

# Deadlock (1)

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# Synchronization – P2

- You should *really* have, today:
  - Figured out where wrappers belong, why
  - Made some system calls
  - Designed mutexes & condition variables
  - Drawn pictures of thread stacks (even if not perfect)
- Wednesday:
  - Coded mutexes and condition variables
  - Thoughtful design for `thr_create()`, maybe `thr_join()`
  - Some code for `thr_create()`, and some “experience”
  - The `start1e` test running

# Debugging Reminder

- We can't really help with queries like:
  - We did x... then something strange happened...
  - ...can you tell us why?
- You need to progress beyond “*something* happened”
  - What happened, exactly?
  - printf() is not always the right tool
    - output correct only if run-time environment is right
    - captures only what you told it to, only “C-level” stuff
    - *changes your code* by its mere presence!!!
  - We're serious about examining register dumps!
  - Overall, maybe re-read “Debugging” lecture notes

# Synchronization – Readings

- **Next three lectures**
  - **Deadlock: 6.5.3, 6.6.3, Chapter 7**
- **Reading ahead**
  - **Scheduling: Chapter 5**
  - **Virtual Memory: Chapter 8, Chapter 9**
- **Don't forget about reading list on web site**

# Outline

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

# Tape Drives

- **A word on “tape drives”**
  - **Ancient computer resources**
  - **Access is sequential, read/write**
  - **Any tape can be mounted on any drive**
  - **One tape at a time is mounted on a drive**
    - **Doesn't make sense for multiple processes to simultaneously access a drive**
    - **Reading/writing a tape takes a while**
- **Think “CD burner”...**

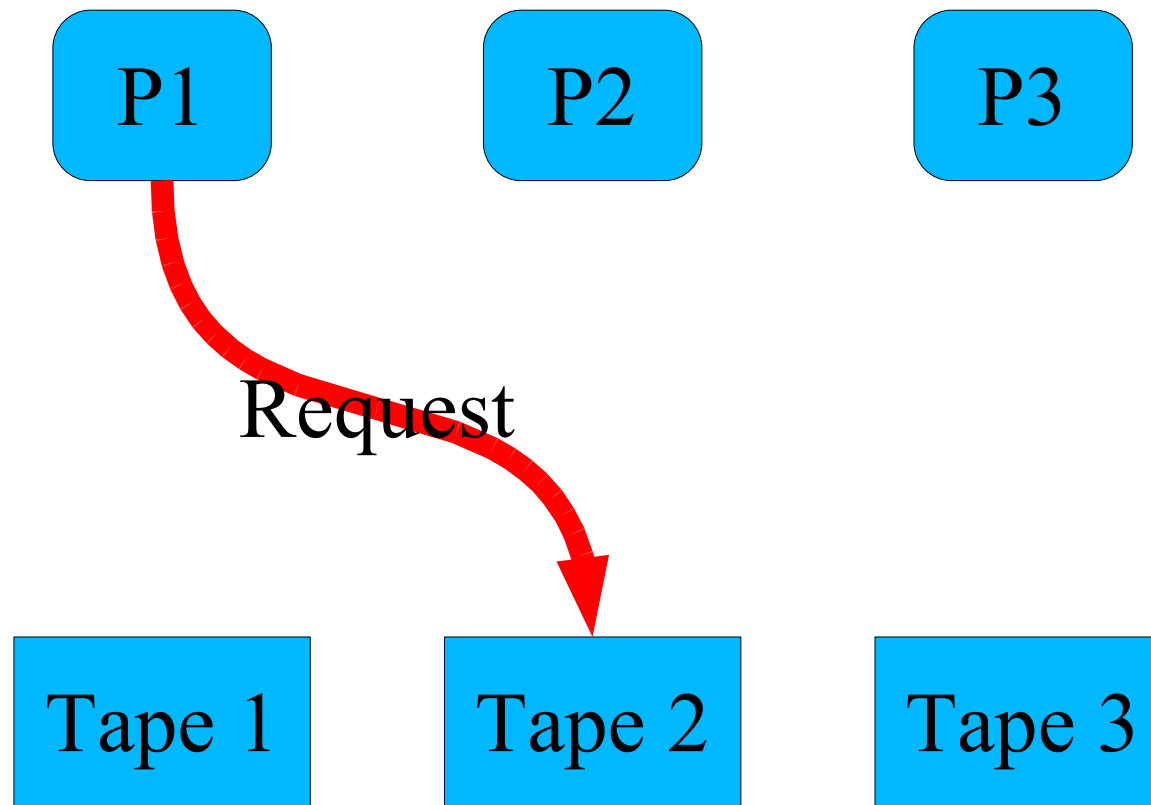


IBM 3420 (1970-1987)  
[www.ibm.com/ibm/history](http://www.ibm.com/ibm/history)  
Not for publication

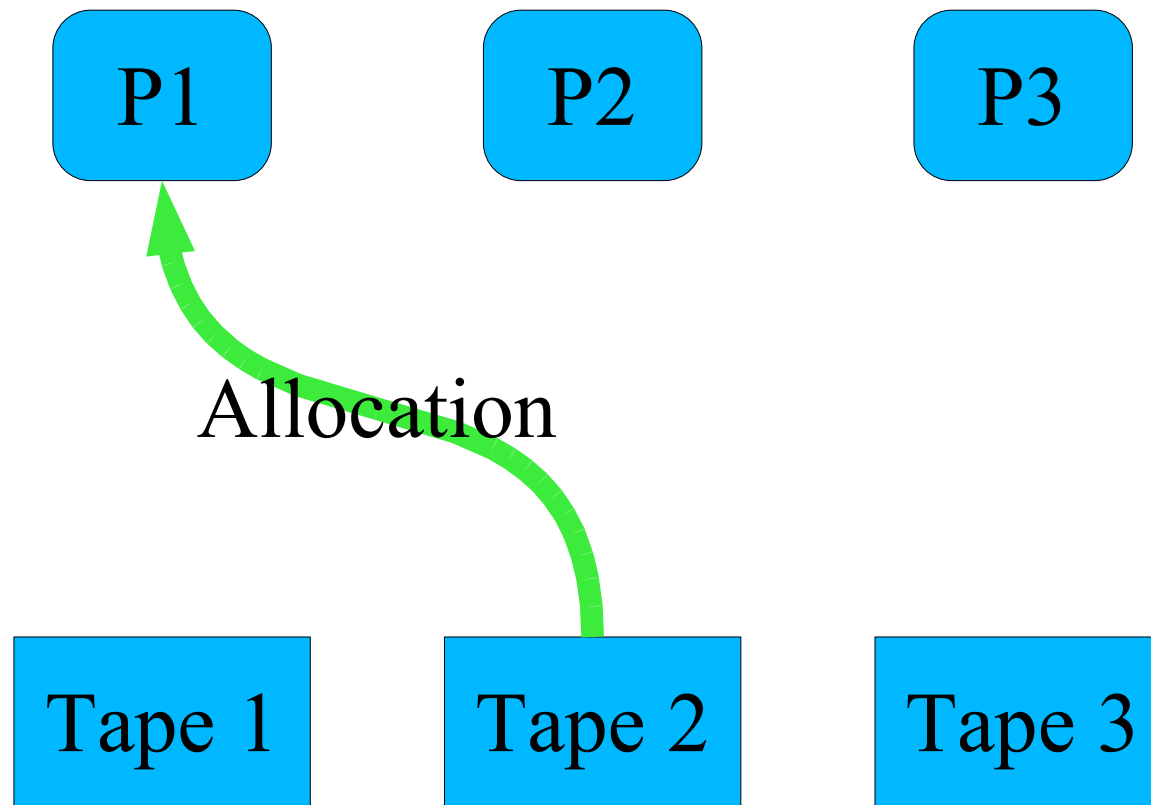


Data General 6023  
[wps.com/NOVA4](http://wps.com/NOVA4)

# Process/Resource graph

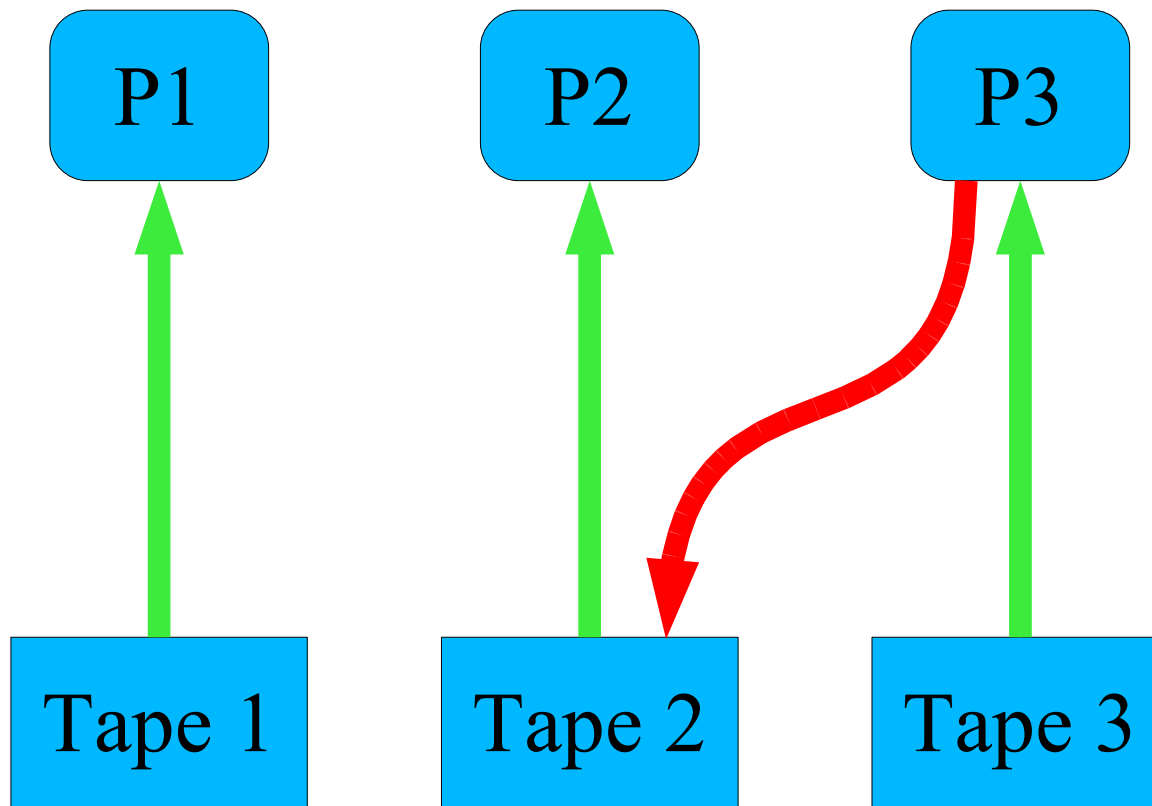


# Process/Resource graph

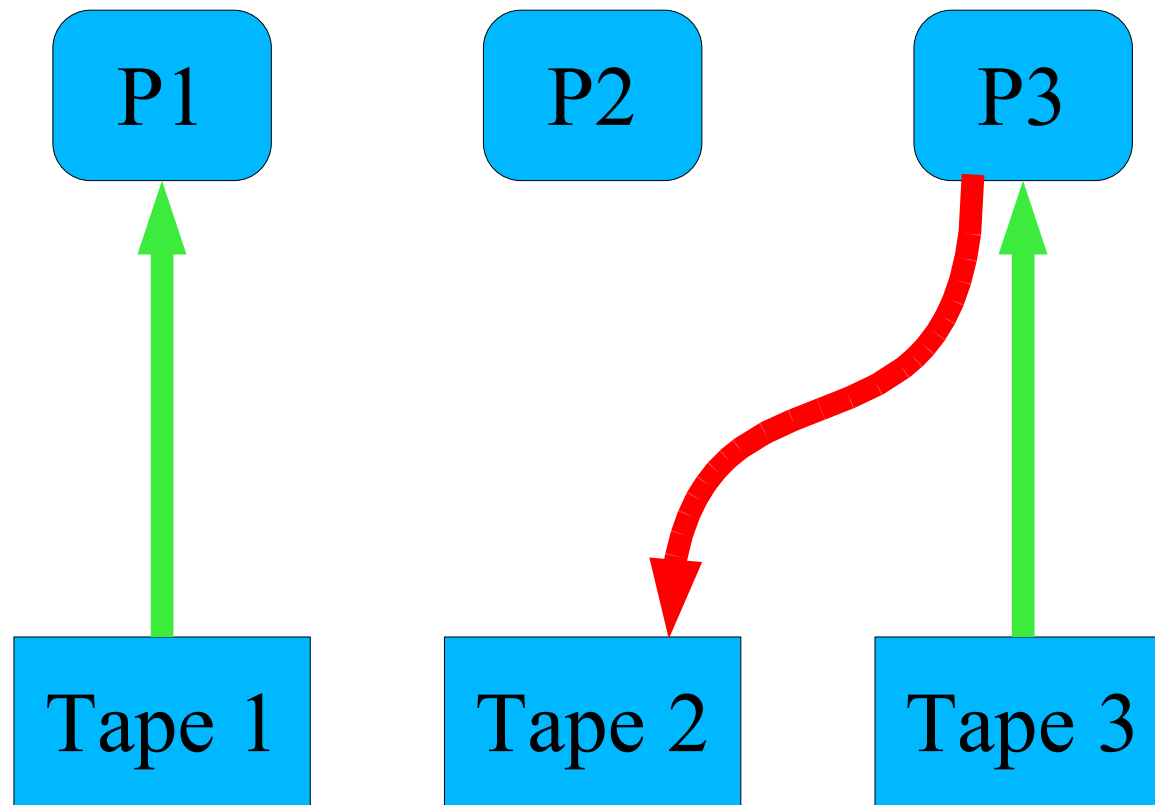




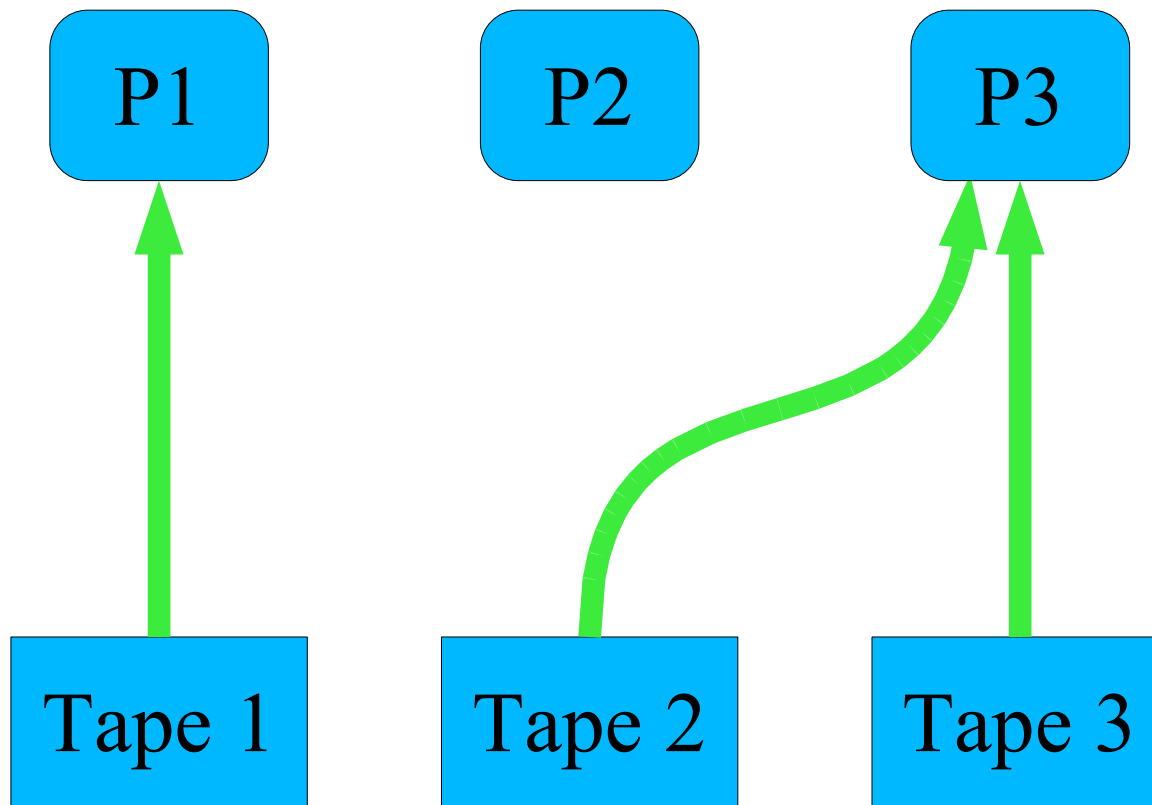
# Waiting



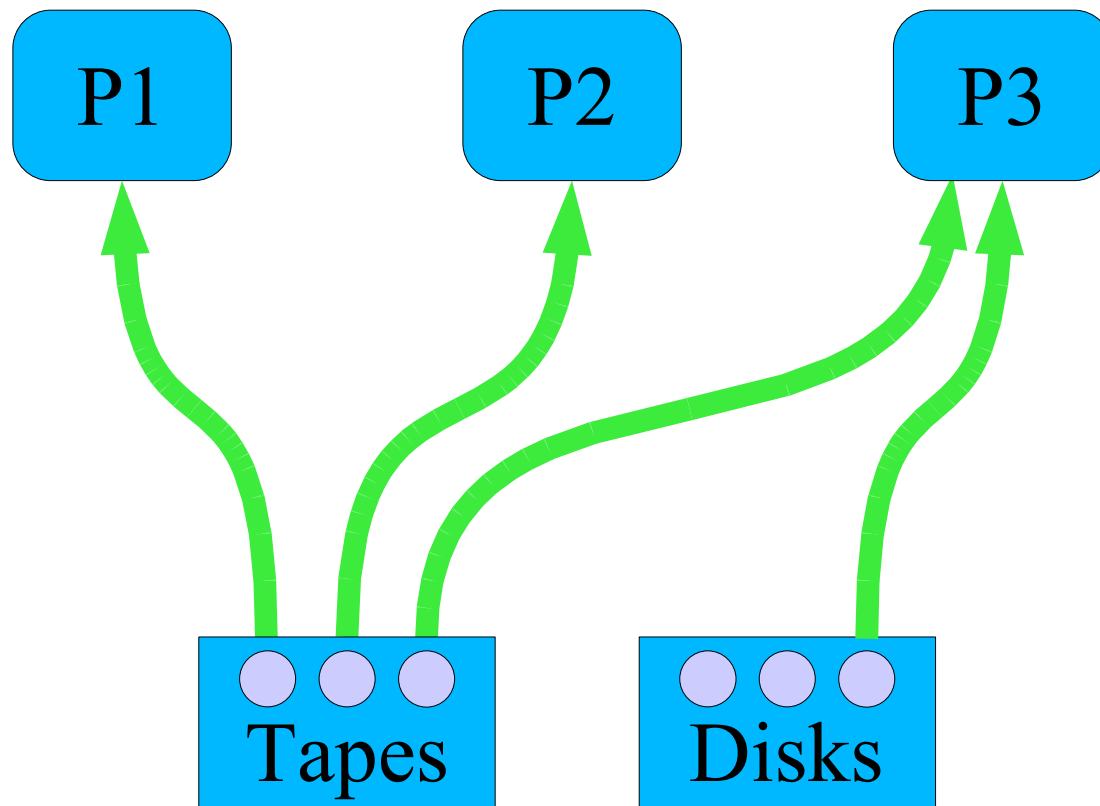
# Release



# Reallocation



# Multi-instance Resources



# Definition of Deadlock

- A deadlock
  - Set of N processes
  - Each waiting for an event
    - ...which can be caused *only by another process in the set*
- 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 some resources while waiting for more

```
mutex_lock(&m1);
```

```
mutex_lock(&m2);
```

```
mutex_lock(&m3);
```

- This locking behavior is *typical*

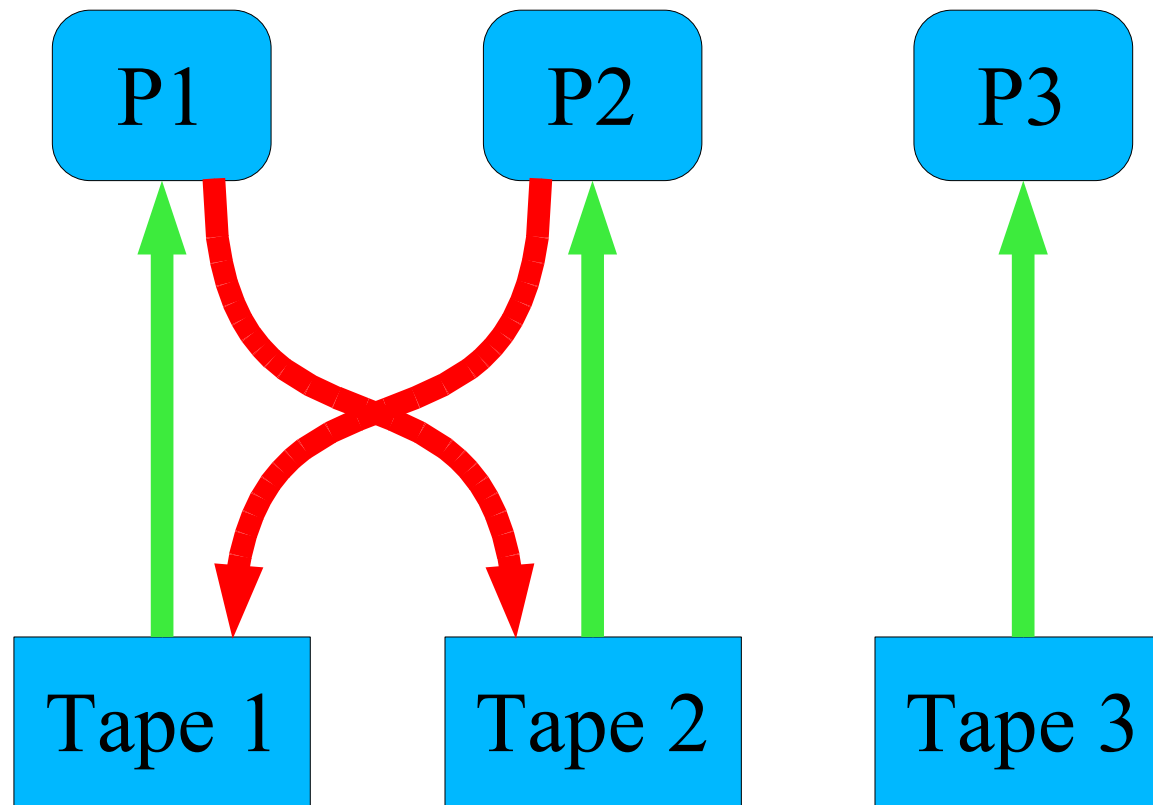
# No Preemption

- **Can't force a process to give up a resource**
- **Interrupting a CD-R burn creates a “coaster”**
  - **So don't do that**
- **Obvious solution**
  - **CD-R device driver forbids second simultaneous `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 7 has**
  - **Process 7 needs something process 1 has**
  - **Process 1 needs something process 0 has – uh-oh...**
- **Described as “cycle in the resource graph”**

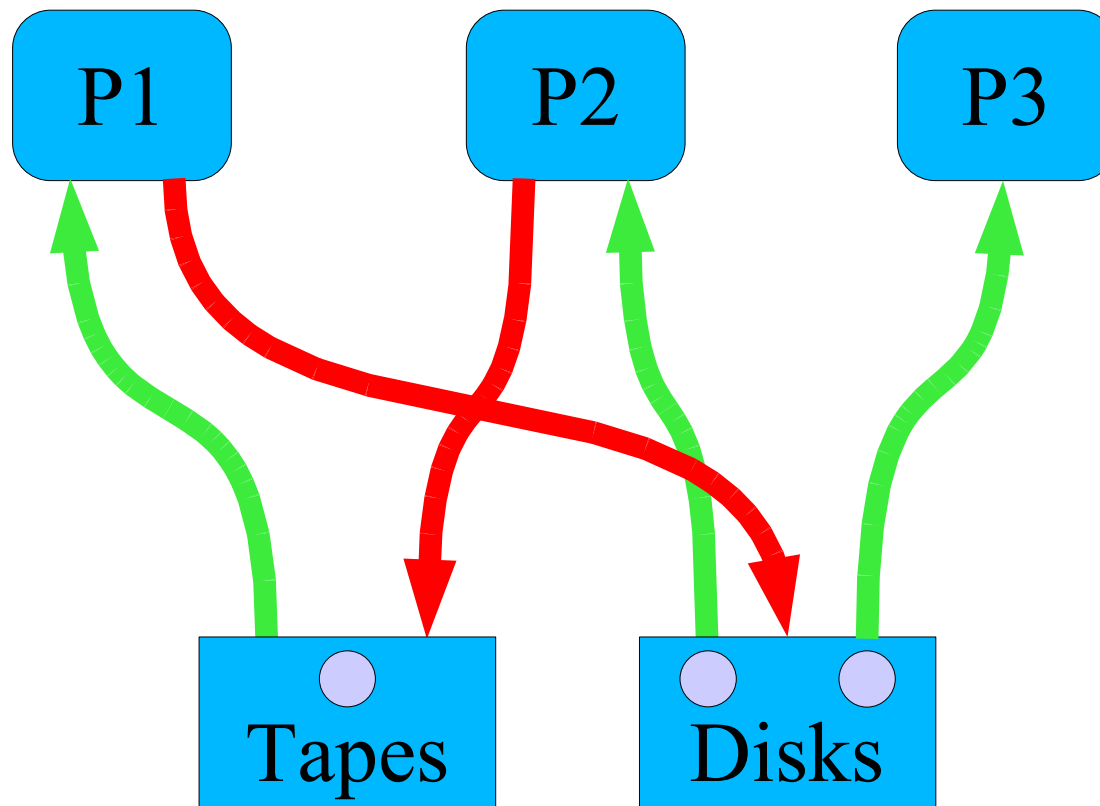
# Cycle in Resource Graph



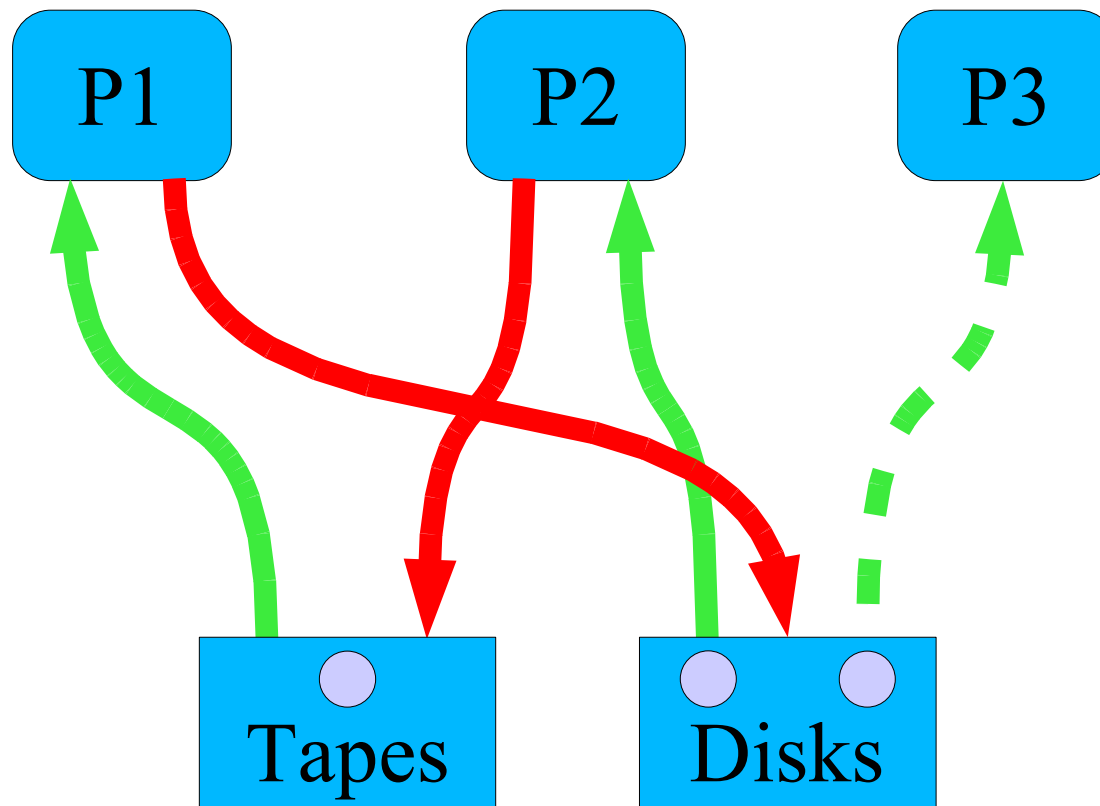
# Deadlock Requirements

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

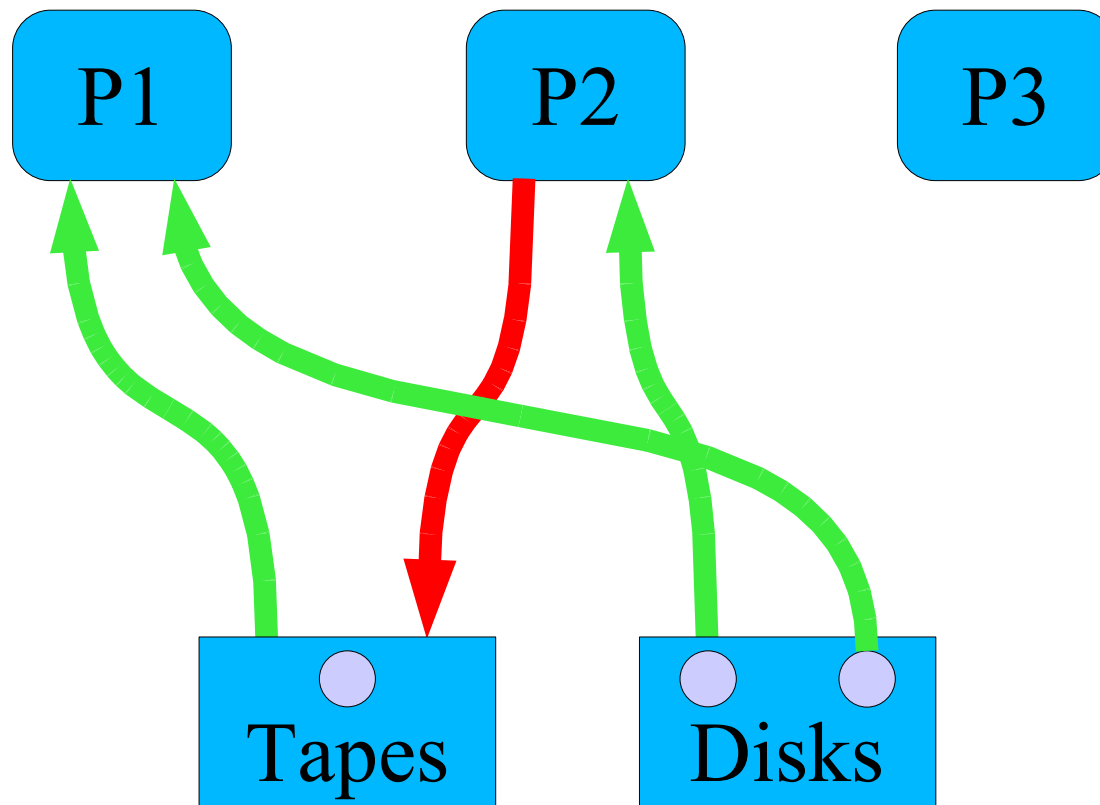
# Multi-Instance Cycle



# Multi-Instance Cycle *(With Rescuer!)*



# Cycle Broken

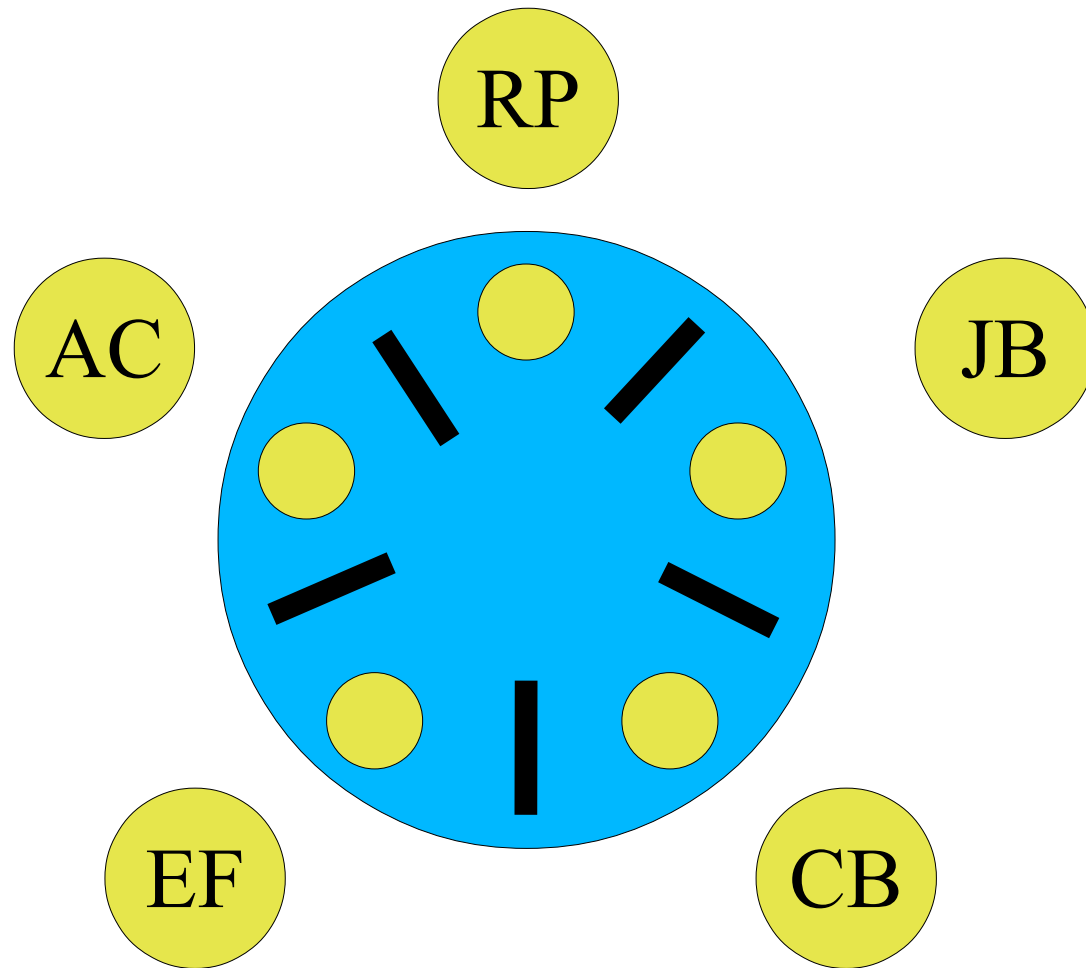




# Dining Philosophers

- **The scene**
  - **410 staff members 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

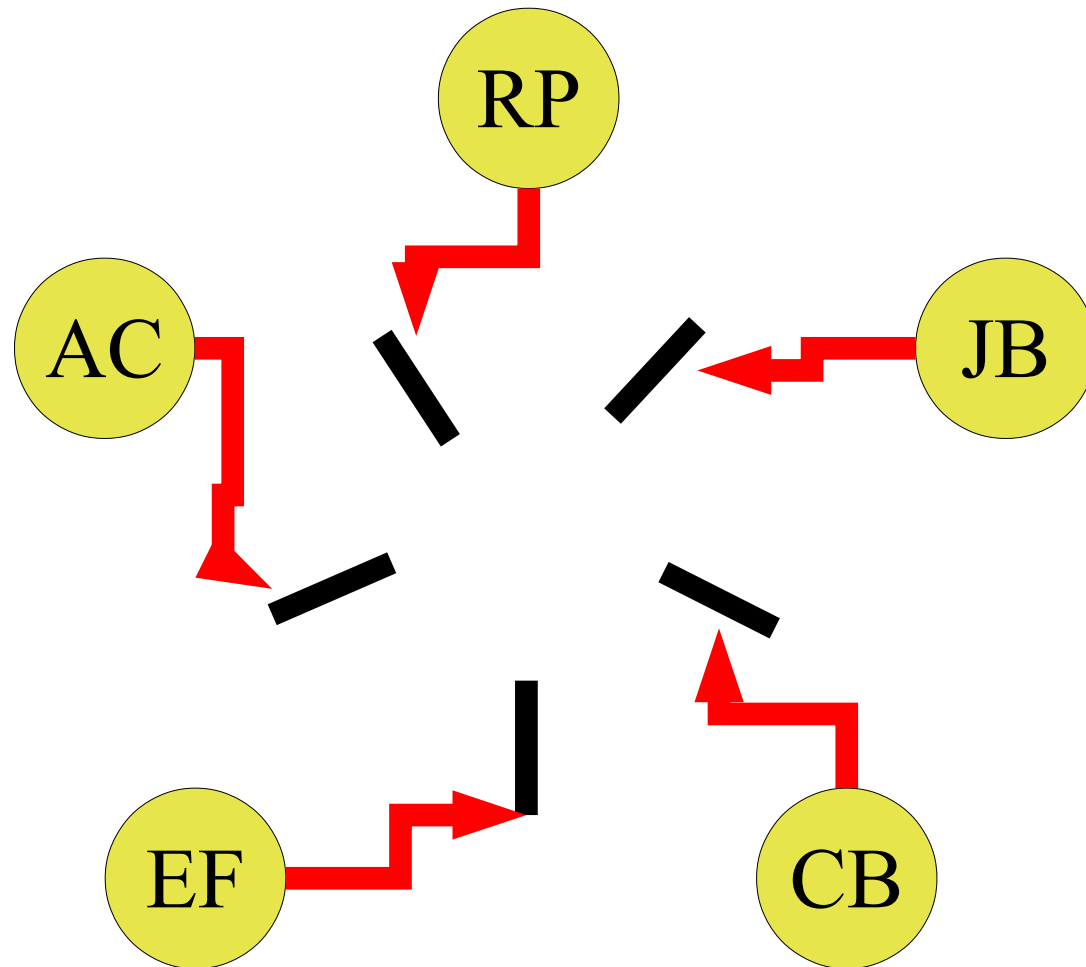
# Dining Philosophers

- **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**

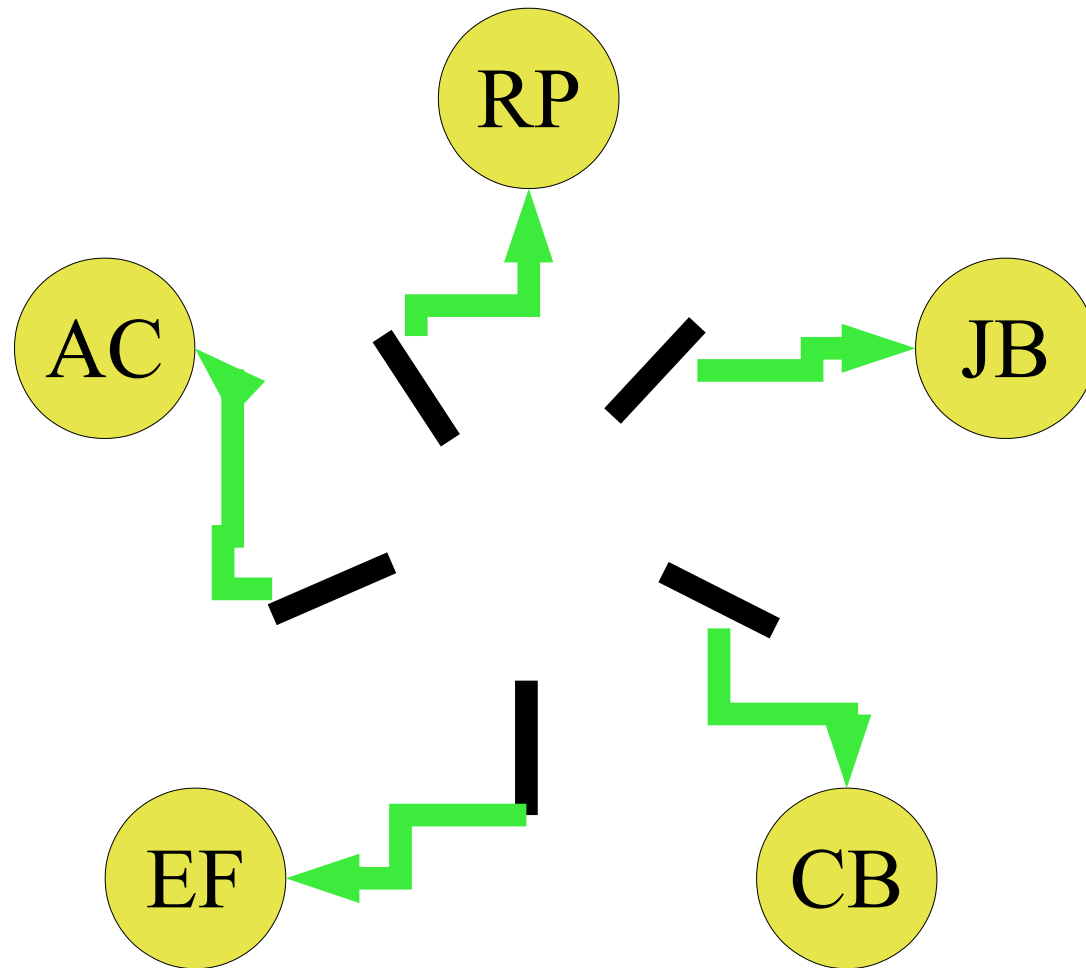
# Dining Philosophers Deadlock

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

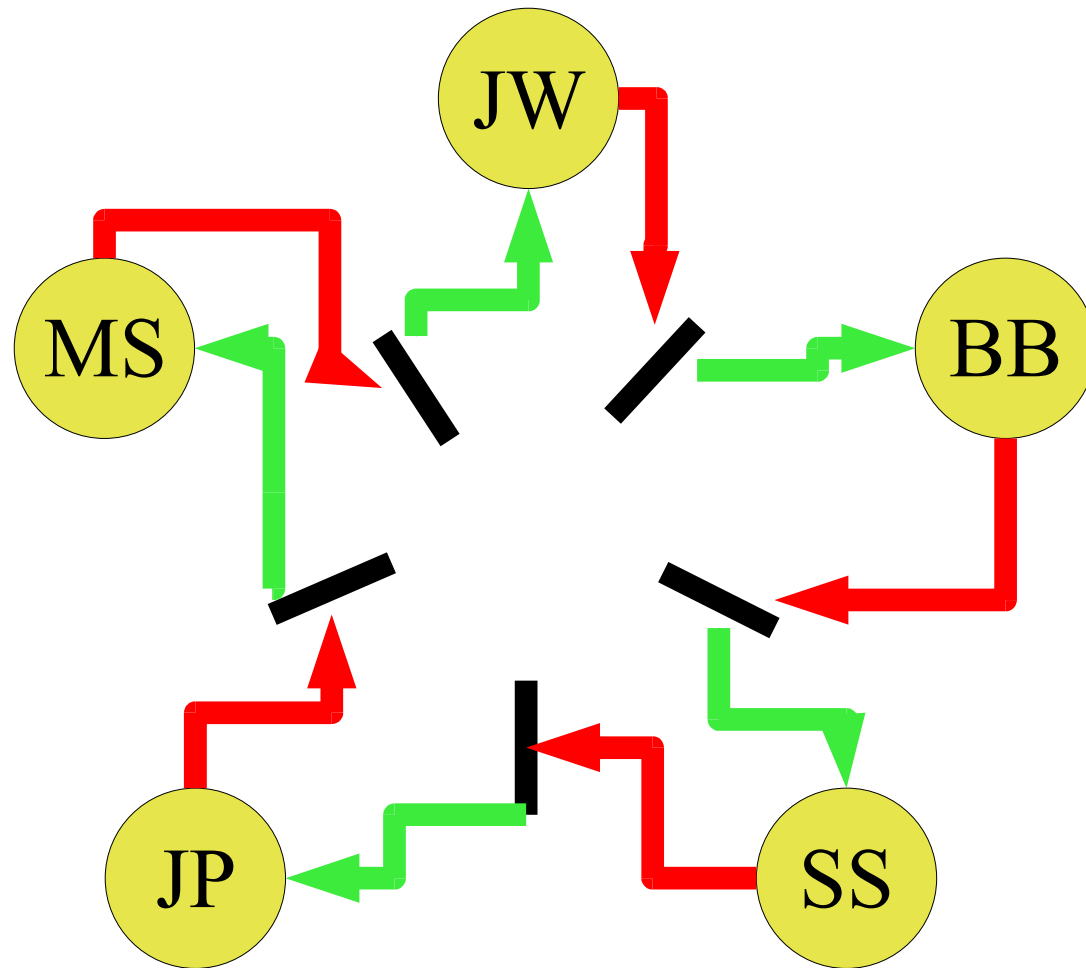
# Reaching Right



# Successful Acquisition



*Deadlock!*





# Dining Philosophers – State

```
int stick[5] = { -1 }; /* owner */  
condition avail[5]; /* newly avail. */  
mutex table = { available };  
  
/* Right-handed convention */  
right = diner;          /* 3  $\Rightarrow$  3 */  
left = (diner + 4) % 5; /* 3  $\Rightarrow$  7  $\Rightarrow$  2 */
```

# 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);
```

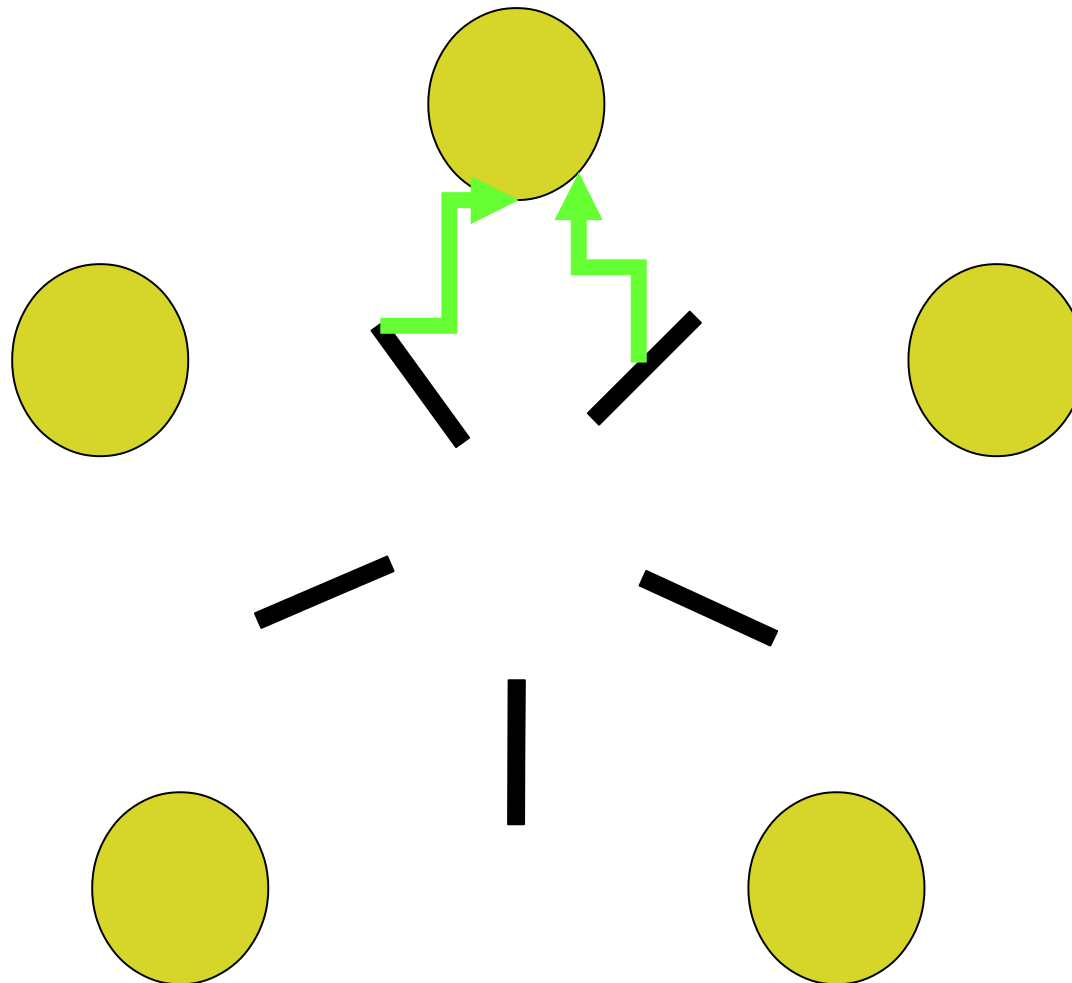
# Can We Deadlock?

- **At first glance the table mutex protects us**
  - **Can't have “everybody reaching right at same time”...**
  - **...mutex means only one person can access table...**
  - **...so allows only one reach at the same time, right?**

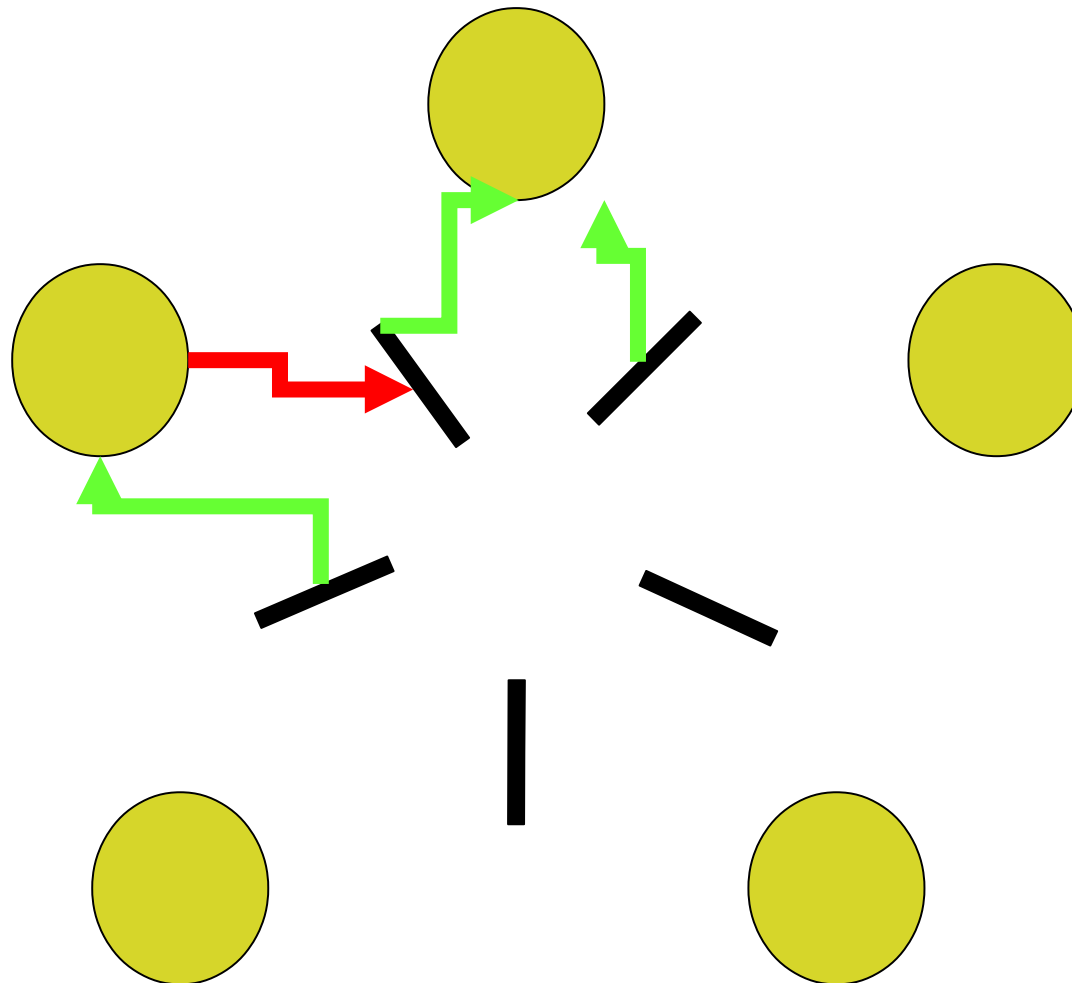
# Can We Deadlock?

- At first glance the table mutex protects us
  - Can't have “everybody reaching right at same time”...
  - ...mutex means only one person can access table...
  - ...so allows only one reach at the same time, right?
- Maybe we can!
  - *condition\_wait()* is a “reach”
  - Can everybody end up in *condition\_wait()*?

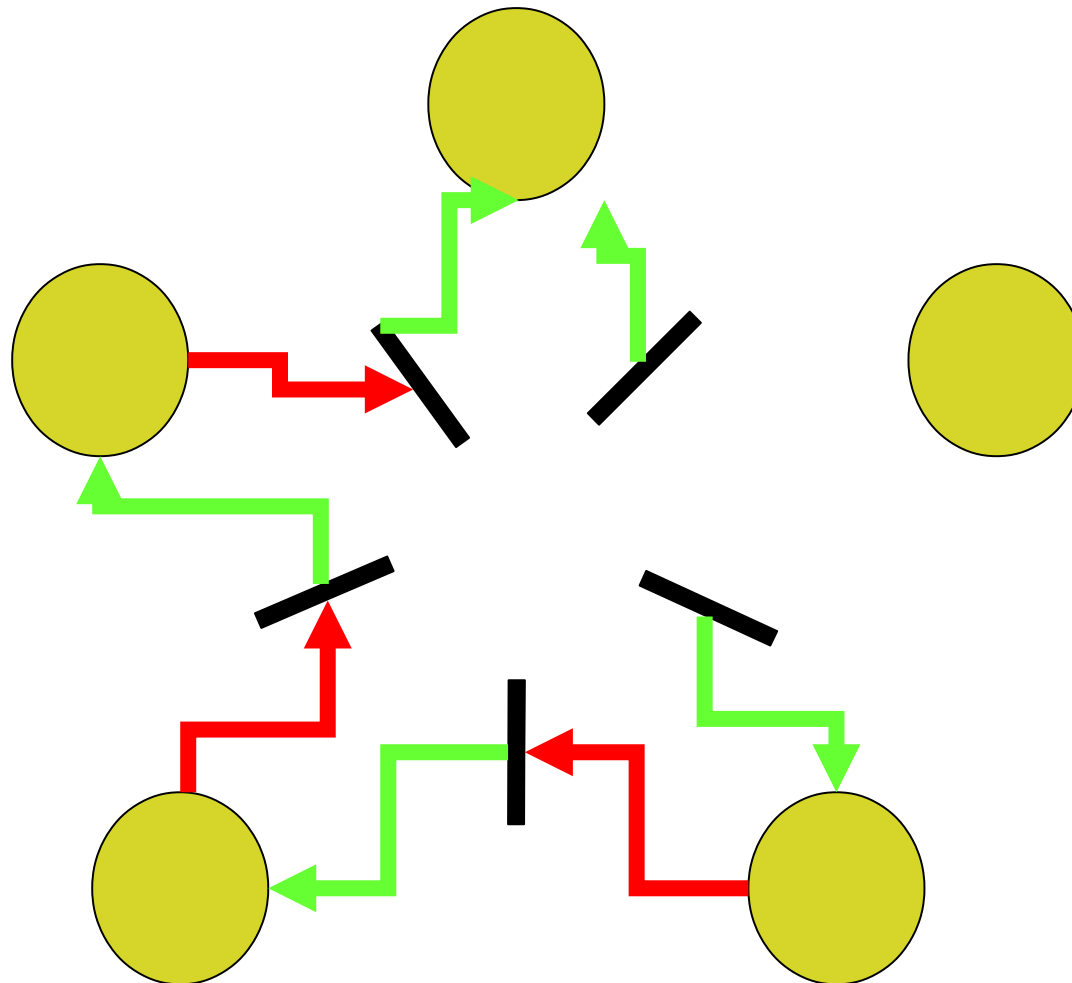
# First diner gets both chopsticks



# Next gets right, waits on left

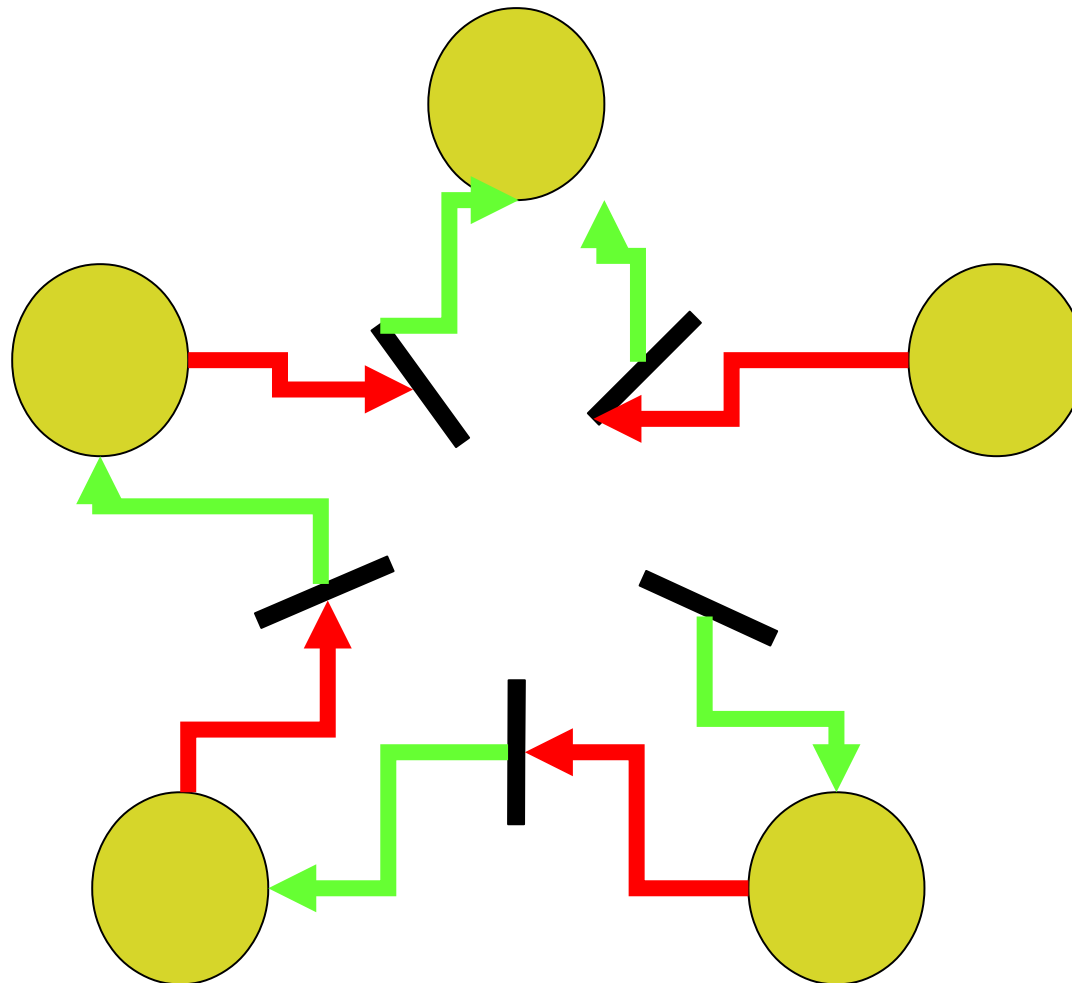


# Next two get right, wait on left

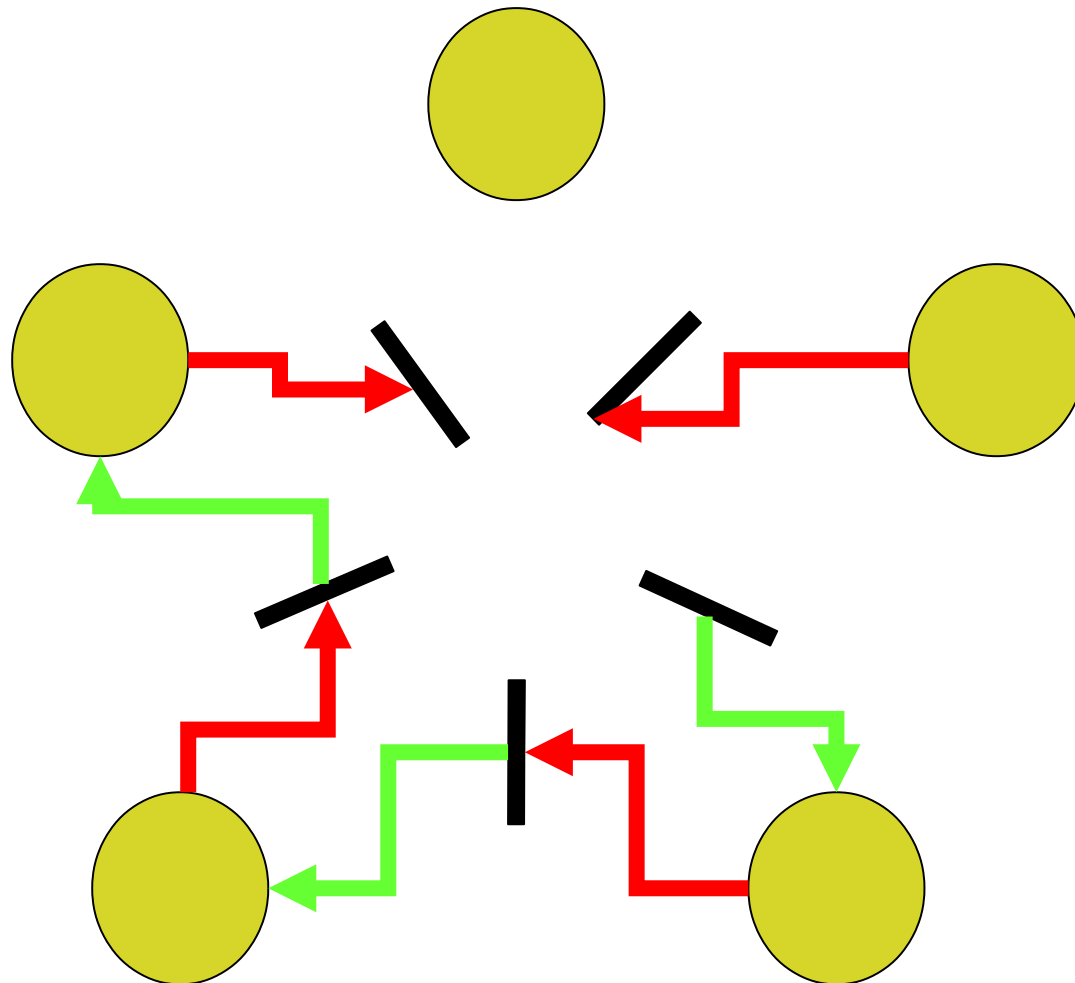




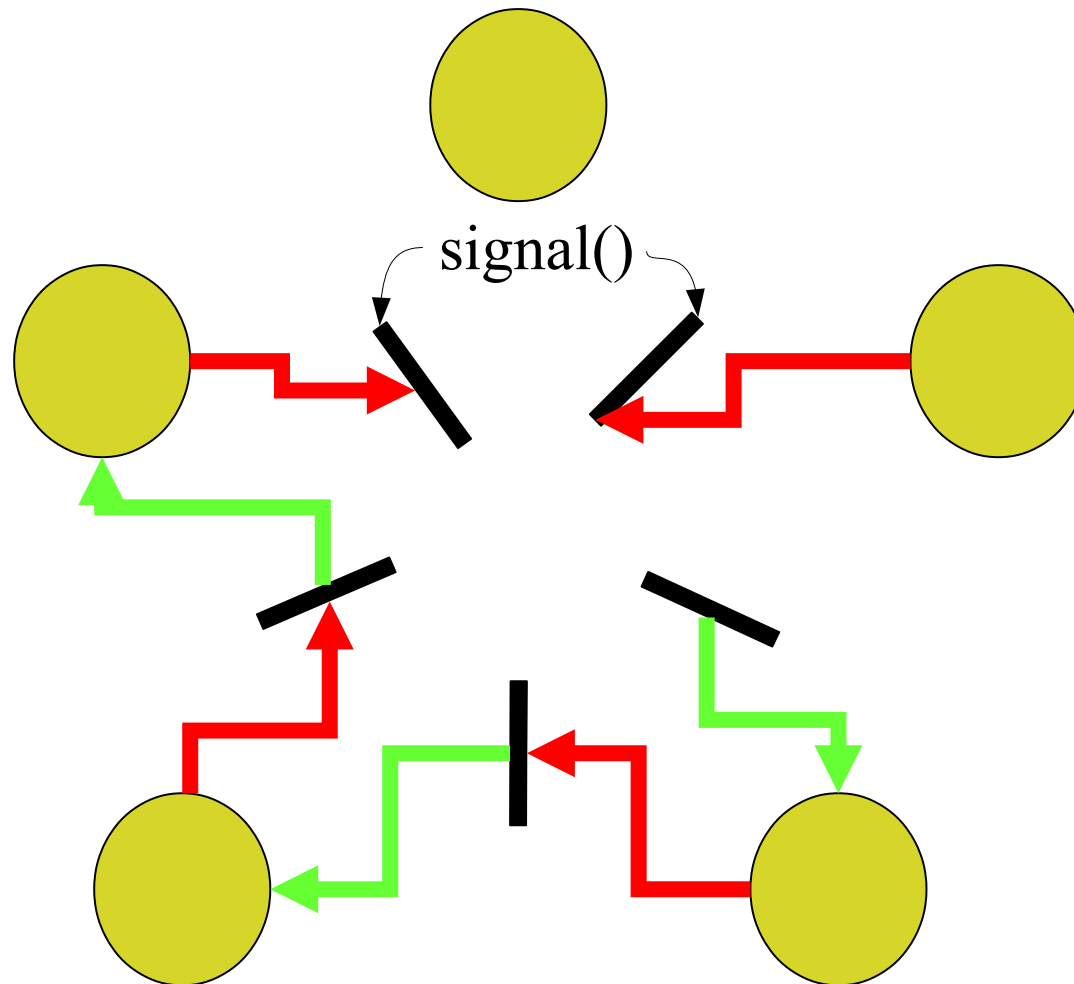
# Last waits on right



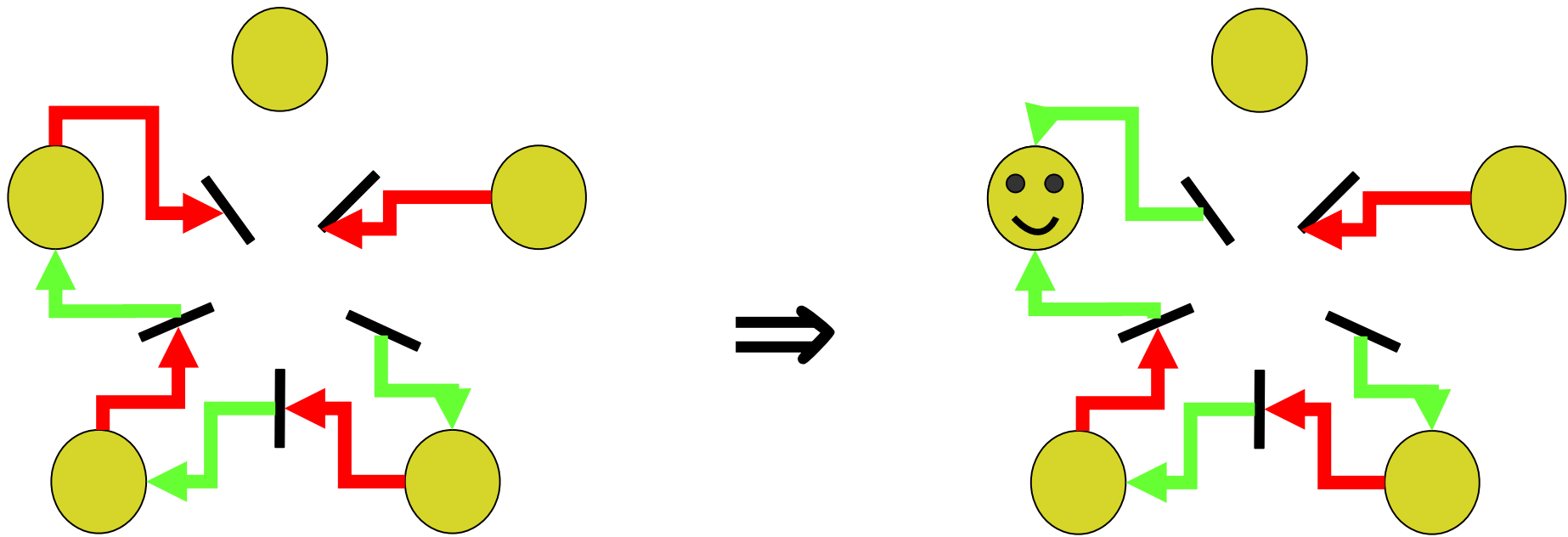
First diner stops eating - *briefly*



# First diner stops eating - *briefly*

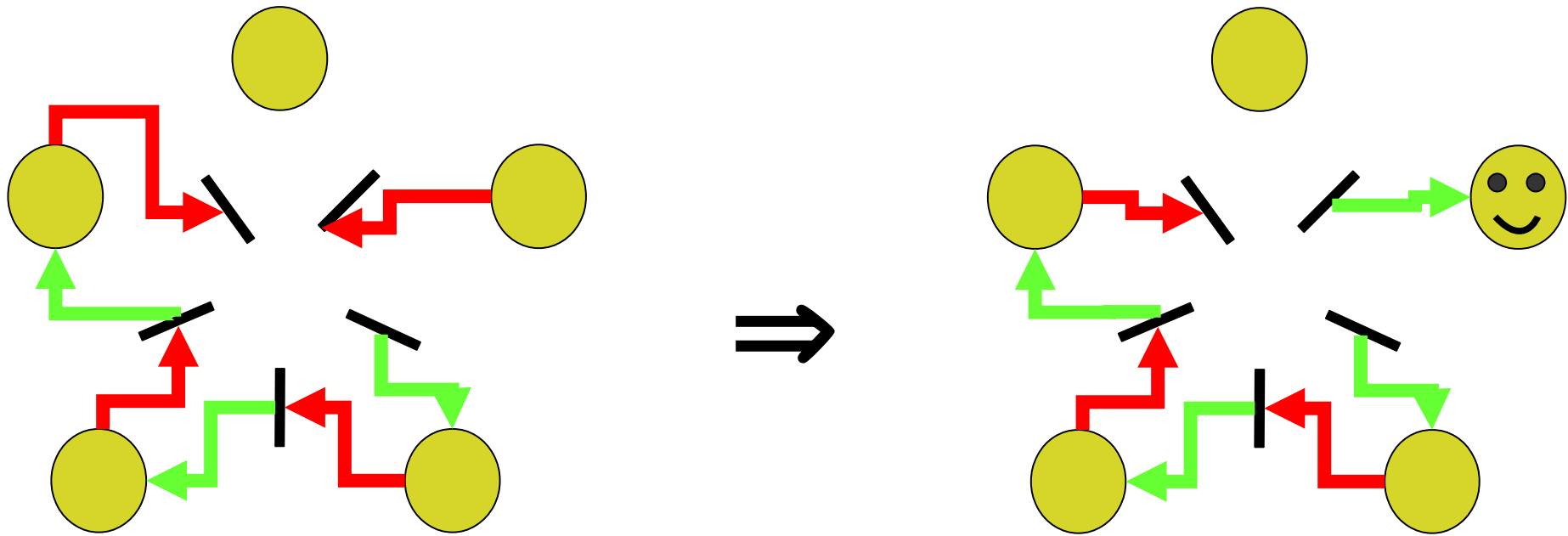


## Next Step – *One* Possibility



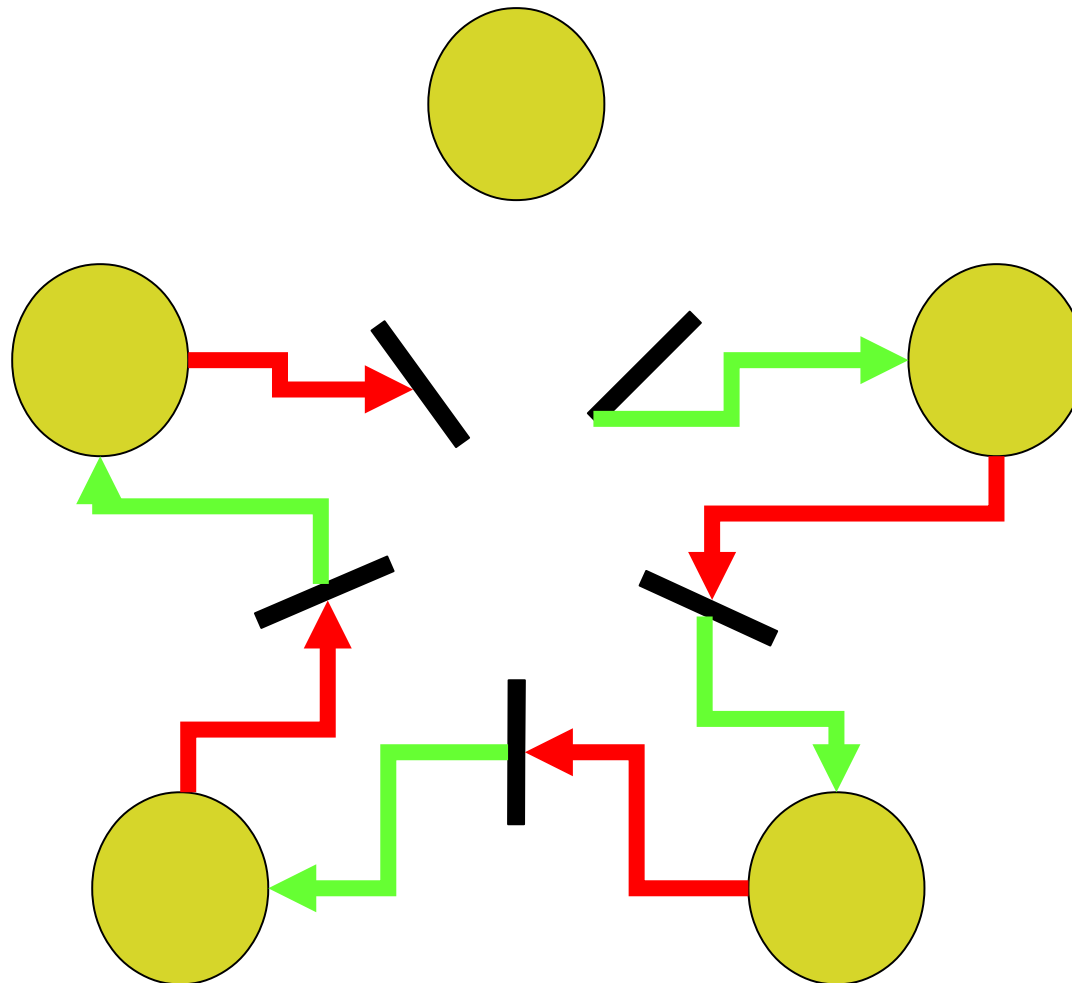
“Natural” –  
longest-waiting diner progresses

## Next Step – *Another* Possibility

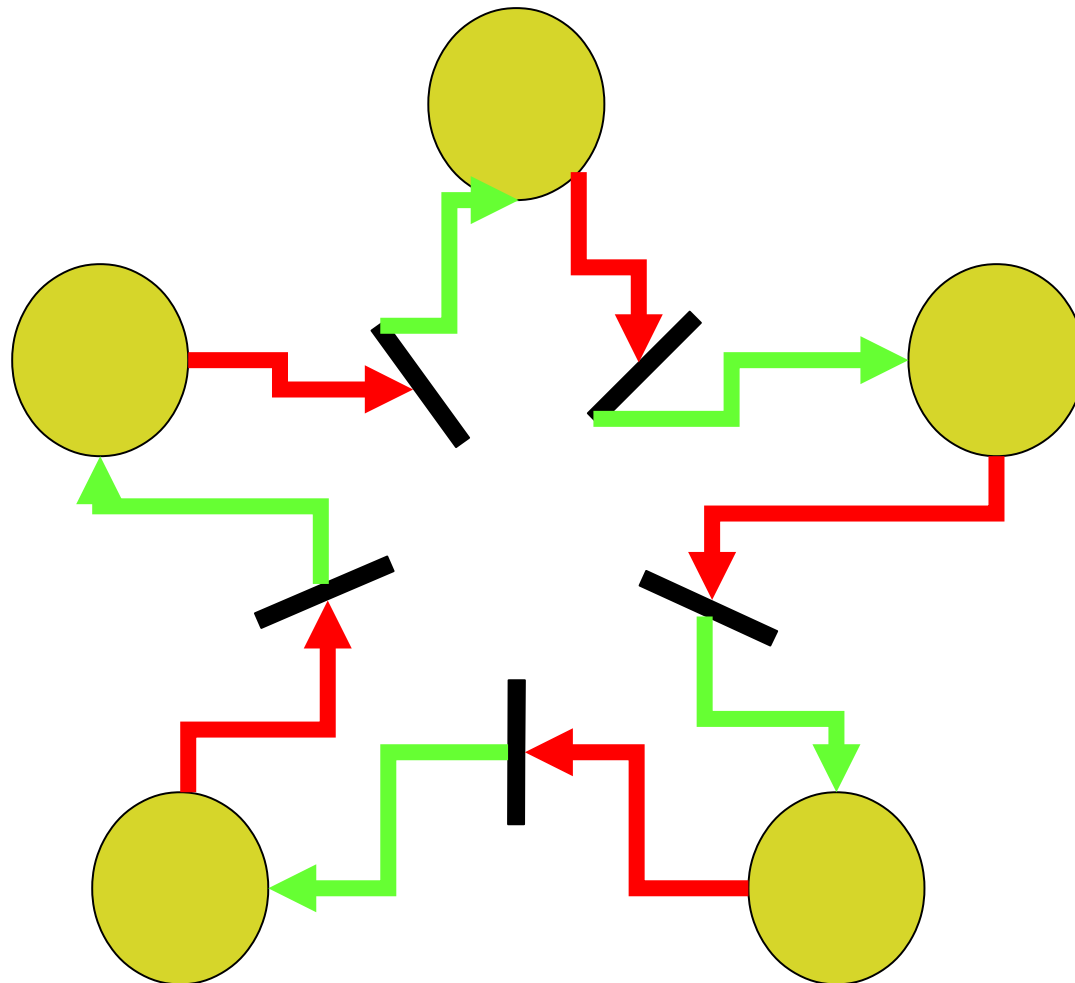


Or –  
somebody else!

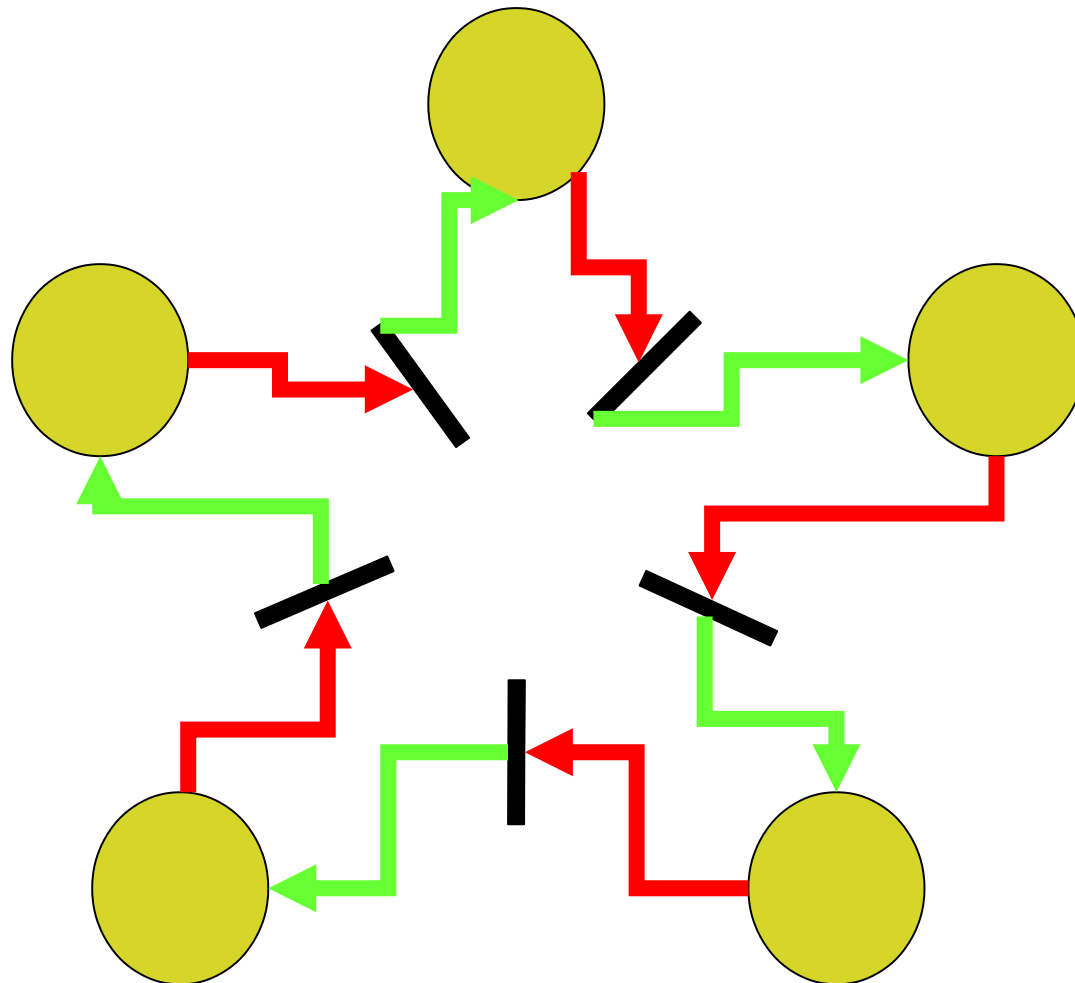
# Last diner gets right, waits on left



**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”**

# 1: 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

## 2: Avoidance

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

# 3: Detection/Recovery

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

## **4: 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 happens only if somebody *transgresses!*

# Outlaw Mutual Exclusion?

- Approach: *ban* 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[lr] == stick[rt] == -1)
```

```
        stick[lr] = stick[rt] = diner
```

```
        mutex_unlock(table)
```

```
        return;
```

```
    condition_wait(released, table);
```



# Problems

- **“Starvation”**
  - **Larger resource set makes grabbing everything harder**
    - **No guarantee a diner eats in bounded time**
- **Low utilization**
  - **Larger peak resource needs hurts whole system always**
    - **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 person can't be eating: take! */
        stick[right] = diner;
    ...same for left...wait() if must...
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 order may work: allocate memory, then files
  - Dynamic – may need to “start over” sometimes
    - Traversing a graph
      - lock(4), visit(4)      /\* 4 has an edge to 13 \*/
      - lock(13), visit(13)    /\* 13 has an edge to 0 \*/
      - lock(0)?
        - Nope!
        - unlock(4), unlock(13)
        - lock(0), lock(4), lock(13), ...

# Assigning Diners a Total Order

- **Lock order: 4, 3, 2, 1, 0  $\equiv$  right chopstick, then left**
  - **Diner 4  $\Rightarrow$  lock(4); lock(3);**
  - **Diner 3  $\Rightarrow$  lock(3); lock(2);**

# Assigning Diners a Total Order

- Lock order: 4, 3, 2, 1, 0  $\equiv$  right chopstick, then left
  - Diner 4  $\Rightarrow$  lock(4); lock(3);
  - Diner 3  $\Rightarrow$  lock(3); lock(2);
  - Diner 0  $\Rightarrow$  lock(0); lock(4);    **/\* violates lock order! \*/**
- Requires special-case locking code to get order 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
- All-at-once allocation can be *painful*
  - Hurts efficiency
  - May starve
  - Resource needs may be unpredictable
- Preemption may be *impossible*
  - Or may lead to starvation
- Ordering restrictions may be *impractical*



# 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

# Deadlock is not...

- **...a simple synchronization bug**
  - Deadlock remains even when those are cleaned up
  - Deadlock is a resource usage design problem
- **...the same as starvation**
  - Deadlocked processes don't ever get resources
  - Starved processes don't ever get resources
  - Deadlock is a “progress” problem; starvation is a “bounded waiting” problem
- **....that “after-you, sir” dance in the corridor**
  - That's “livelock” – continuous changes of state without forward progress

# Next Time

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