Deadlock (1)

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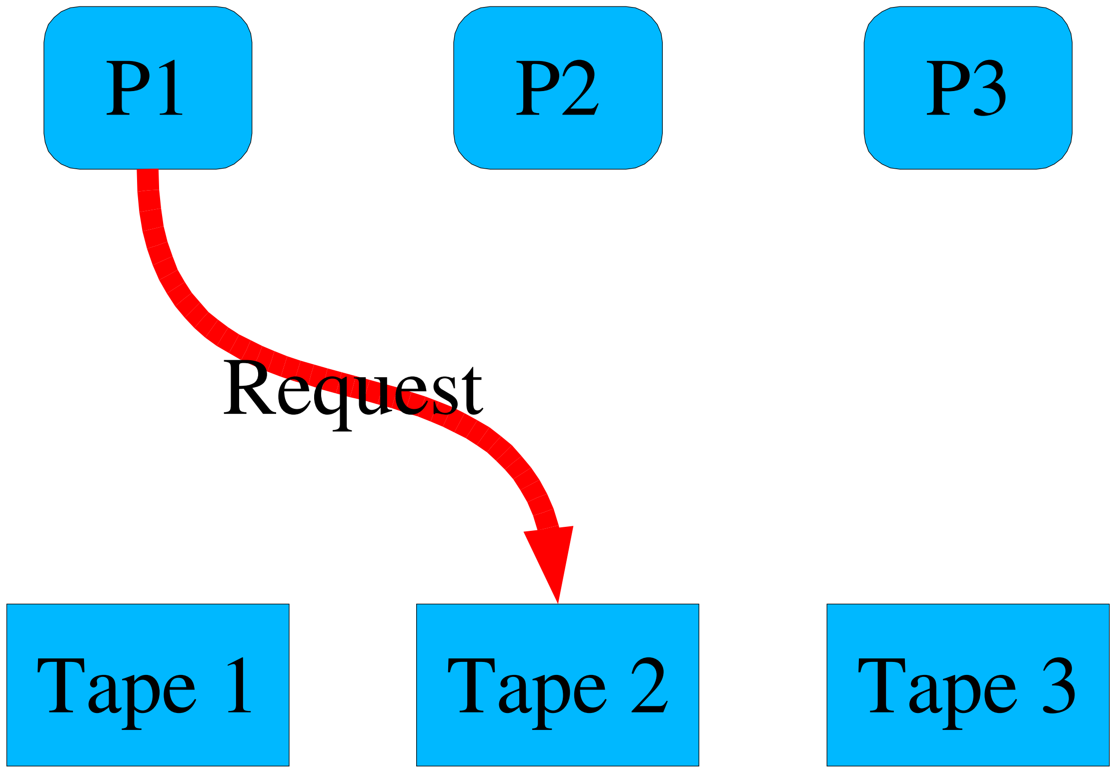
Synchronization

- P2 – You should ***really*** have
  - Made each syscall once
    - Except maybe minclone()
  - A ***detailed*** design for {thr,mutex,cond}_*()
- Readings (posted on course web)
  - Deadlock: 7.4.3, 7.5.3, Chapter 8
  - Scheduling: Chapter 6
  - Memory: Chapter 9, Chapter 10

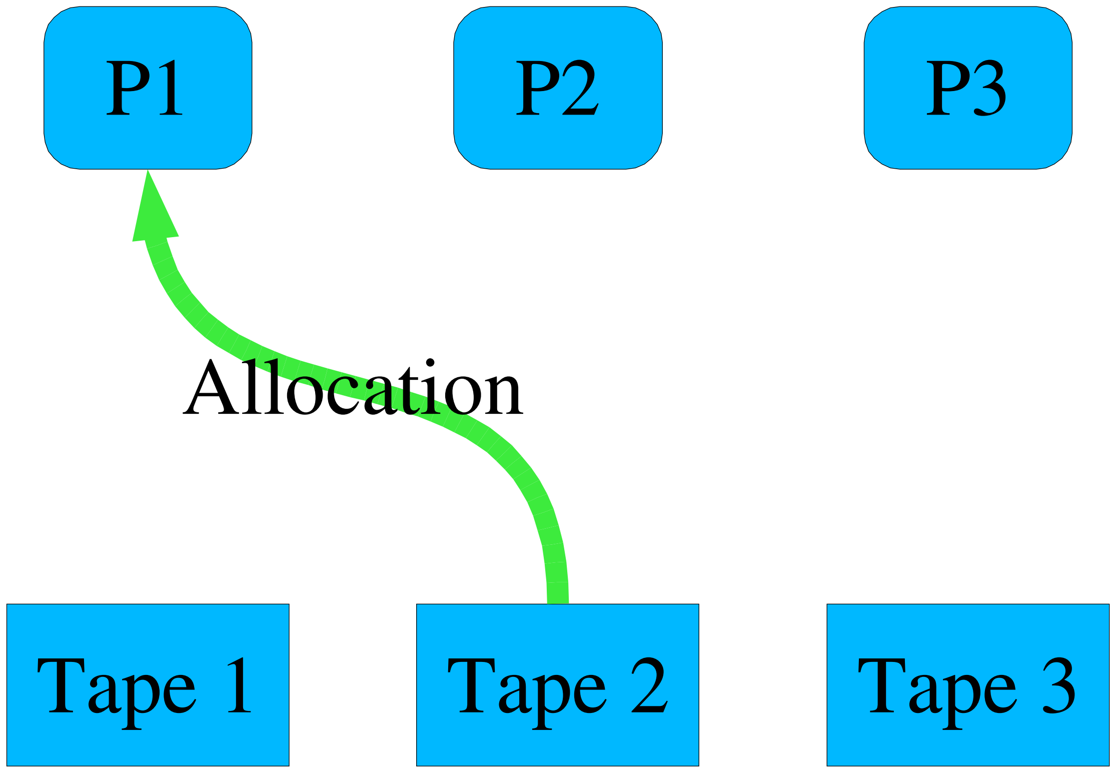
Outline

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

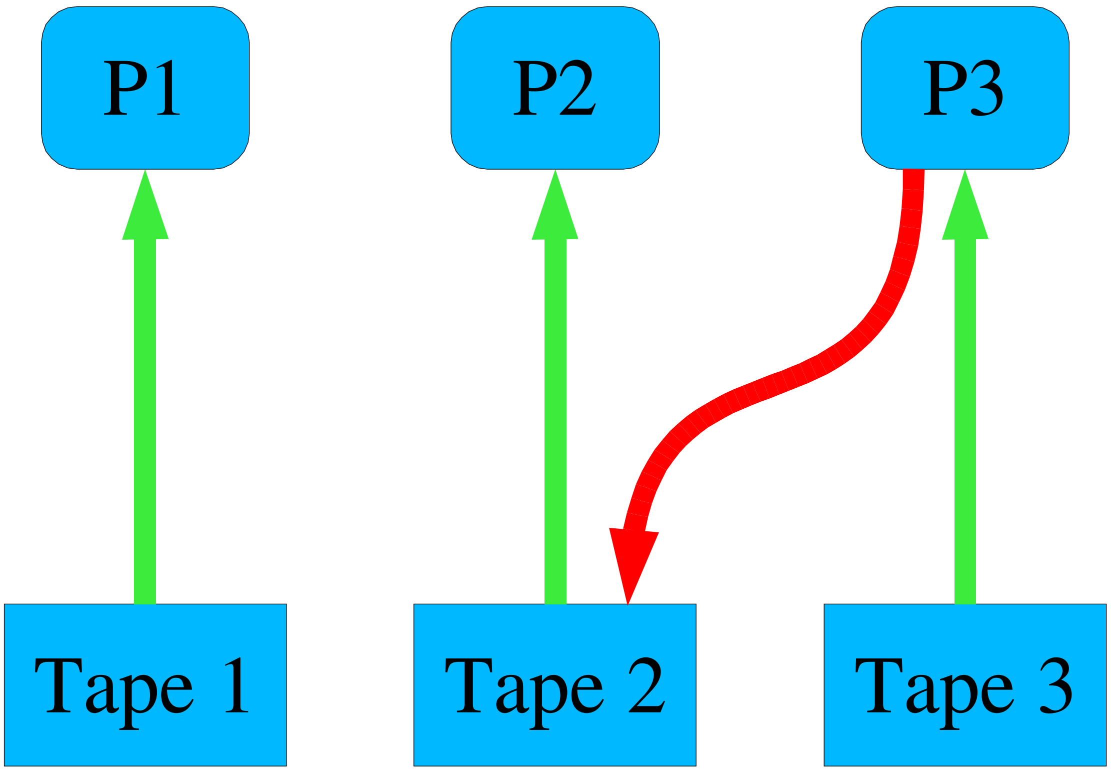
Process/Resource graph



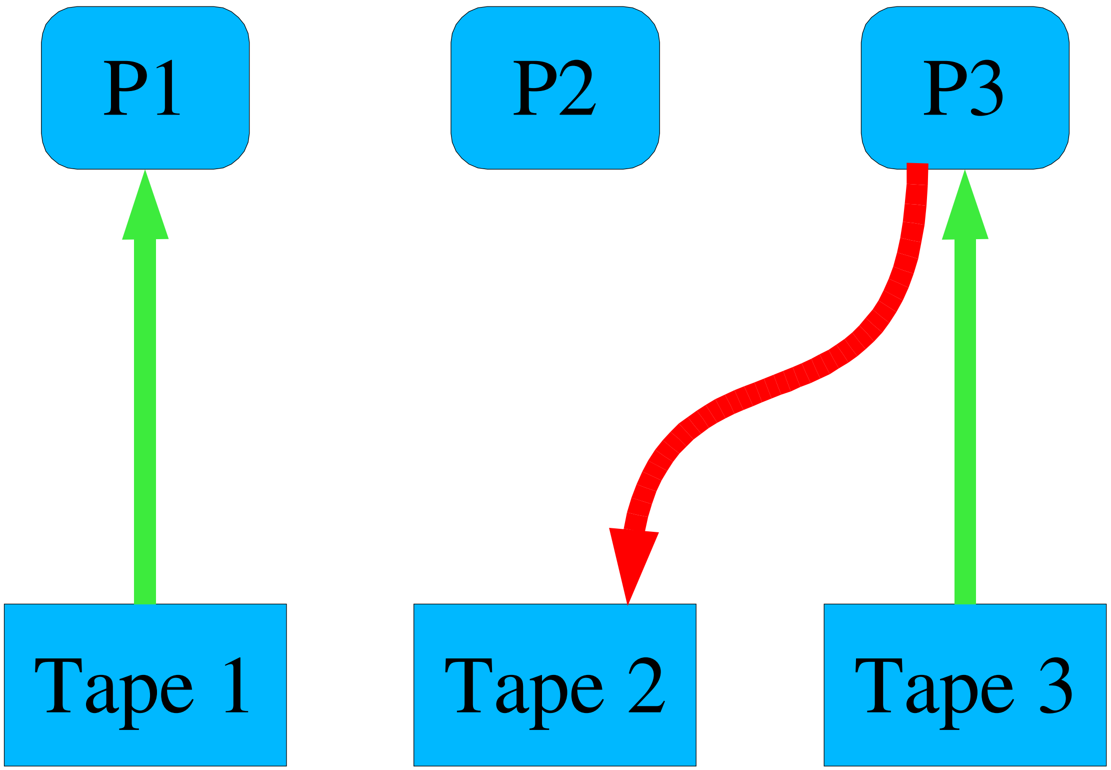
Process/Resource graph



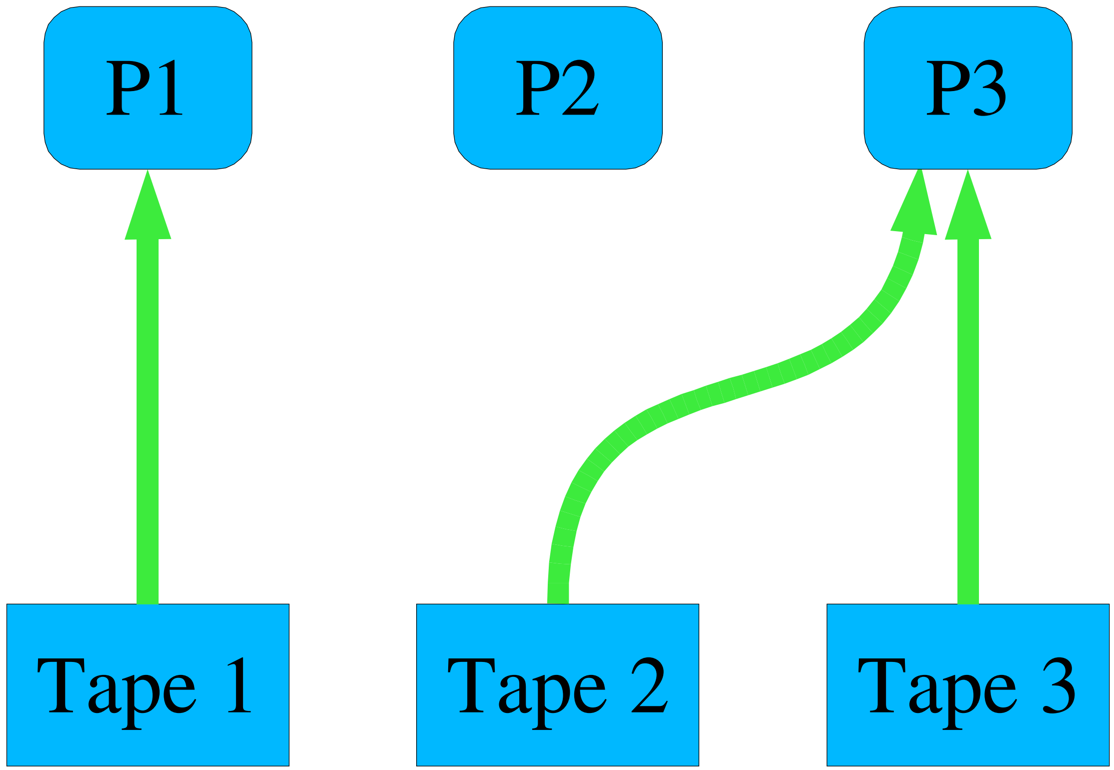
Waiting



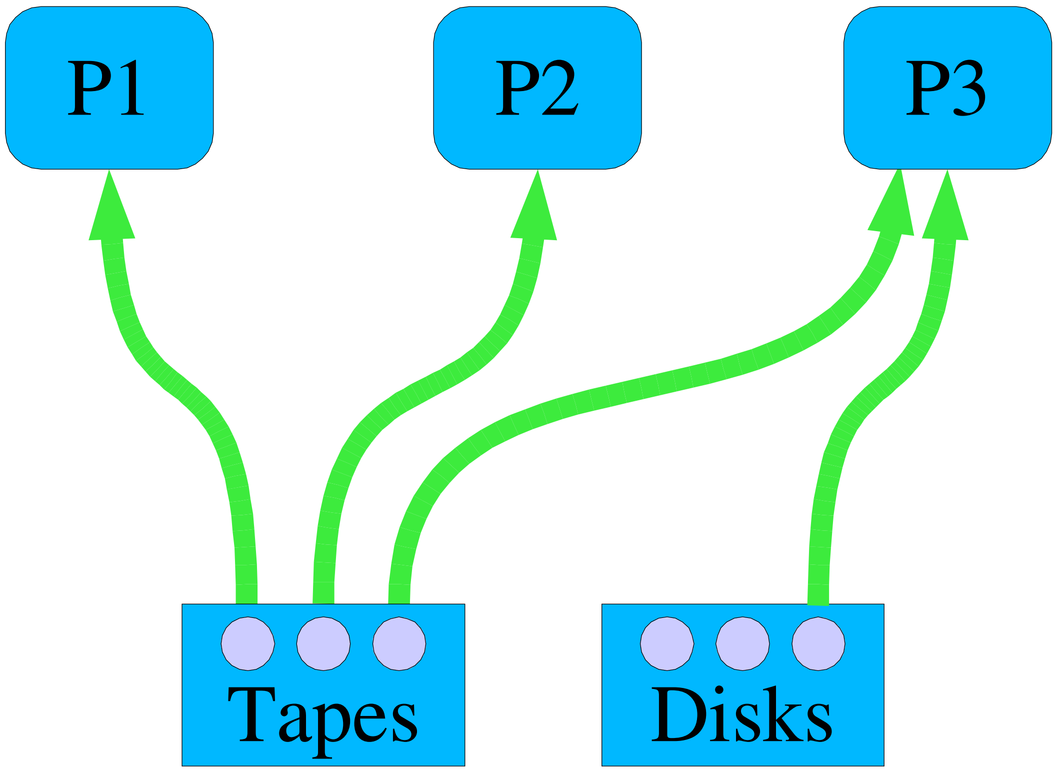
Release



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);
```

- ***Typical*** locking behavior

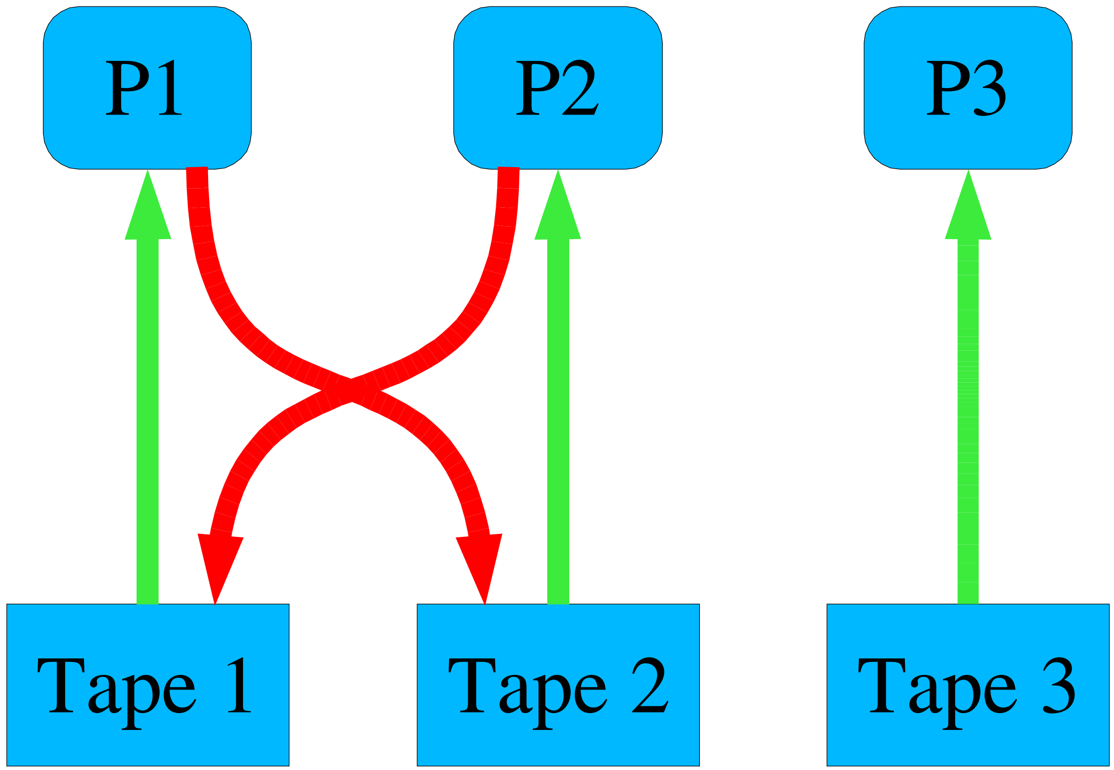
No Preemption

- Can't force a process to give up a resource
- Interrupting a CD-R write creates a “coaster”
- Obvious solution
  - CD-R device driver forbids second open()

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

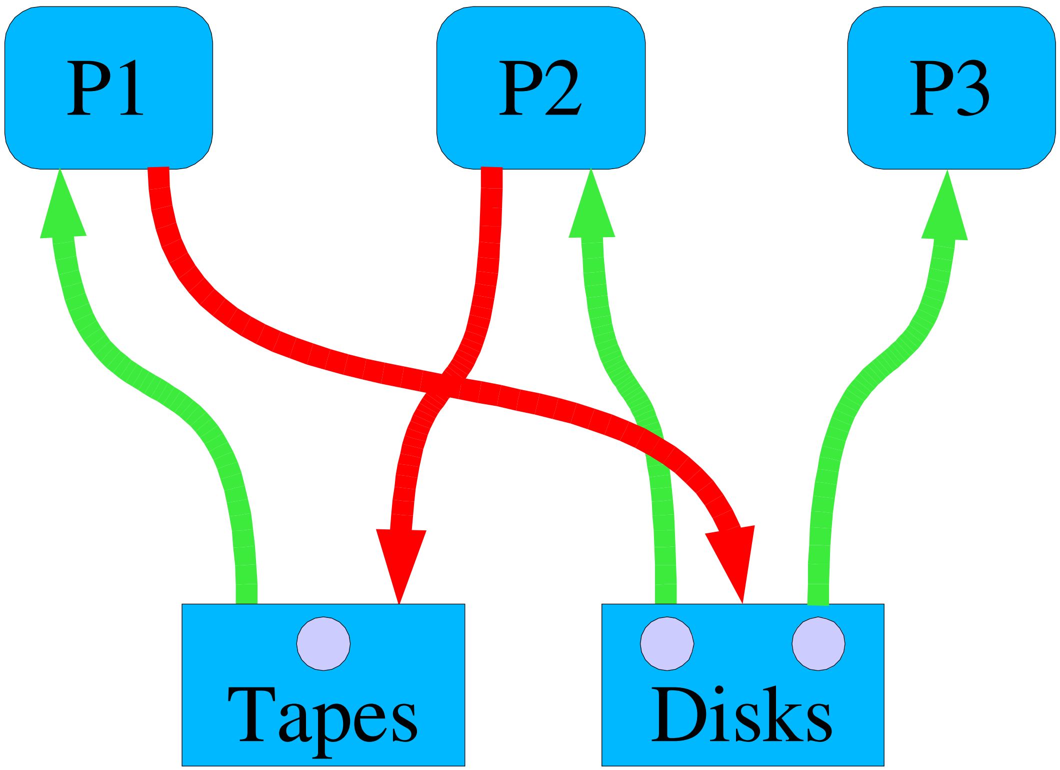
Cycle in Resource Graph



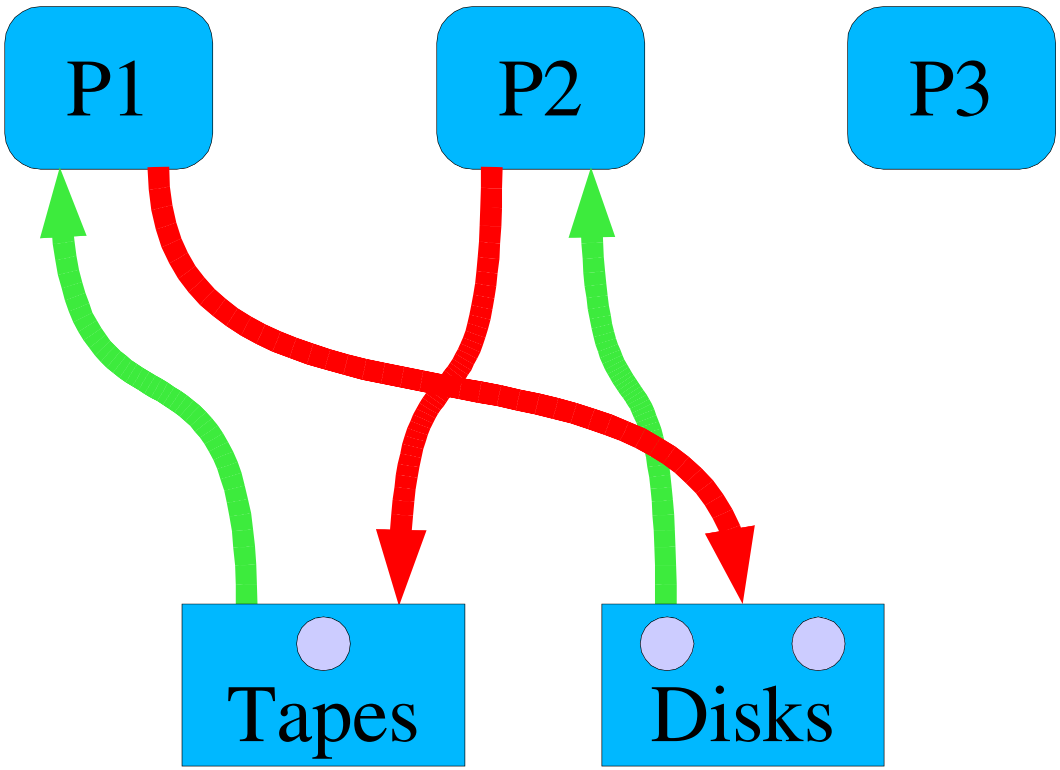
Deadlock Requirements

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

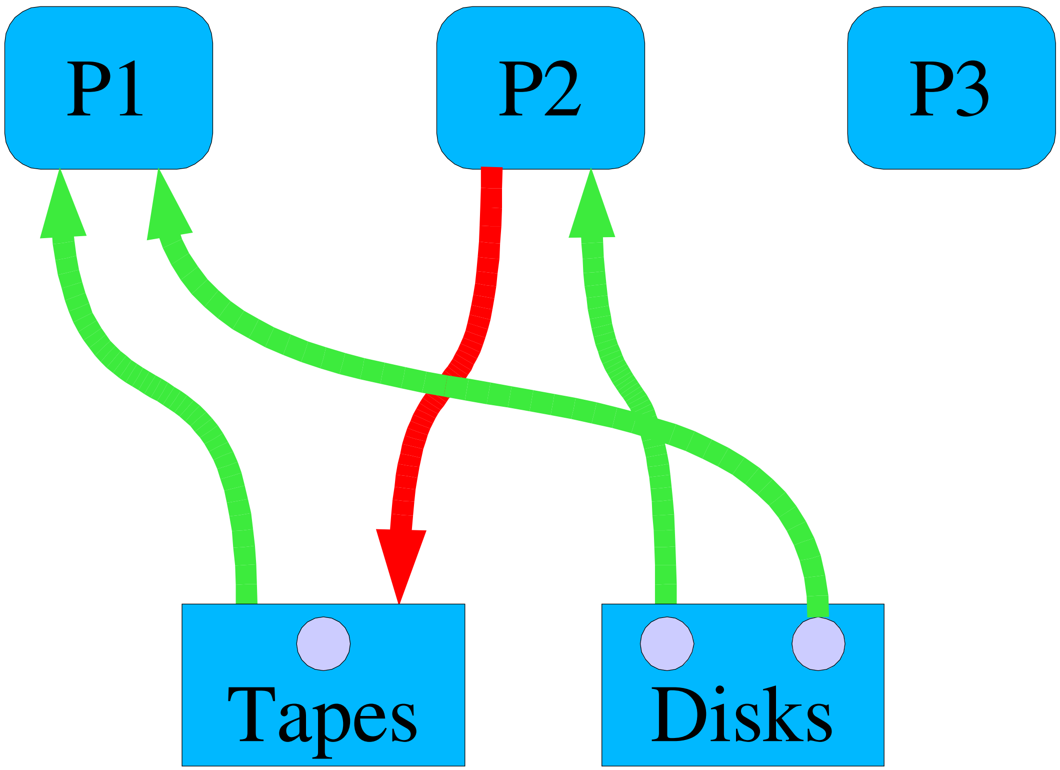
Multi-Instance Cycle



Multi-Instance Cycle *(With Rescuer!)*



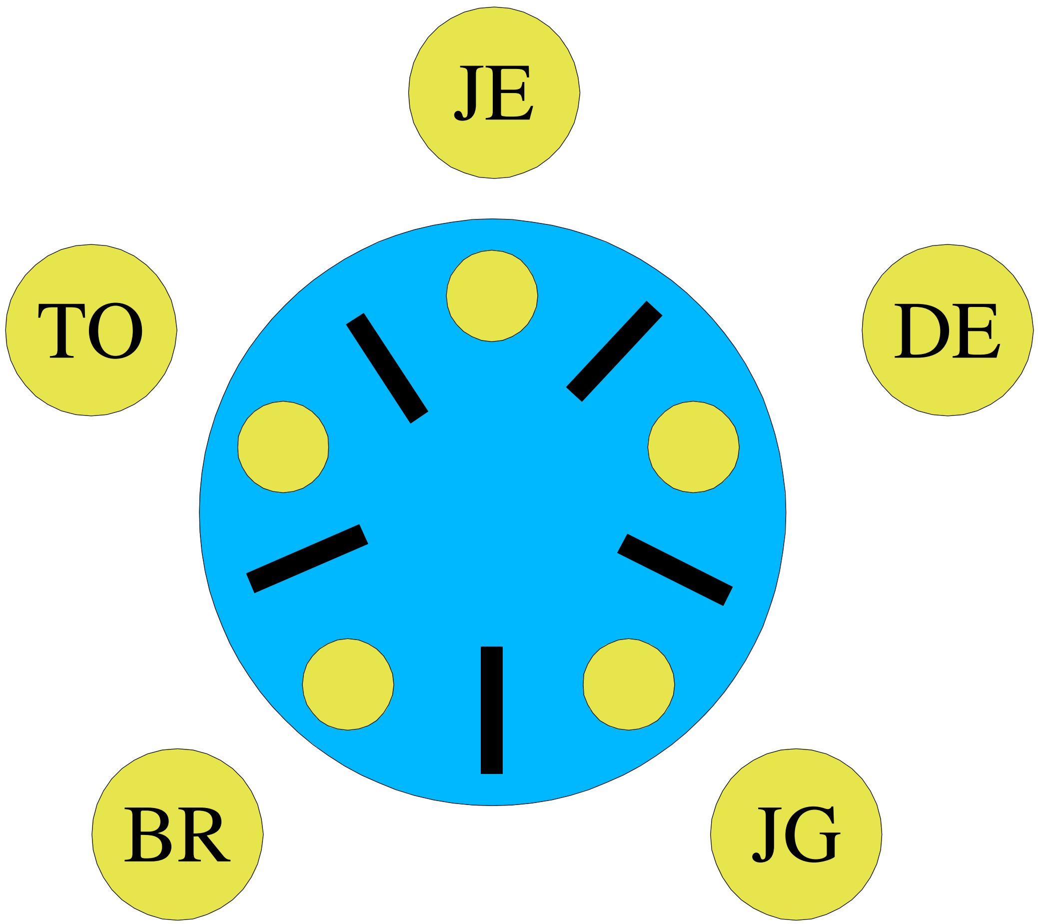
Cycle Broken



Dining Philosophers

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

Dining Philosophers



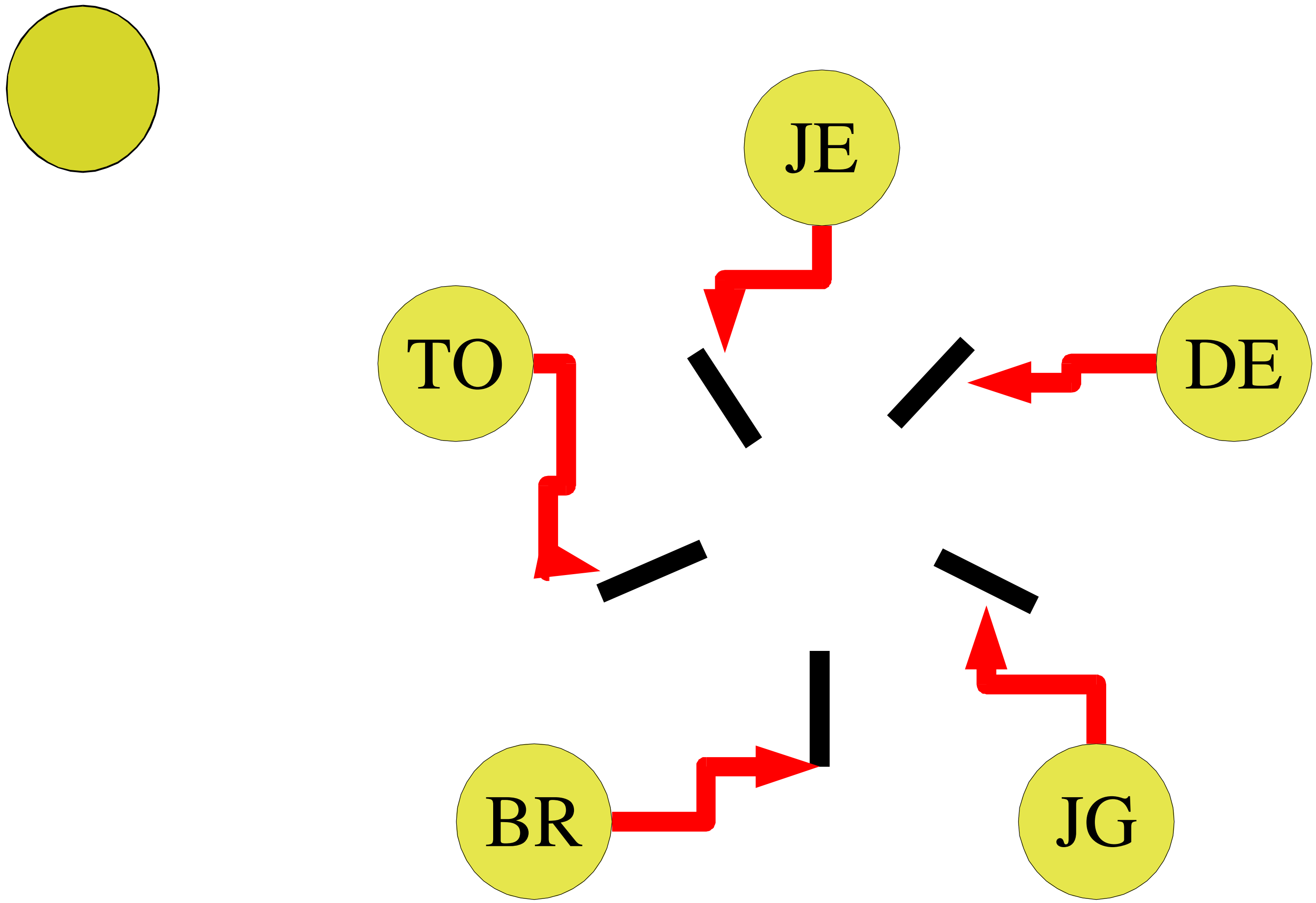
Dining Philosophers

- Processes
  - 5, one per person
- Resources
  - 5 bowls (dedicated to a diner: ignore)
- 5 chopsticks
  - 1 between every adjacent pair of diners
- Contrived example?
  - Illustrates contention, starvation, deadlock

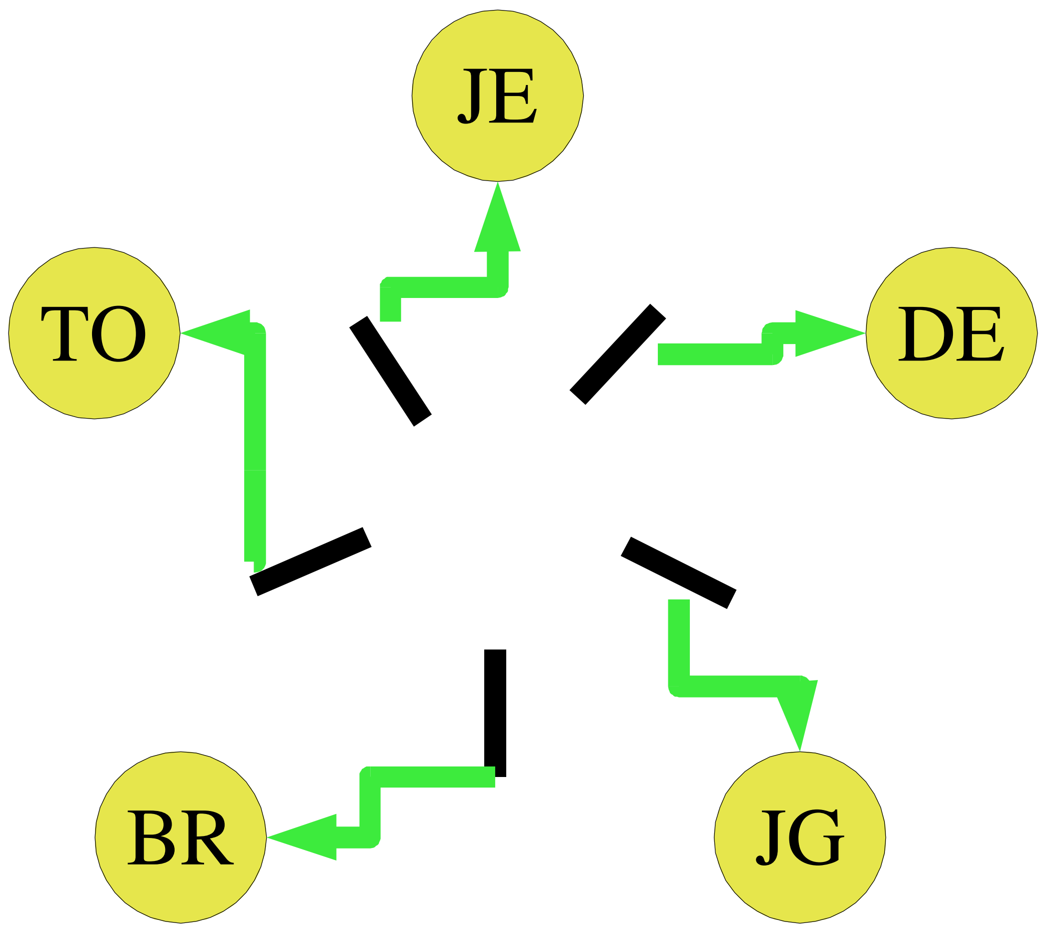
Dining Philosophers Deadlock

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

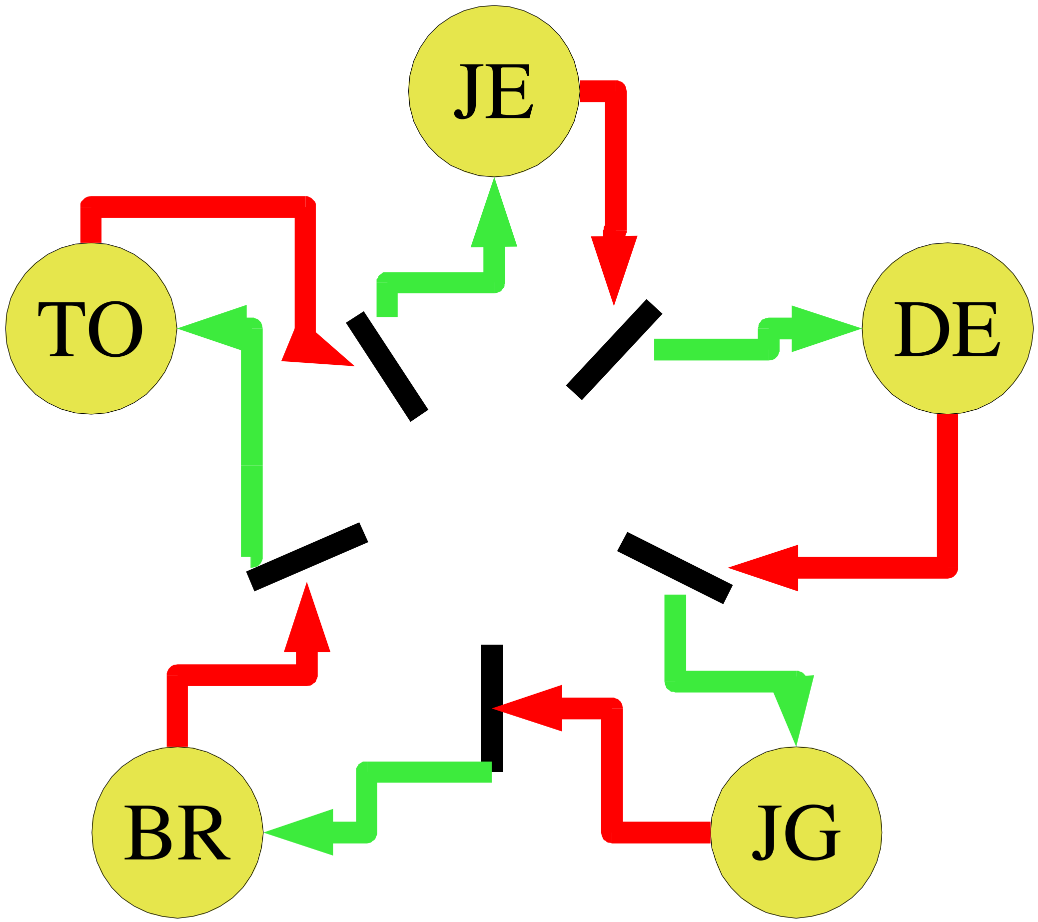
Reaching Right



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)

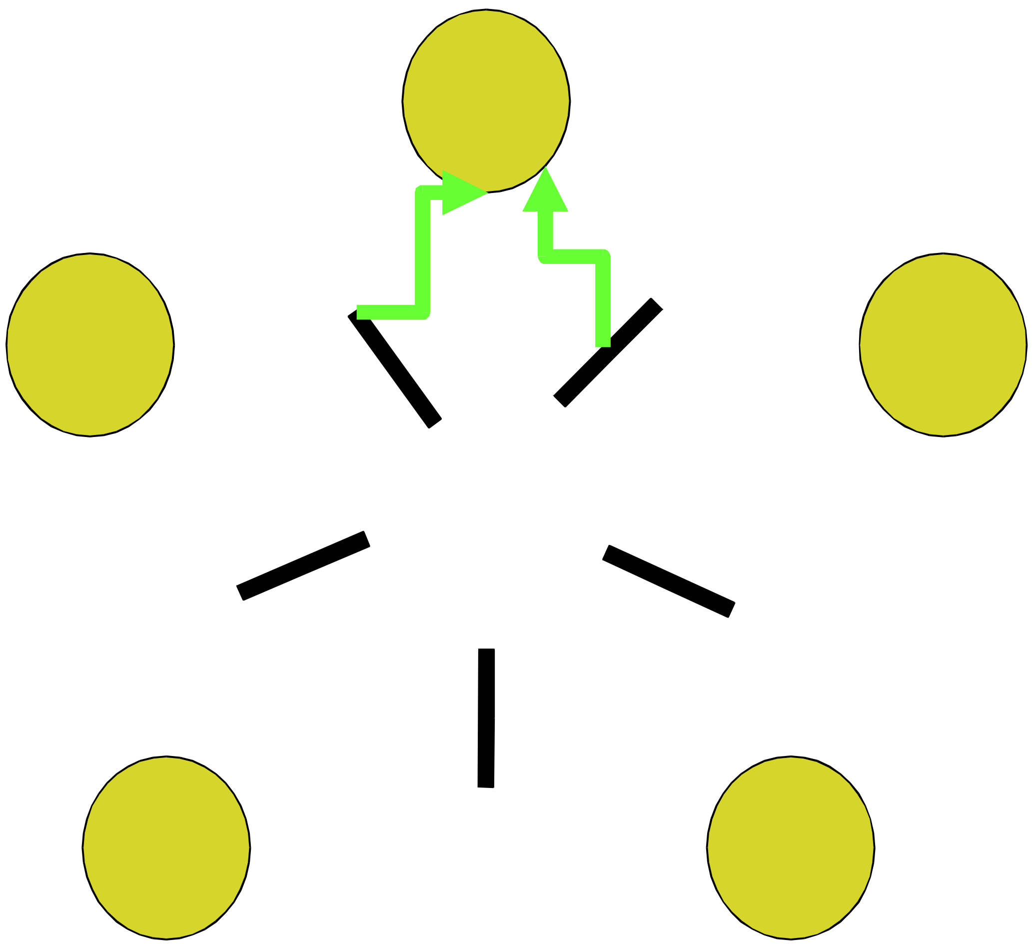
```
mutex_lock(table);
stick[left] = stick[right] = -1;
condition_signal(avail[right]);
condition_signal(avail[left]);
mutex_unlock(table);
```

Analyze using pthread semantics

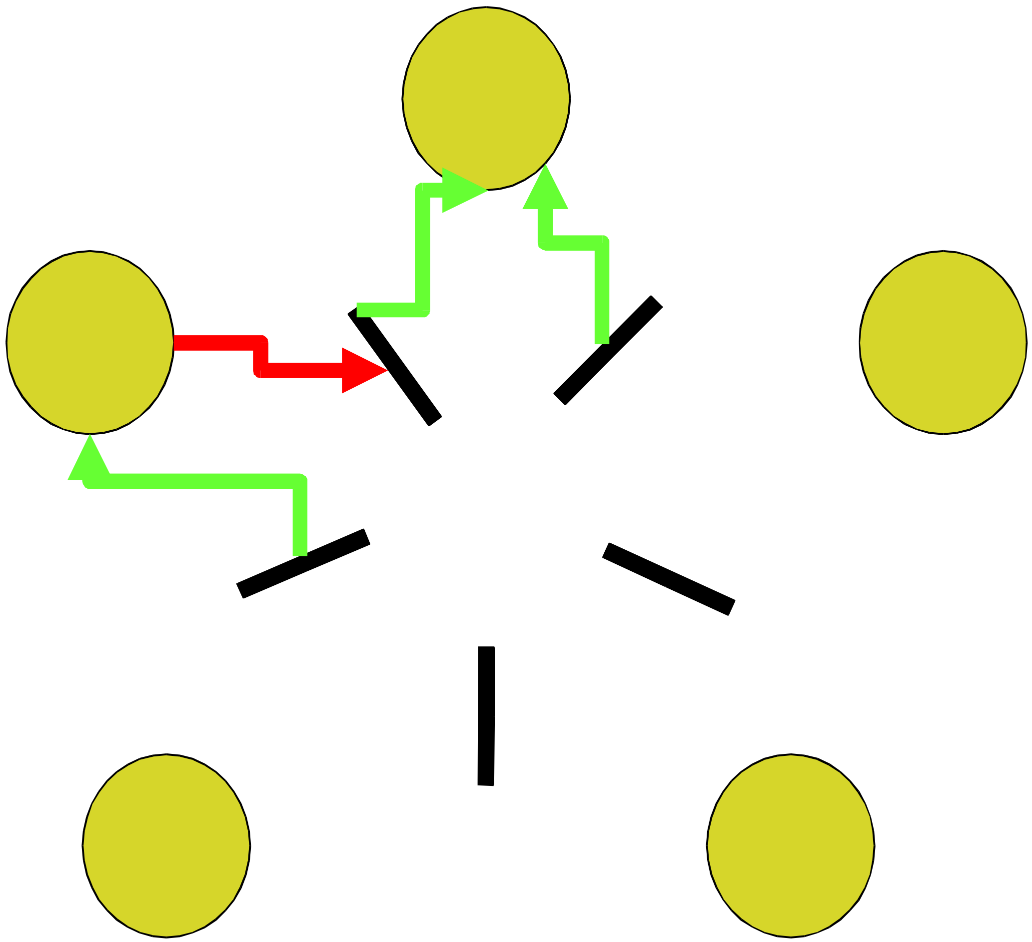
```
pthread_cond_wait(pthread_cond_t *cond, pthread_mutex_t *mutex)
    unlock mutex;
    wait for condition;
    contend for mutex;


pthread_cond_signal(pthread_cond_t *cond)
    wake up some thread waiting for condition;
```

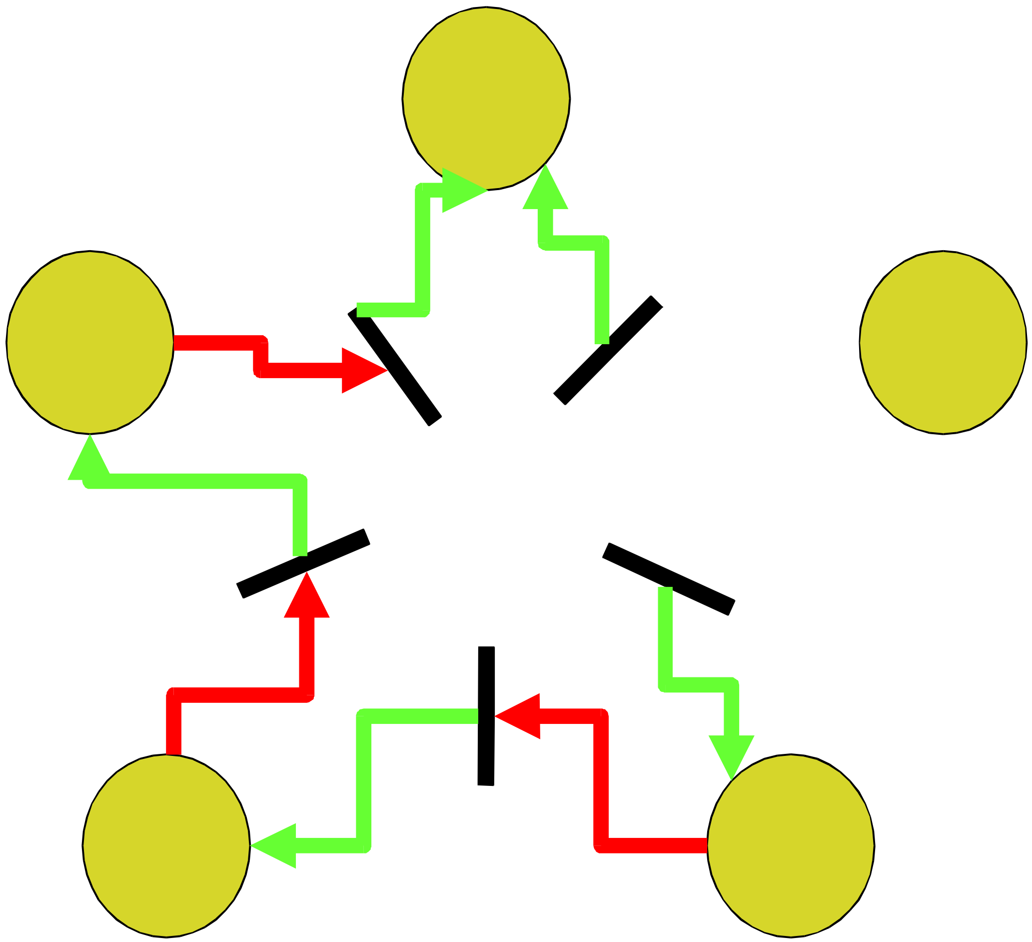
First diner gets both chopsticks



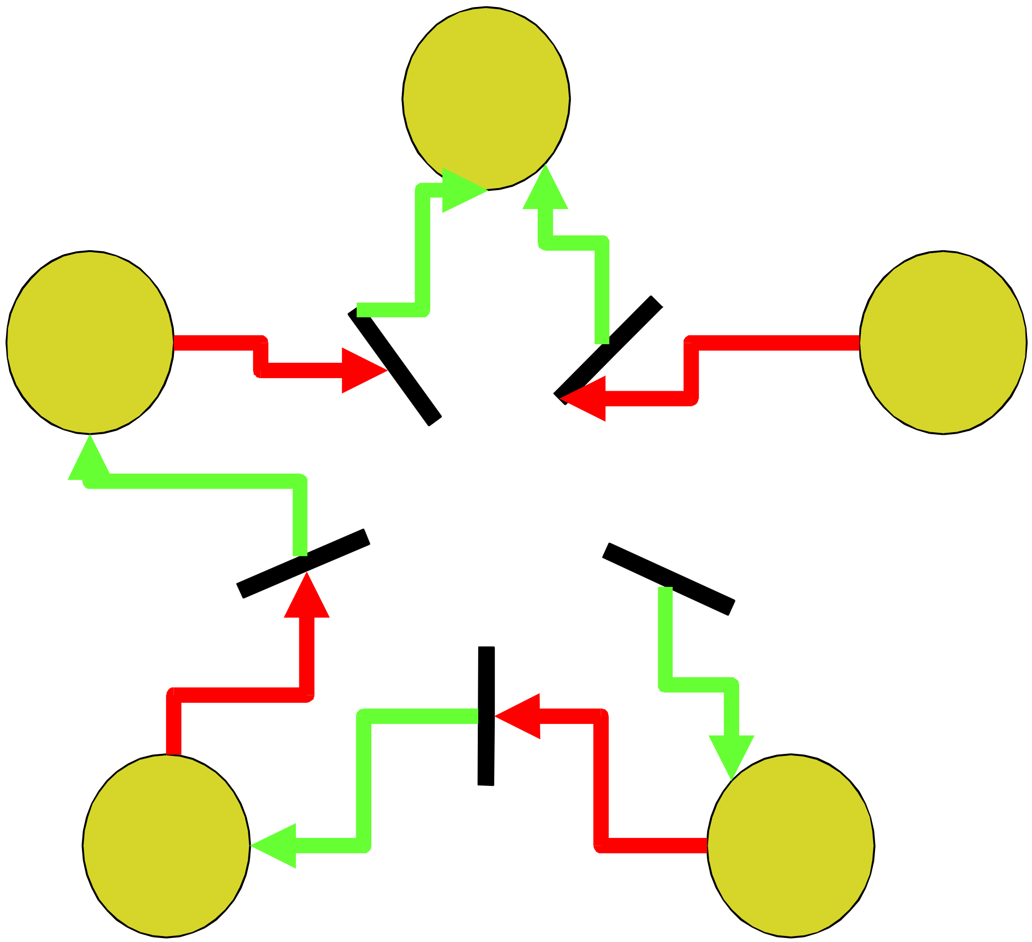
Next gets right, waits on left



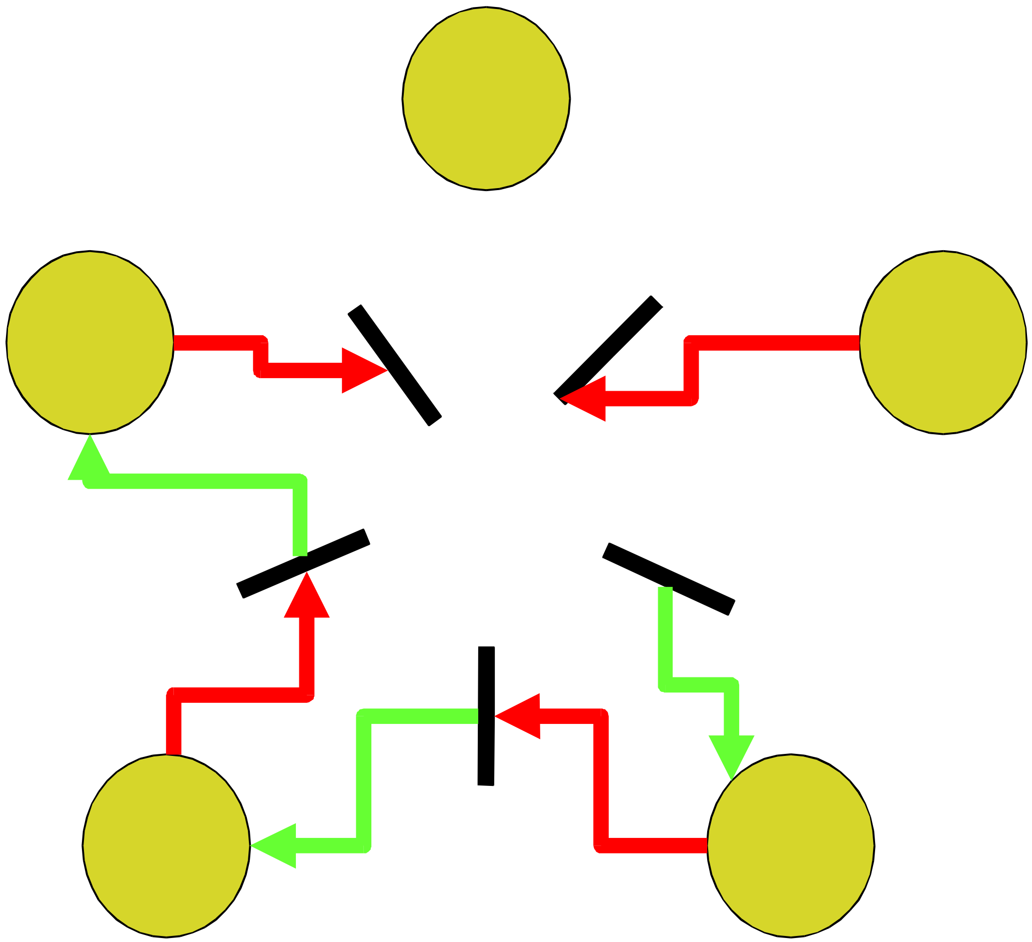
Next two get right, wait on left



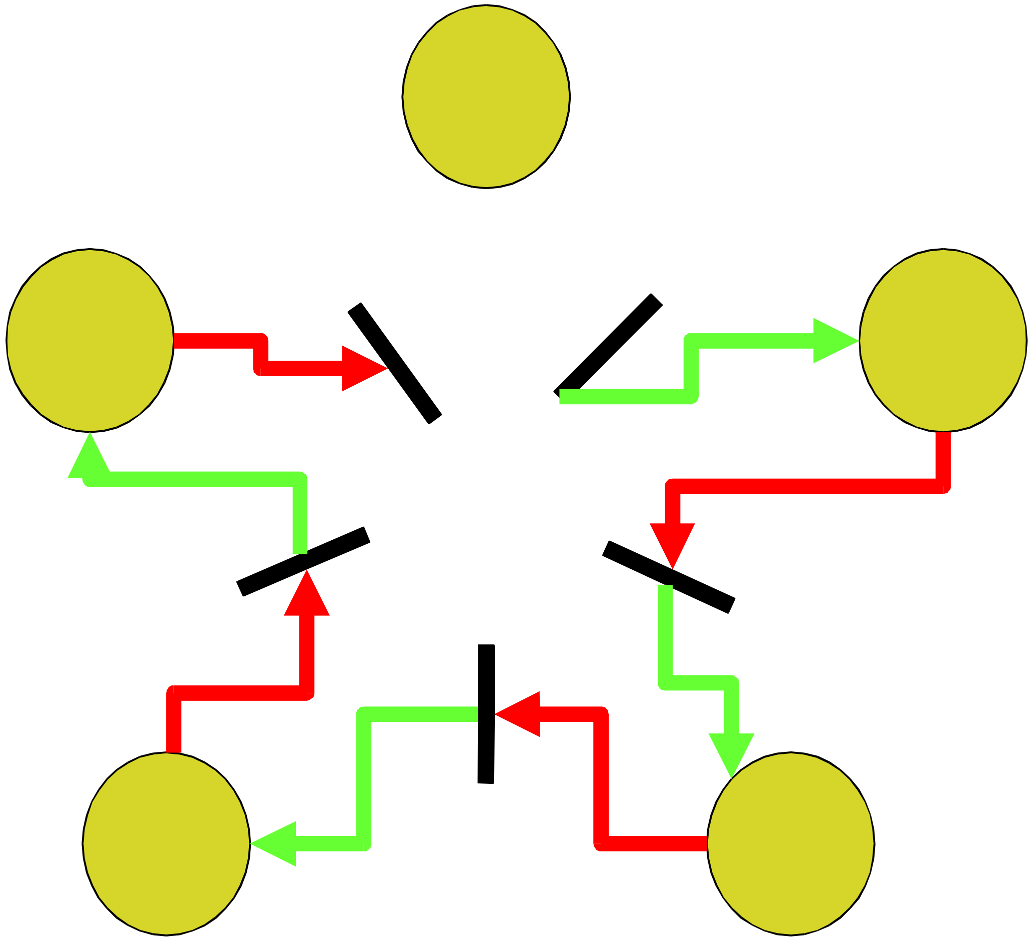
Last waits on right



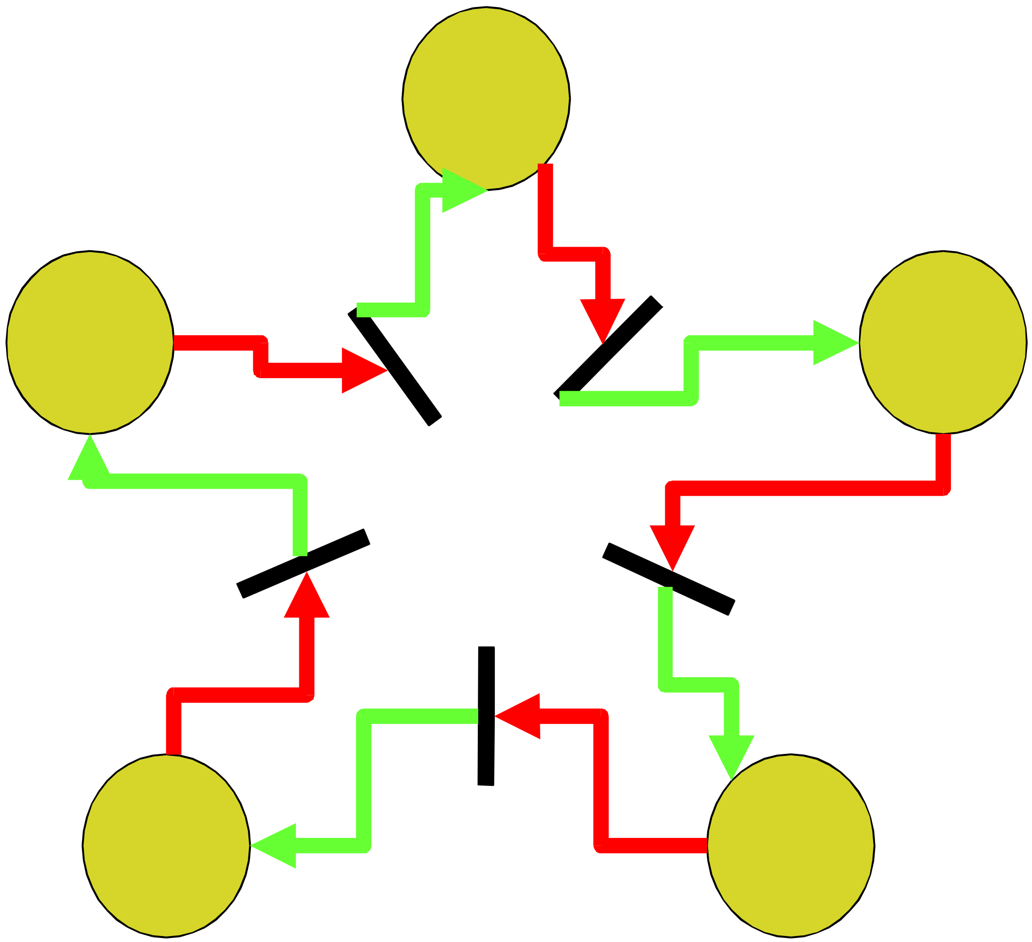
First diner gives up chopsticks



Last diner gets right, waits on left



First diner gets right, waits on left



Monitor semantics

- Only one thread active within “monitor” at a time.
- Textbook, Section 7.7.
- Signaling thread gives control to waiting thread (“possibility 1”) or signaling thread continues (“possibility 2”).
- Differs from pthread condition semantics!

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
- Prevention
  - ***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) $\Rightarrow$ (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