle Broken



Dining Philosophers

- **The scene**
  - **410 staff at a Chinese restaurant**
  - **A little short on utensils**

Dining Philosophers



Dining Philosophers

- **Processes**
  - **5, one per person**
- **Resources**
  - **5 bowls (dedicated to a diner: no contention: ignore)**
- **5 chopsticks**
  - **1 between every adjacent pair of diners**
- **Contrived example?**
  - **Illustrates contention, starvation, deadlock**

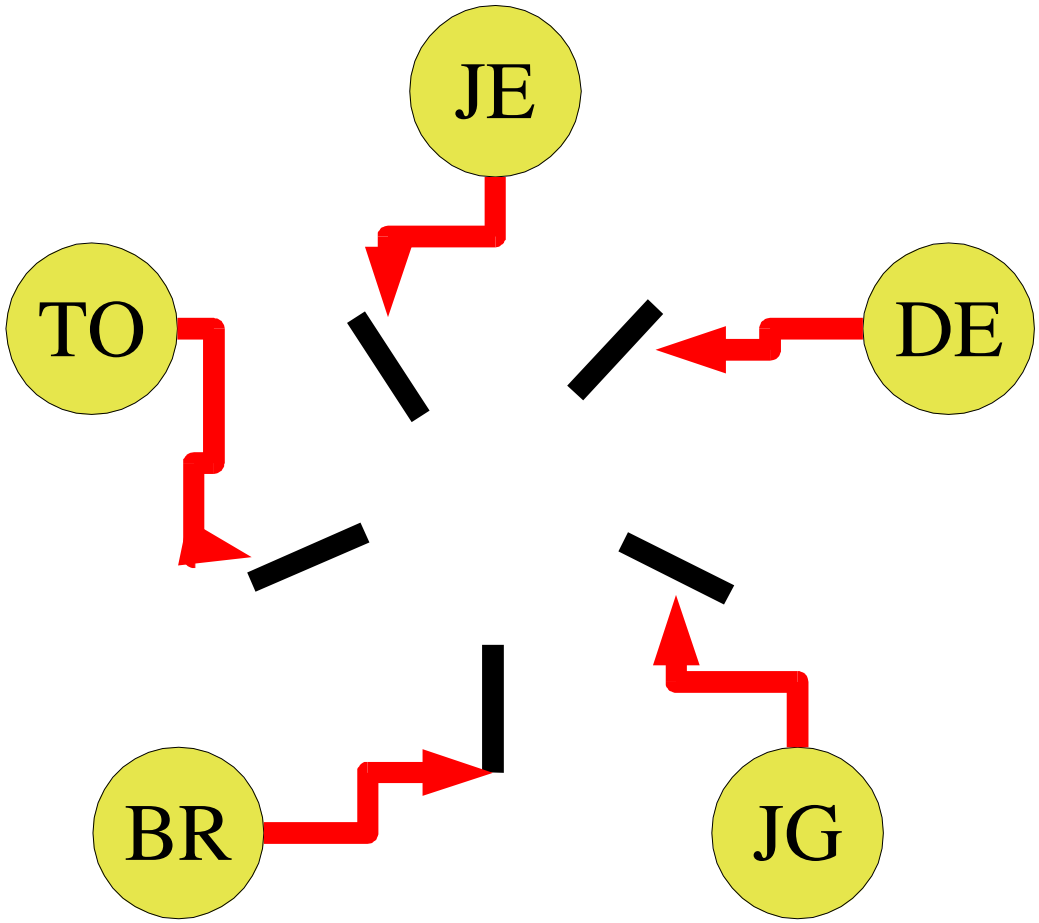
Dining Philosophers

- **A simple rule for eating**
  - **Wait until the chopstick to your right is free; take it**
  - **Wait until the chopstick to your left is free; take it**
  - **Eat for a while**
  - **Put chopsticks back down**

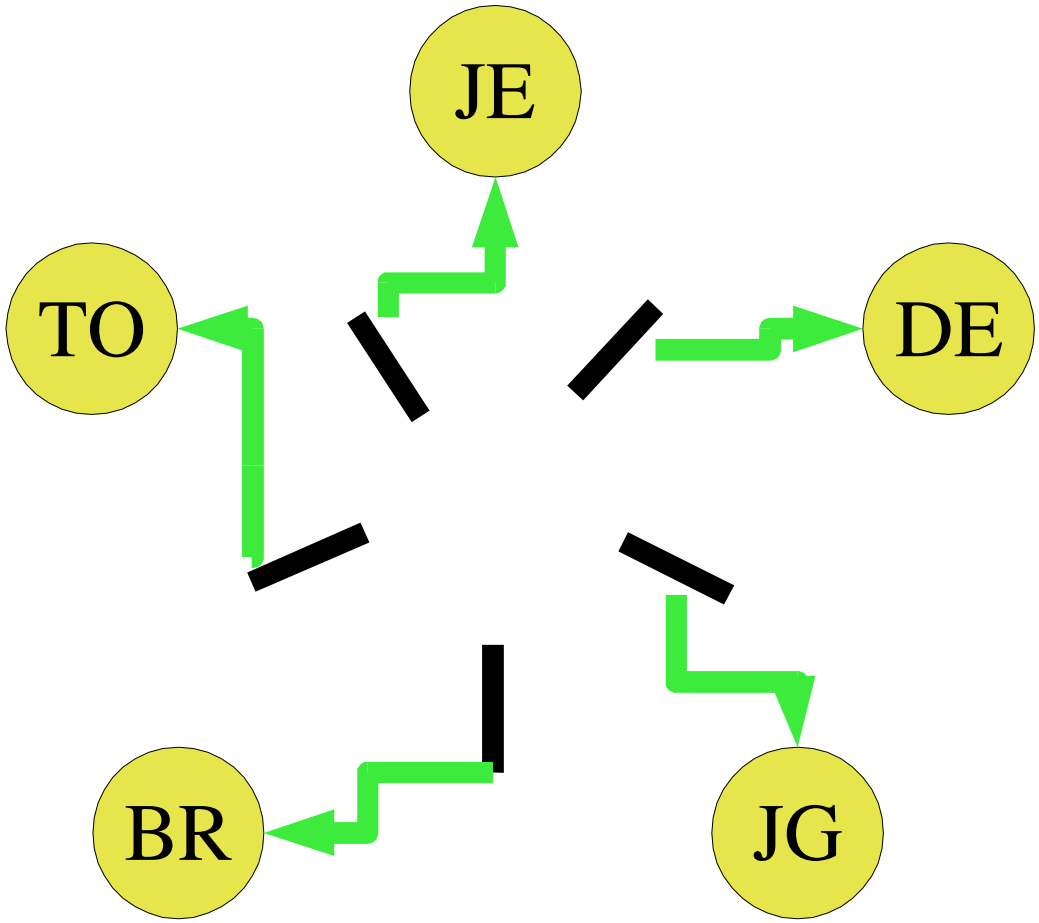
Dining Philosophers Deadlock

- **Everybody reaches clockwise...**
  - **...at the same time?**

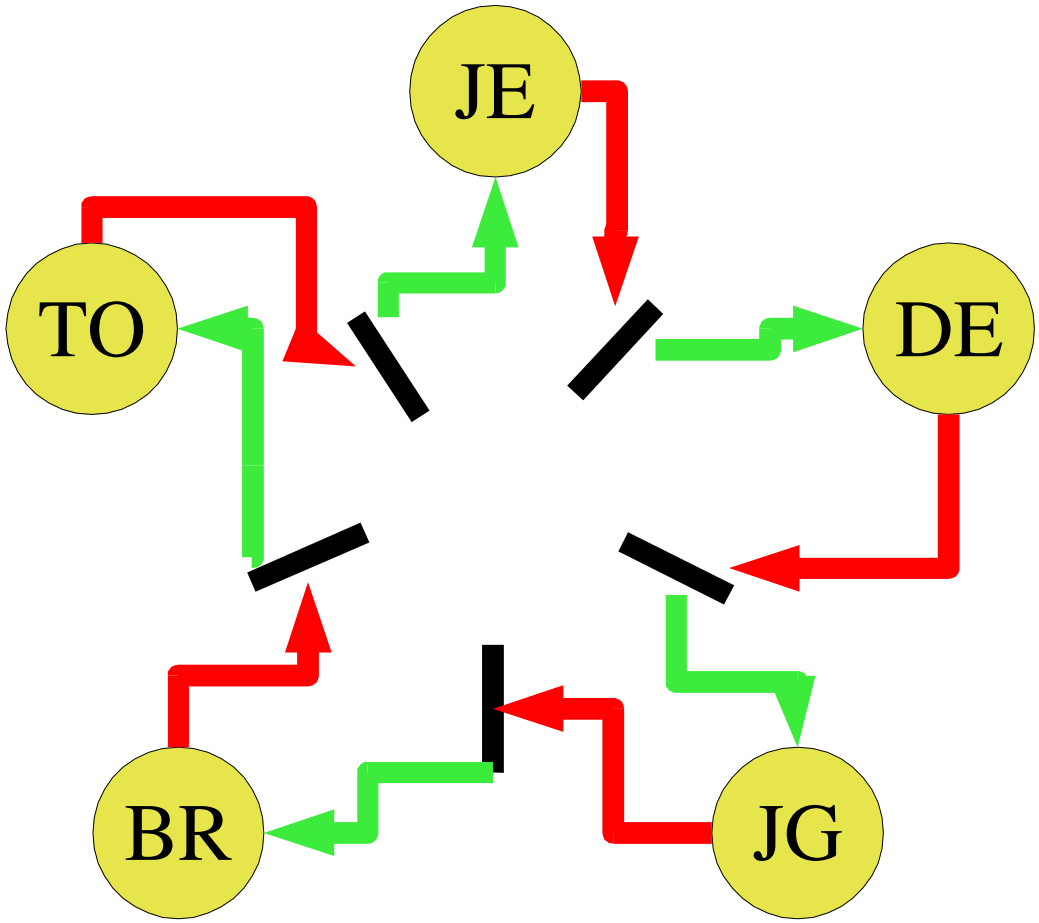
Reaching Right



Process graph



Deadlock!



Dining Philosophers – State

```
int stick[5] = { -1 }; /* owner */
condition avail[5]; /* now avail. */
mutex table = { available };

/* Right-handed convention */
right = diner;
left = (diner + 4) % 5;
```

start_eating(int diner)

```
mutex_lock(table);

while (stick[right] != -1)
  condition_wait(avail[right], table);
stick[right] = diner;

while (stick[left] != -1)
  condition_wait(avail[left], table);
stick[left] = diner;

mutex_unlock(table);
```

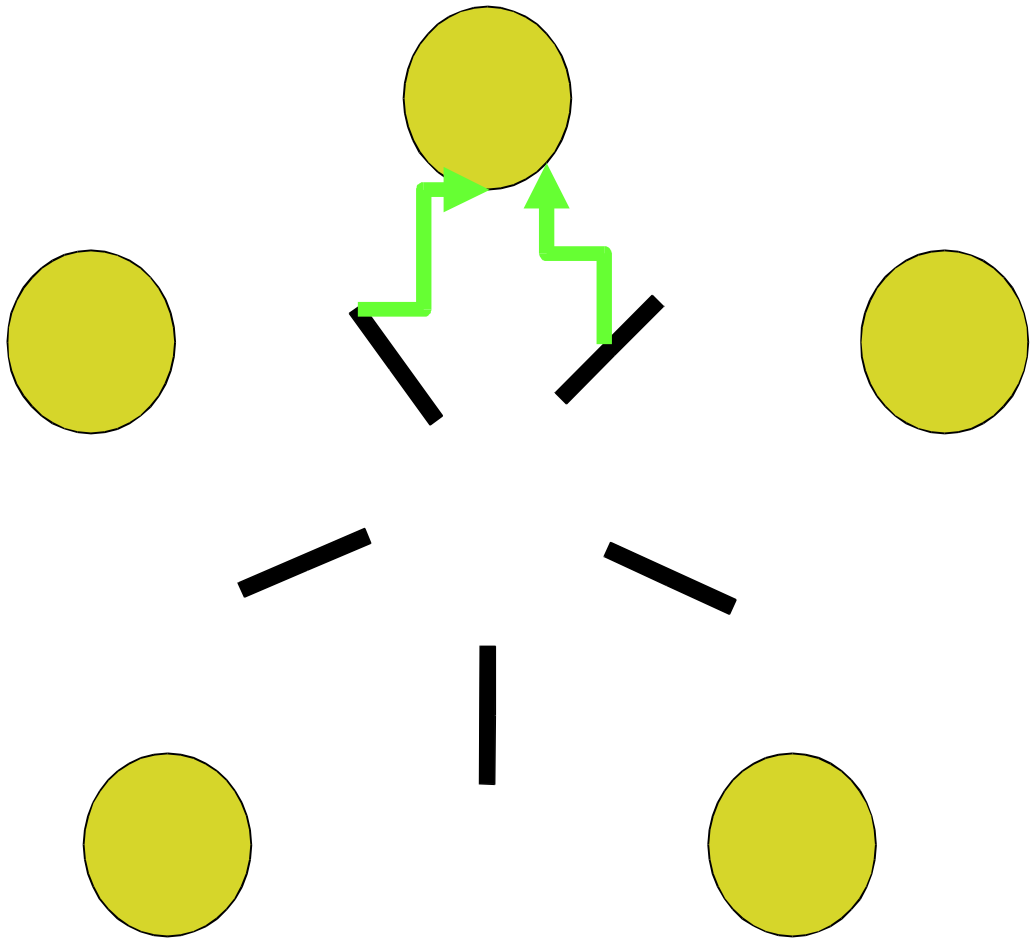
done_eating(int diner)

```
mutex_lock(table);

stick[left] = stick[right] = -1;
condition_signal(want[right]);
condition_signal(want[left]);

mutex_unlock(table);
```

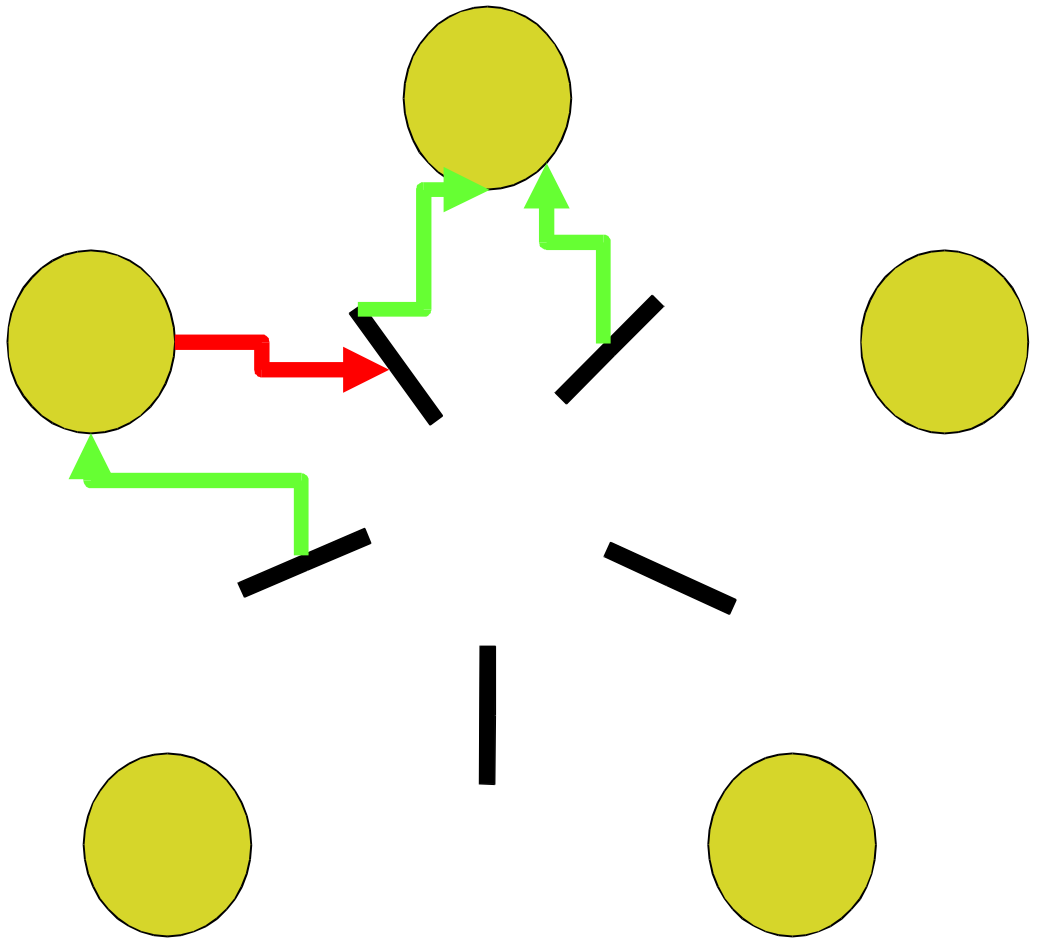
Can We Deadlock?

- At first glance the mutex protects us
  - Can't have “everybody reaching right at same time”...
  - ...mutex allows only one reach at the same time, right?
- Yes, we can
  - condition_wait() is a “reach”
  - Can everybody end up in condition_wait()?

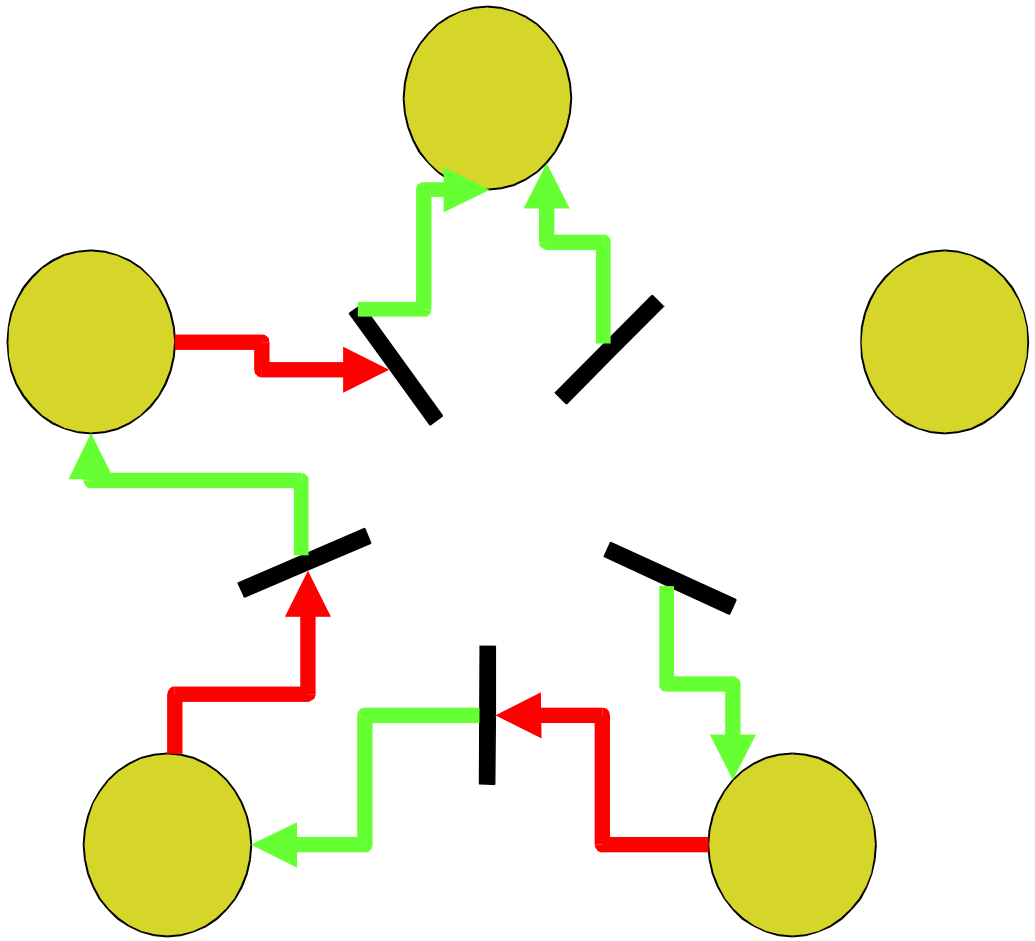
First diner gets both chopsticks



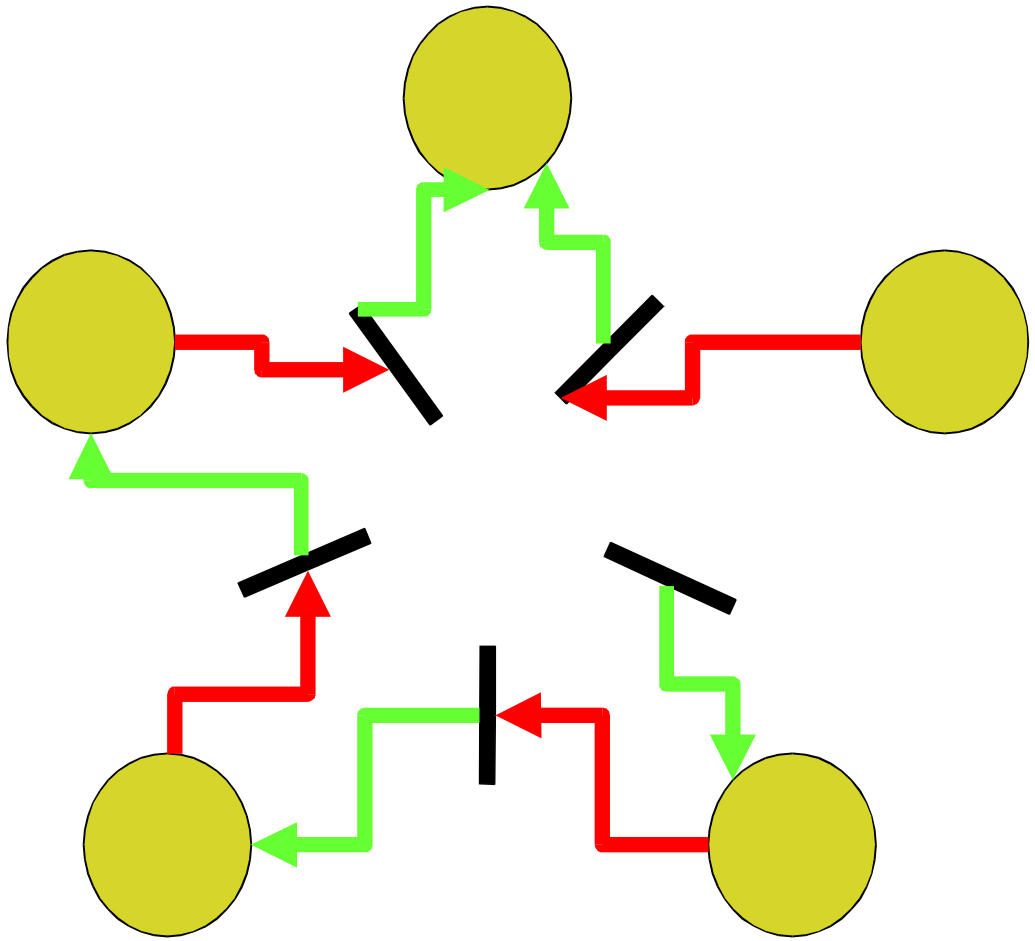
Next gets right, waits on left



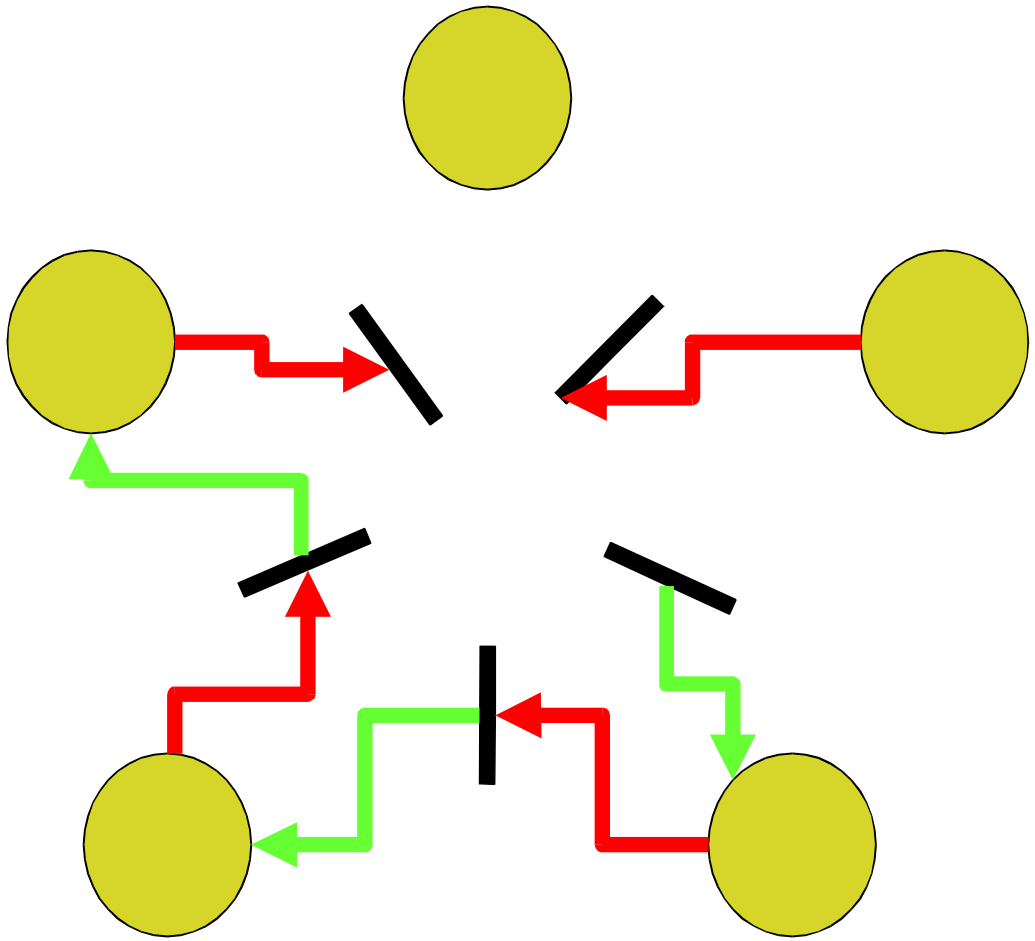
Next two get right, wait on left



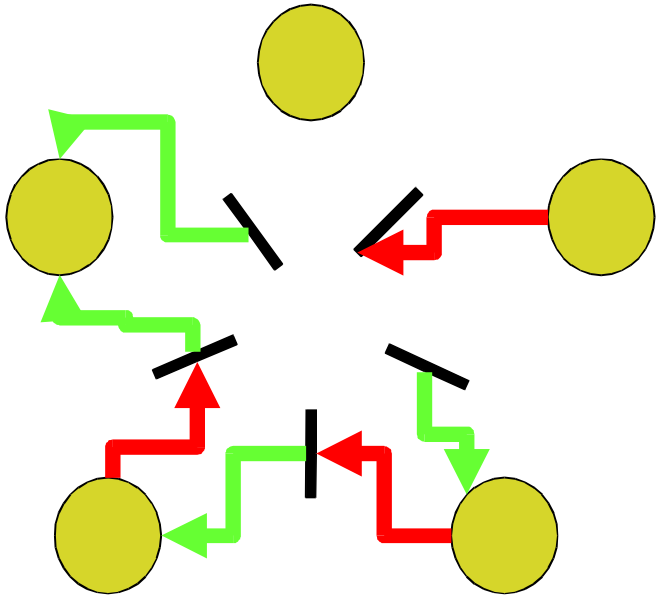
Last waits on right



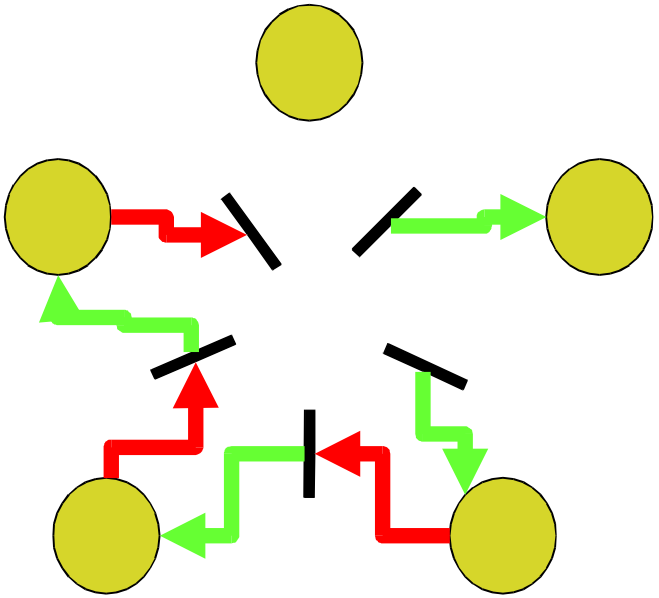
First diner stops eating - *briefly*



Next Step – *Several* Possibilities

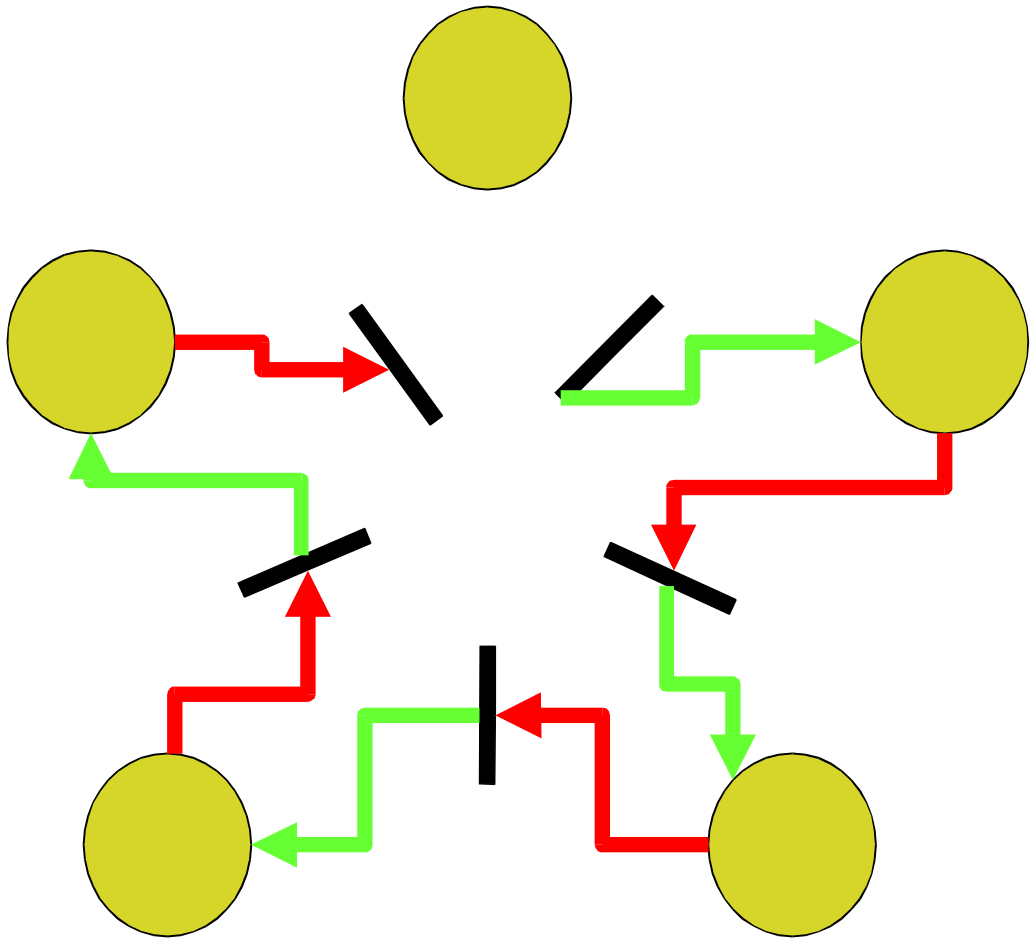


“Natural” –
longest-waiting diner progresses

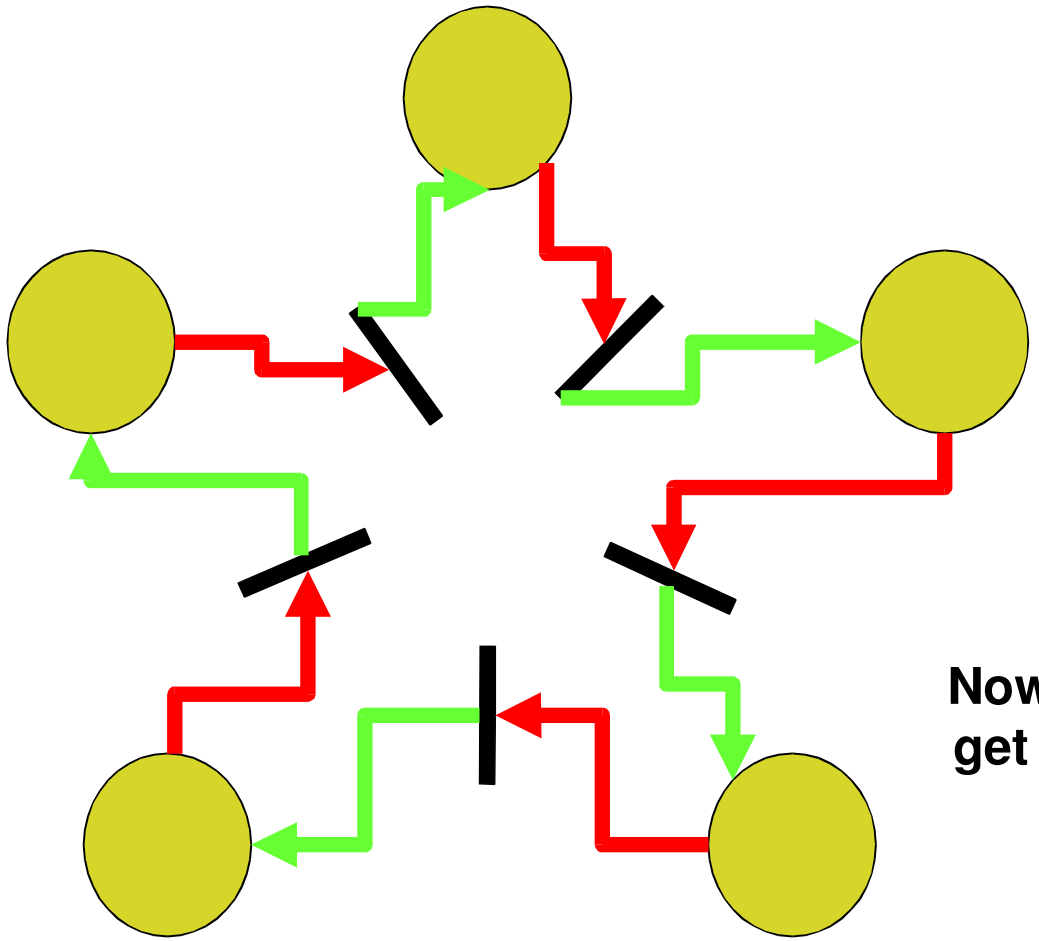


Or –
somebody else!

Last diner gets right, waits on left



First diner gets right, waits on left



Now things get boring.

Deadlock - What to do?

- **Prevention**
- **Avoidance**
- **Detection/Recovery**
- **Just reboot when it gets “too quiet”**

Prevention

- **Restrict behavior or resources**
  - **Find a way to violate one of the 4 conditions**
    - **To wit...?**
- **What we will talk about today**
  - **4 conditions, 4 possible ways**

Avoidance

- **Processes *pre-declare* usage patterns**
- **Dynamically examine requests**
  - **Imagine what other processes could ask for**
  - **Keep system in "safe state"**

Detection/Recovery

- **Maybe deadlock won't happen today...**
- **...Hmm, it seems quiet...**
- **...Oops, here is a cycle...**
- ***Abort some process***
  - **Ouch!**

Reboot When It Gets “Too Quiet”

- **Which systems would be so simplistic?**

Four Ways to Forgiveness

- *Each deadlock* **requires** *all four*
  - **Mutual Exclusion**
  - **Hold & Wait**
  - **No Preemption**
  - **Circular Wait**
- **"Deadlock Prevention" - this is a technical term**
  - ***Pass a law*** **against one (pick one)**
  - **Deadlock only if somebody** ***transgresses!***

Outlaw Mutual Exclusion

- ***Don't have*** **single-user resources**
  - **Require all resources to "work in shared mode"**
- **Problem**
  - **Chopsticks???**
  - **Many resources don't work that way**

Outlaw Hold&Wait

- **Acquire resources *all-or-none***

```
start_eating(int diner)

mutex_lock(table);
while (1)
  if (stick[lt] == stick[rt] == -1)
    stick[lt] = stick[rt] = diner
    mutex_unlock(table)
    return;
  condition_wait(released, table);
```

Problem – *Starvation*

- Larger resource set makes grabbing harder
  - No guarantee a diner eats in bounded time
- Low utilization
  - Must allocate 2 chopsticks (and waiter!)
  - Nobody else can use waiter while you eat

Outlaw Non-preemption

- **Steal resources from sleeping processes!**

```
start_eating(int diner)
right = diner;   rright = (diner+1)%5;
mutex_lock(table);
while (1)
  if (stick[right] == -1)
    stick[right] = diner
  else if (stick[rright] != rright)
    /* right can't be eating: take! */
    stick[right] = diner;
...same for left...
mutex_unlock(table);
```

Problem

- **Some resources cannot be cleanly preempted**
  - **CD burner**

Outlaw Circular Wait

- **Impose *total order* on all resources**
- **Require acquisition in *strictly increasing order***
  - **Static: allocate memory, then files**
  - **Dynamic: ooops, need resource 0; drop all, start over**

Assigning a Total Order

- **Lock order: 4, 3, 2, 1, 0: right, then left**
  - **Issue: (diner == 0) ⇒ (left == 4)**
  - **would lock(0), lock(4): *left, then right!***

```
if diner == 0
  right = (diner + 4) % 5;
  left = diner;
else
  right = diner;
  left = (diner + 4) % 5;
...
```

Problem

- **May not be possible to force allocation order**
  - **Some trains go east, some go west**

Deadlock Prevention problems

- Typical resources require mutual exclusion
- Allocation restrictions can be painful
  - All-at-once
    - Hurts efficiency
    - May starve
  - Resource needs may be unpredictable
- Preemption may be impossible
  - Or may lead to starvation
- Ordering restrictions may not be feasible

Deadlock Prevention

- **Pass a law against one of the four ingredients**
  - **Great if you can find a tolerable approach**
- ***Very*** **tempting to just let processes try their luck**

Next Time

- **Deadlock Avoidance**
- **Deadlock Recovery**