Deadlock Solutions

CS 241

March 28, 2012

University of Illinois

Announcements

Office hours today: 3-4 and 5-6

In between: Talk by Tom Wenisch

- Energy efficiency in warehouse-scale computers
- 4pm, in 3405 SC

Midterm exams: you may look at them through the end of this week

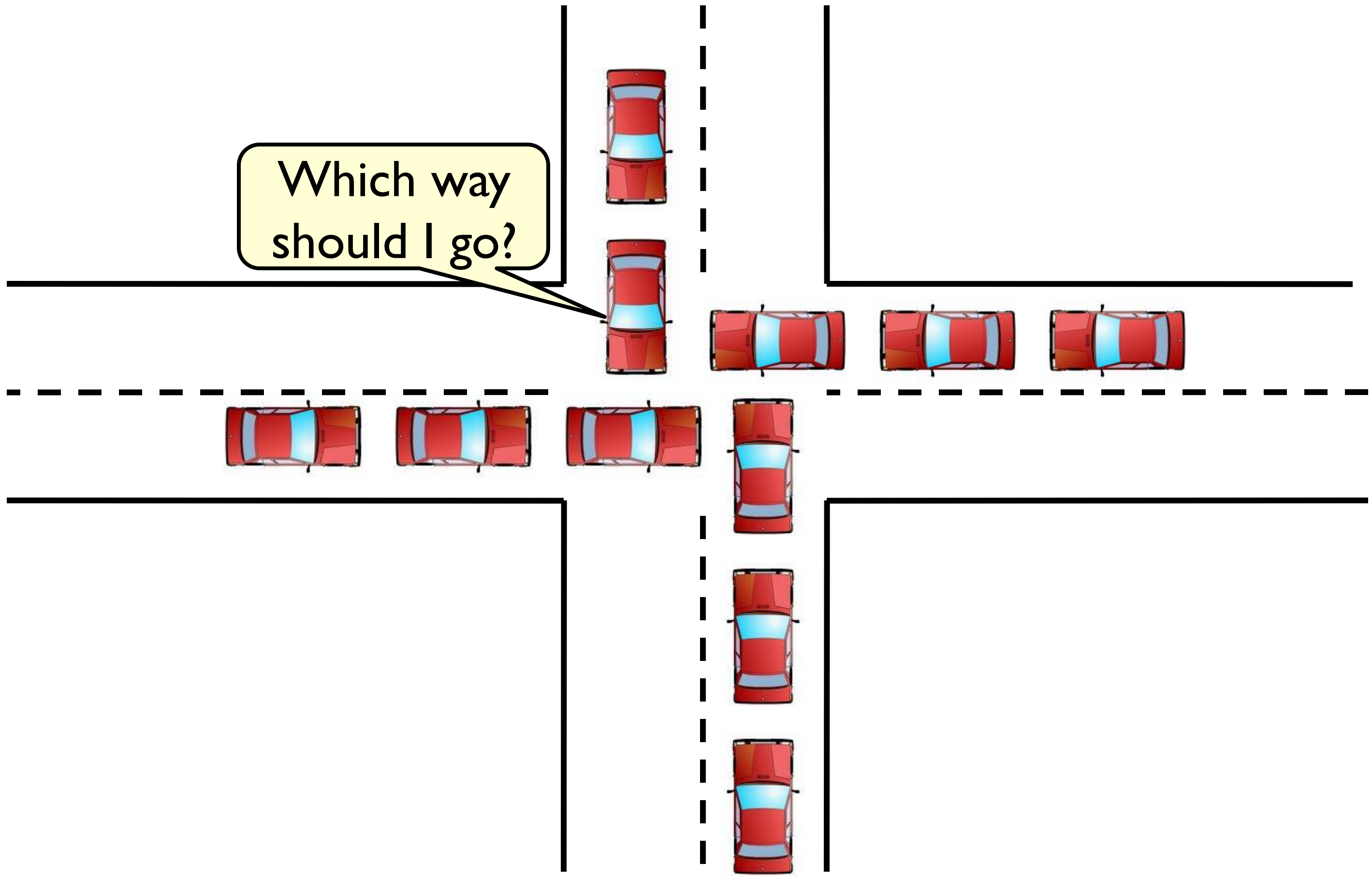
- An extension of our one-week policy
- Drop by office hours today (3-4 and 5-6) or schedule appointment

Deadlock: definition

There exists a cycle of processes such that each process cannot proceed until the next process takes some specific action.

Result: all processes in the cycle are stuck!

Deadlock in the real world



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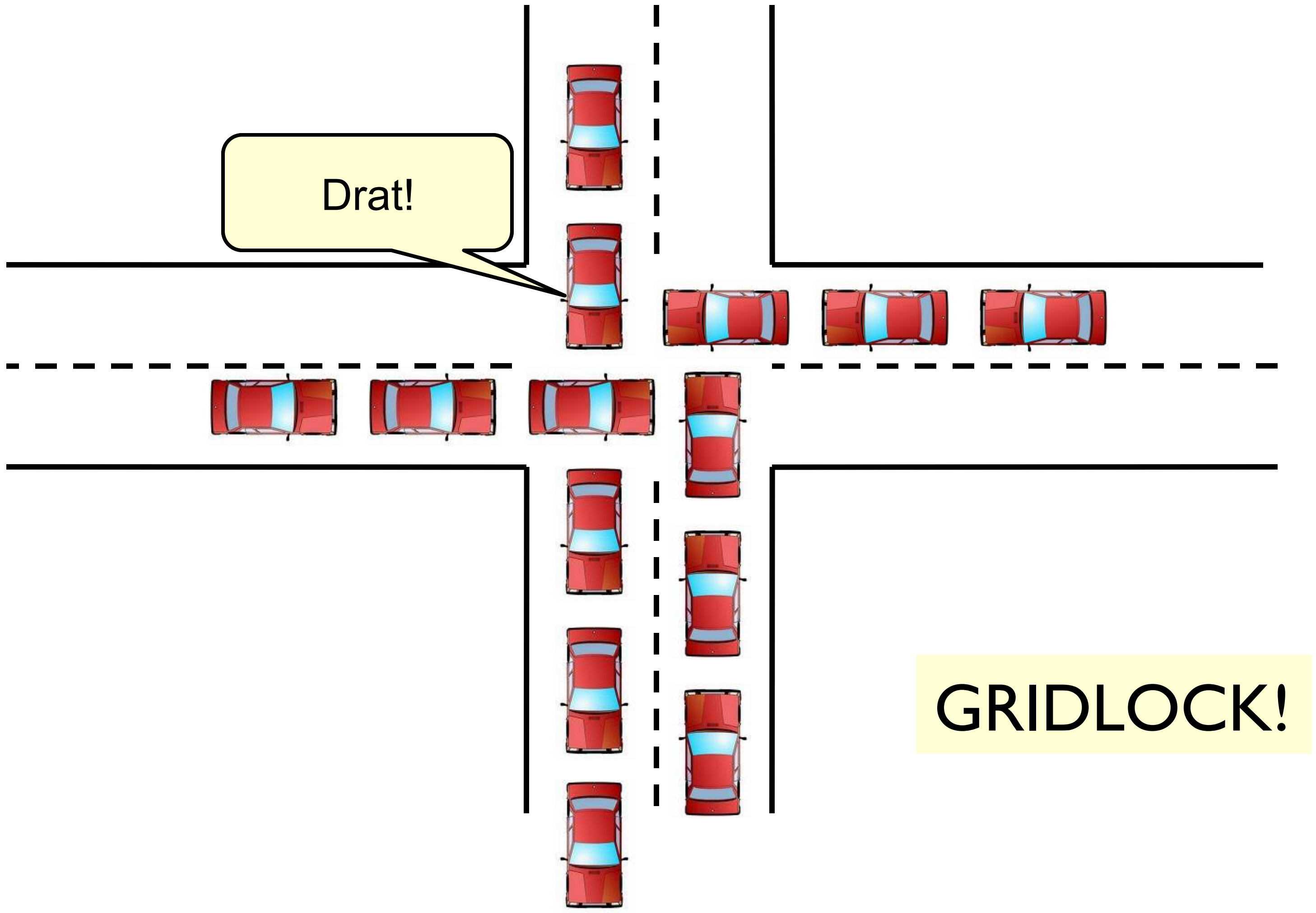
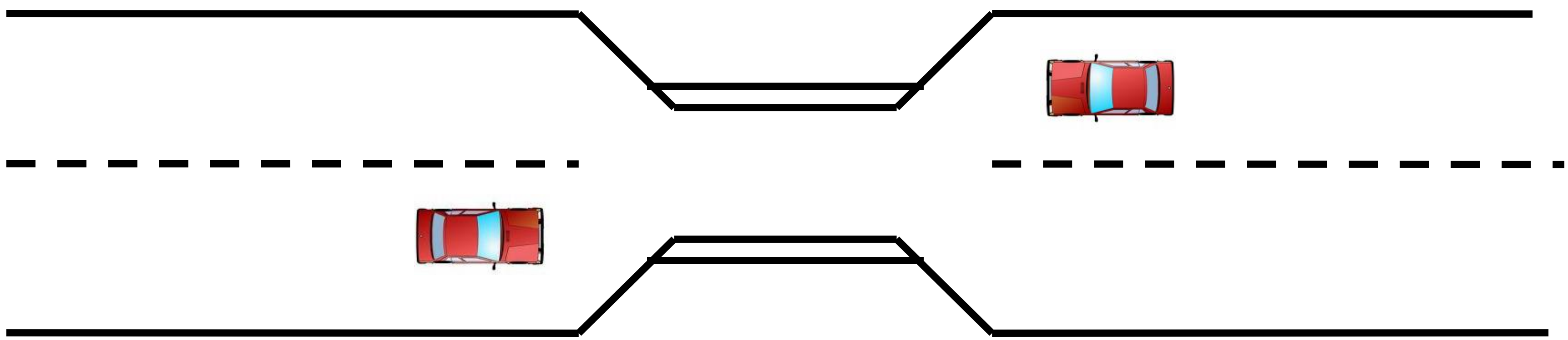


Deadlock: One-lane Bridge

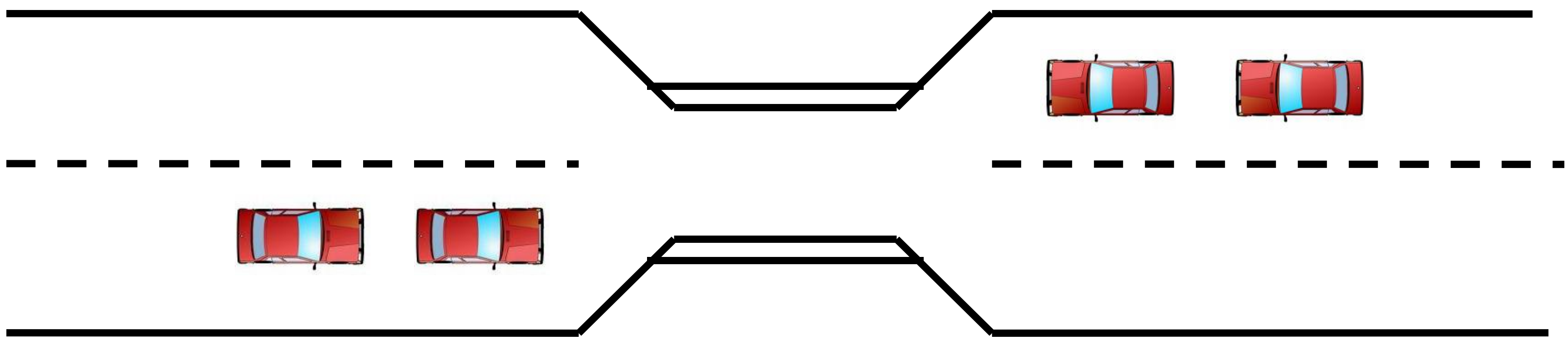


Traffic only in one direction

Each section of a bridge can be viewed as a resource

What can happen?

Deadlock: One-lane Bridge



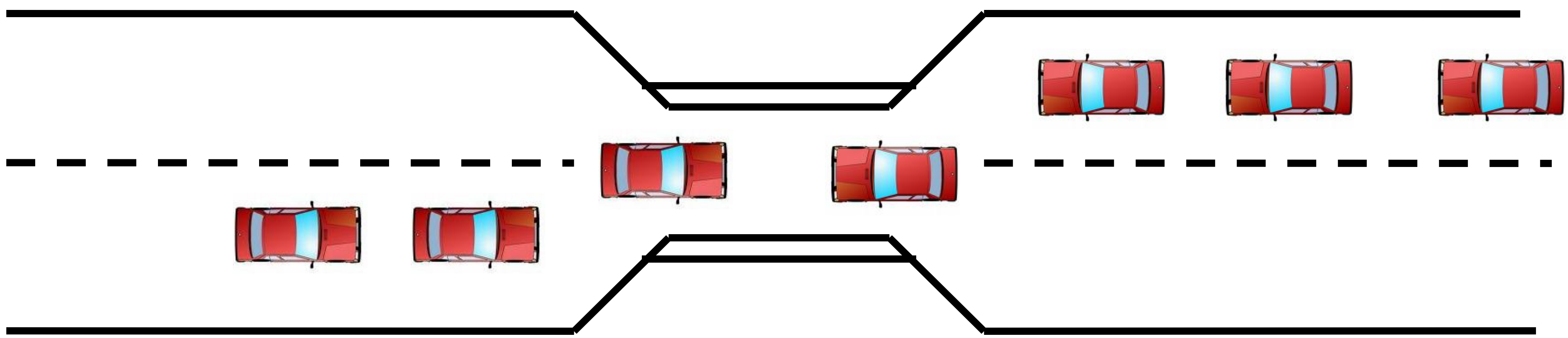
Traffic only in one direction

Each section of a bridge can be viewed as a resource

Deadlock

- Resolved if cars back up (preempt resources and rollback)
- Several cars may have to be backed up

Deadlock: One-lane Bridge



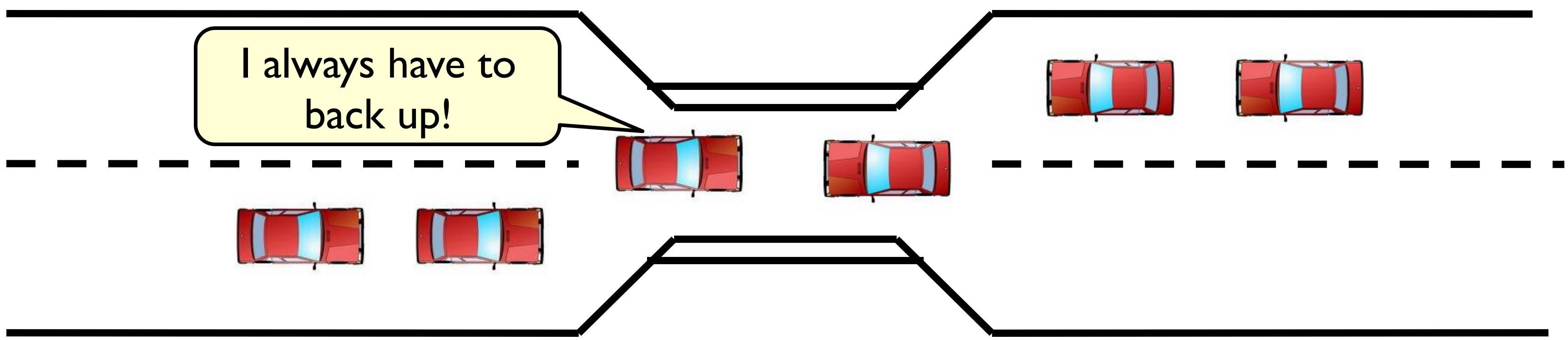
Traffic only in one direction

Each section of a bridge can be viewed as a resource

Deadlock
- Resolved if cars back up (preempt resources and rollback)
- Several cars may have to be backed up

But, starvation is possible
- e.g., if the rule is that Westbound cars always go first when present

Deadlock: One-lane Bridge



Deadlock vs. Starvation

- Starvation = Indefinitely postponed
  - Delayed repeatedly over a long period of time while the attention of the system is given to other processes
  - Logically, the process may proceed but the system never gives it the CPU (unfortunate scheduling)
- Deadlock = no hope
  - All processes blocked; scheduling change won't help

Deadlock solutions

Prevention

- Design system so that deadlock is impossible

Avoidance

- Steer around deadlock with smart scheduling

Detection & recovery

- Check for deadlock periodically
- Recover by killing a deadlocked processes and releasing its resources

Do nothing

- Prevention, avoidance and detection/recovery are expensive
- If deadlock is rare, is it worth the overhead?
- Manual intervention (kill processes, reboot) if needed

Deadlock Prevention

Aside: Necessary Conditions for Deadlock

- Mutual exclusion
  - Processes claim exclusive control of the resources they require
- Hold-and-wait (a.k.a. wait-for) condition
  - Processes hold resources already allocated to them while waiting for additional resources
- No preemption condition
  - Resources cannot be removed from the processes holding them until used to completion
- Circular wait condition
  - A circular chain of processes exists in which each process holds one or more resources that are requested by the next process in the chain

Deadlock prevention

Goal 1: devise resource allocation rules which make circular wait impossible

- Resources include mutex locks, semaphores, pages of memory, ...
- ...but you can think about just mutex locks for now

Goal 2: make sure useful behavior is still possible!

- The rules will necessarily be conservative
  - Rule out some behavior that would not cause deadlock
- But they shouldn't be to be *too* conservative
  - We still need to get useful work done

Rule #1: No Mutual Exclusion

For deadlock to happen: processes must claim exclusive control of the resources they require

How to break it?

Rule #1: No Mutual Exclusion

For deadlock to happen: processes must claim exclusive control of the resources they require

How to break it?

- Non-exclusive access only
  - Read-only access
- Battle won!
  - War lost
  - Very bad at Goal #2

Rule #2: Allow preemption

A lock can be taken away from current owner

- Let it go: If a process holding some resources is denied a further request, that process must release its original resources
- Or take it all away: OS preempts current resource owner, gives resource to new process/thread requesting it

Breaks circular wait

- ...because we don't have to wait

Reasonable strategy sometimes

- e.g. if resource is memory: "preempt" = page to disk

Not so convenient for synchronization resources

- e.g., locks in multithreaded application
- What if current owner is in the middle of a critical section updating pointers? Data structures might be left in inconsistent state!

Rule #3: No hold and wait

When waiting for a resource, must not hold others

- So, process can only have one resource locked
- Or, it must request all resources at the beginning
- Or, before asking for more: give up everything you have and request it all at one time

Breaks circular wait

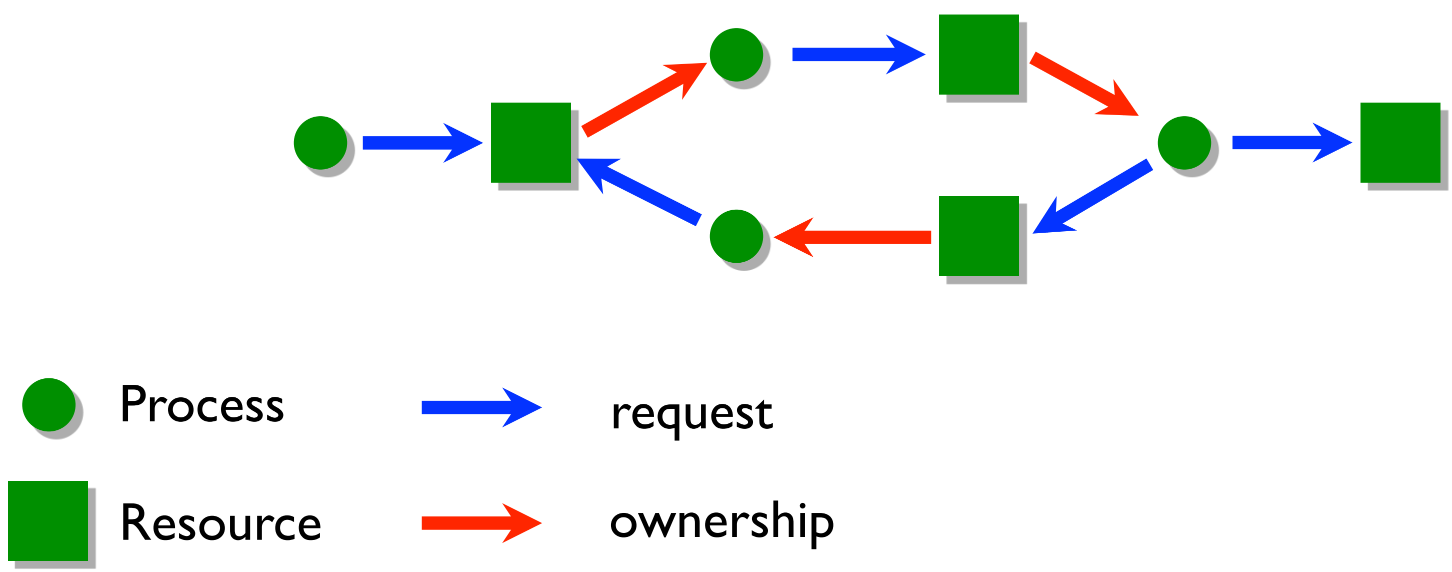
- In resource allocation diagram: process with an outgoing link must have no incoming links
- Therefore, cannot have a loop!

Rule #3: No hold and wait

Breaks circular wait

- In resource allocation diagram: process with an outgoing link must have no incoming links
- Therefore, cannot have a loop!

Q: Which of these request links would be disallowed?



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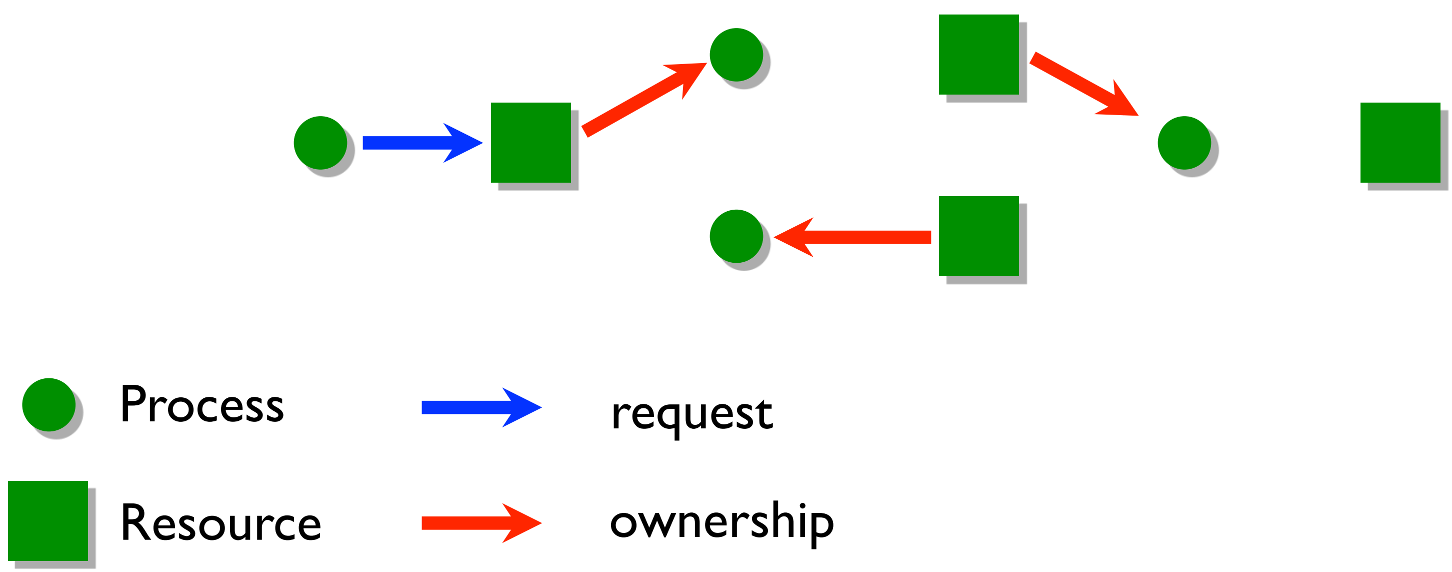
A: Legal links are...



Rule #3: No hold and wait

Very constraining (bad job on Goal #2)

- Better than Rules #1 and #2, but...
- Often need more than one resource
- Hard to predict at the begining what resources you'll need
- Releasing and re-requesting is inefficient, complicates programming, might lead to starvation

Rule #4: request resources in order

Must request resources in increasing order

- Impose ordering on resources (any ordering will do)
- If holding resource *i*, can only request resources > *i*

Much less constraining (decent job on Goal #2)

- Strictly easier to satisfy than "No hold and wait": If we can request all resources at once, then we can request them in increasing order
- But now, we don't need to request them all at once
- Can pick the arbitrary ordering for convenience to the application
- Still might be inconvenient at times

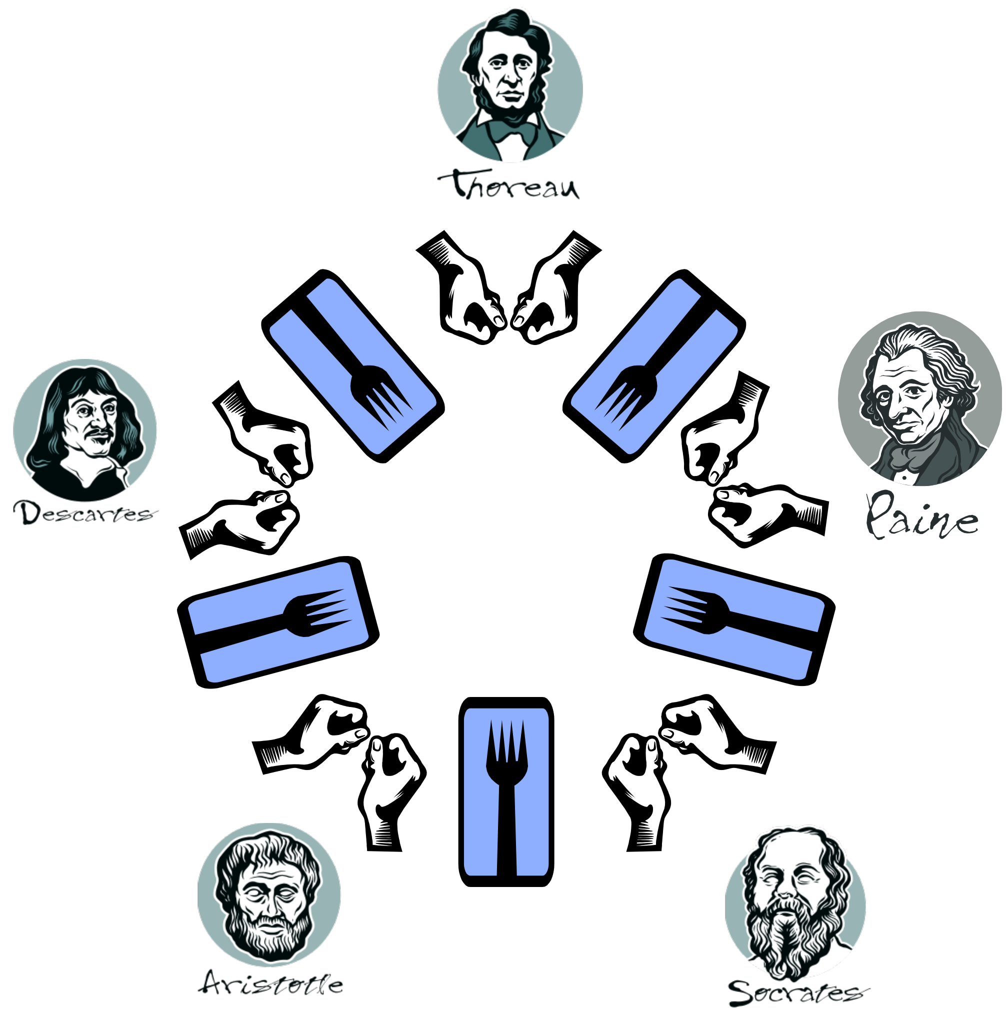
But why is it guaranteed to preclude circular wait?

Dining Philosophers solution with unnumbered resources

Back to the trivial broken "solution"...

```
# define N 5

void philosopher (int i) {
    while (TRUE) {
        think();
        take_fork(i);
        take_fork((i+1)%N);
        eat(); /* yummy */
        put_fork(i);
        put_fork((i+1)%N);
   }
}
```



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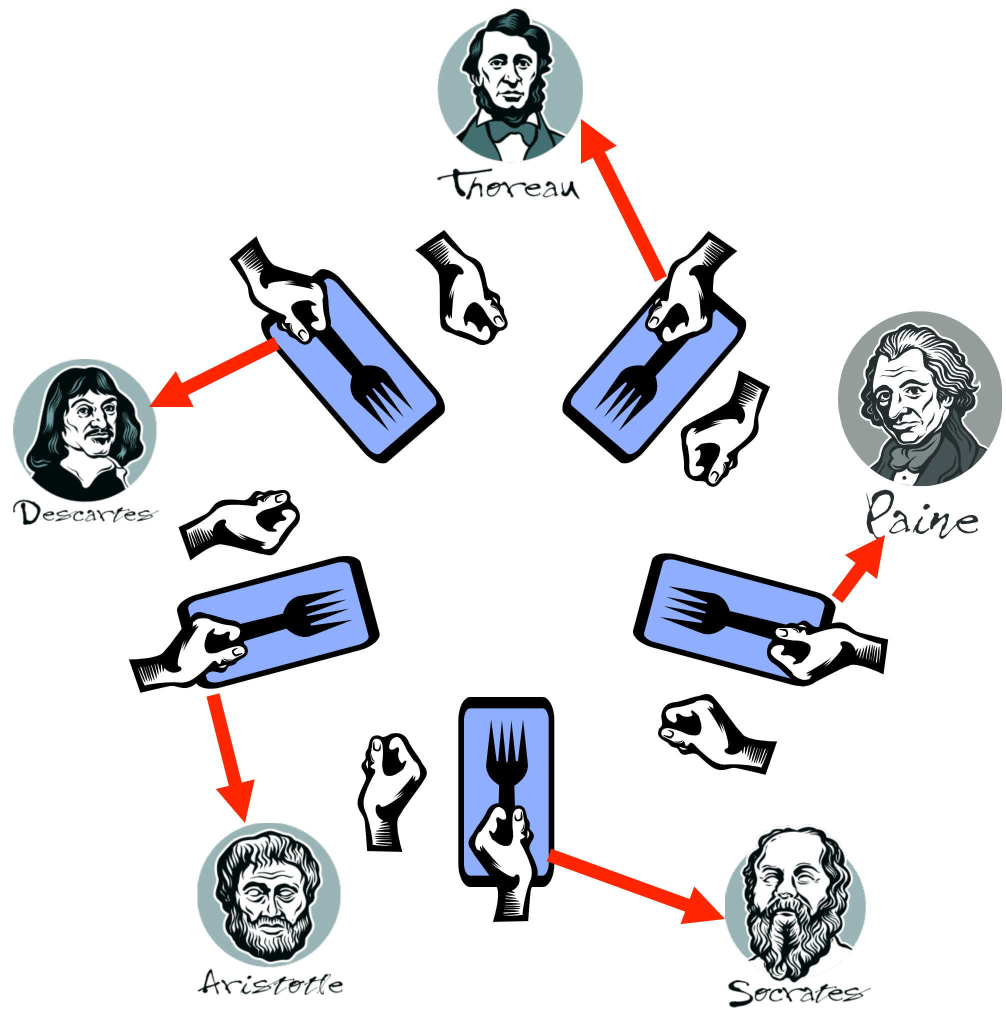

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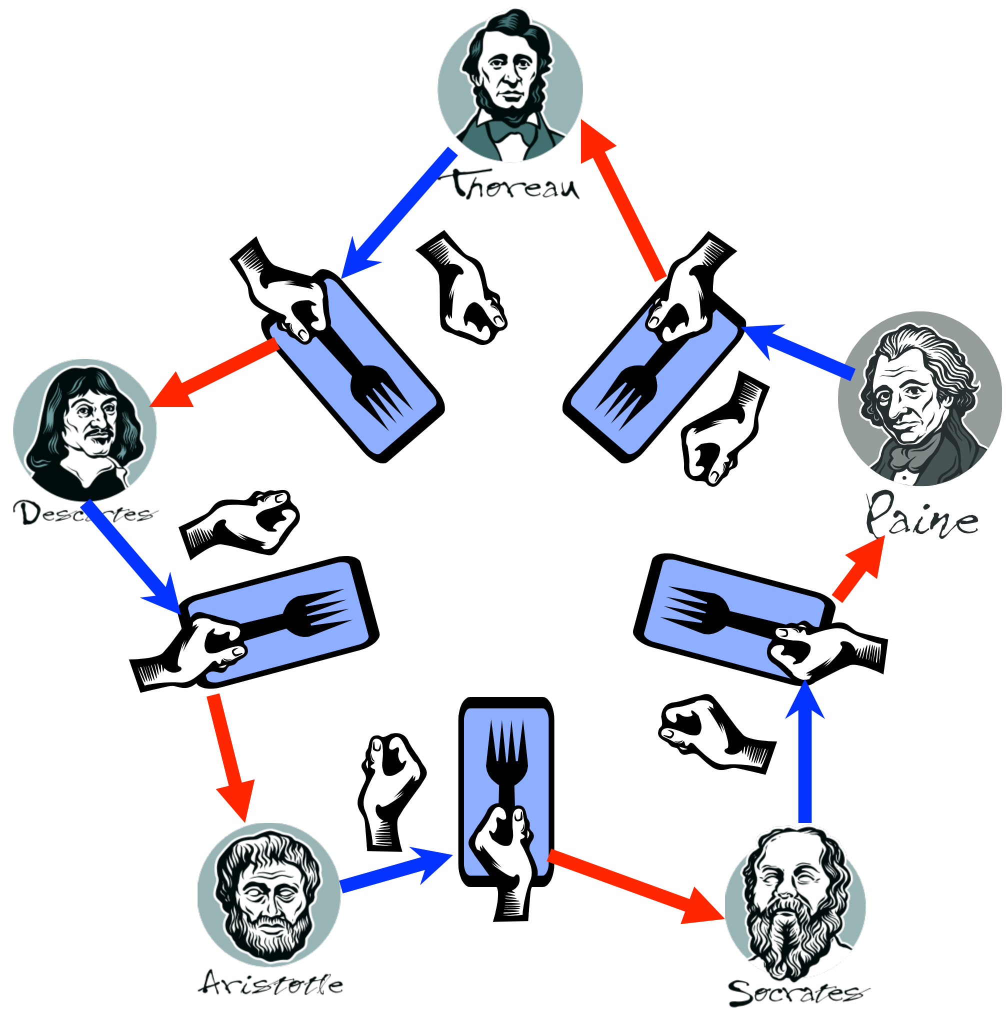

Dining Philosophers solution with numbered resources

Instead, number resources

First request lower numbered fork

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# define N 5

void philosopher (int i) {
    while (TRUE) {
        think();
        take_fork(LOWER(i));
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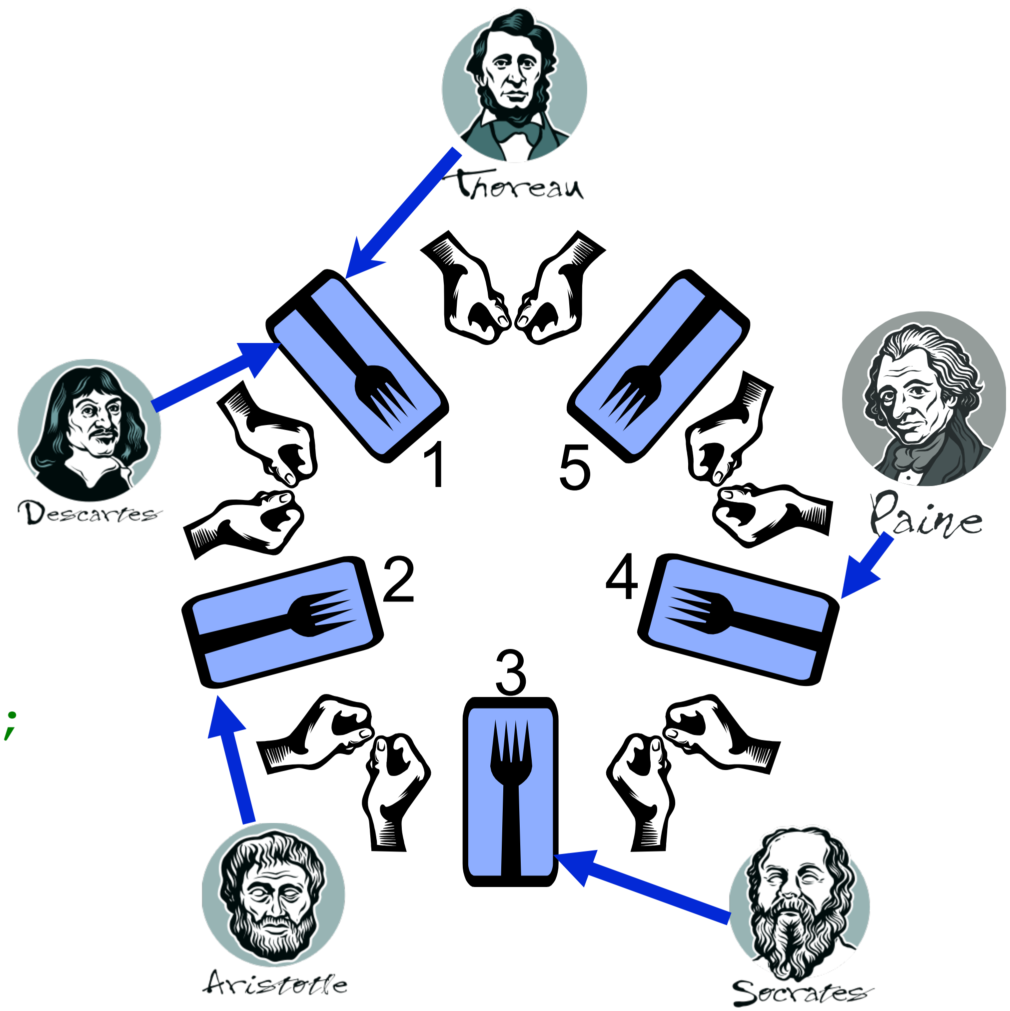

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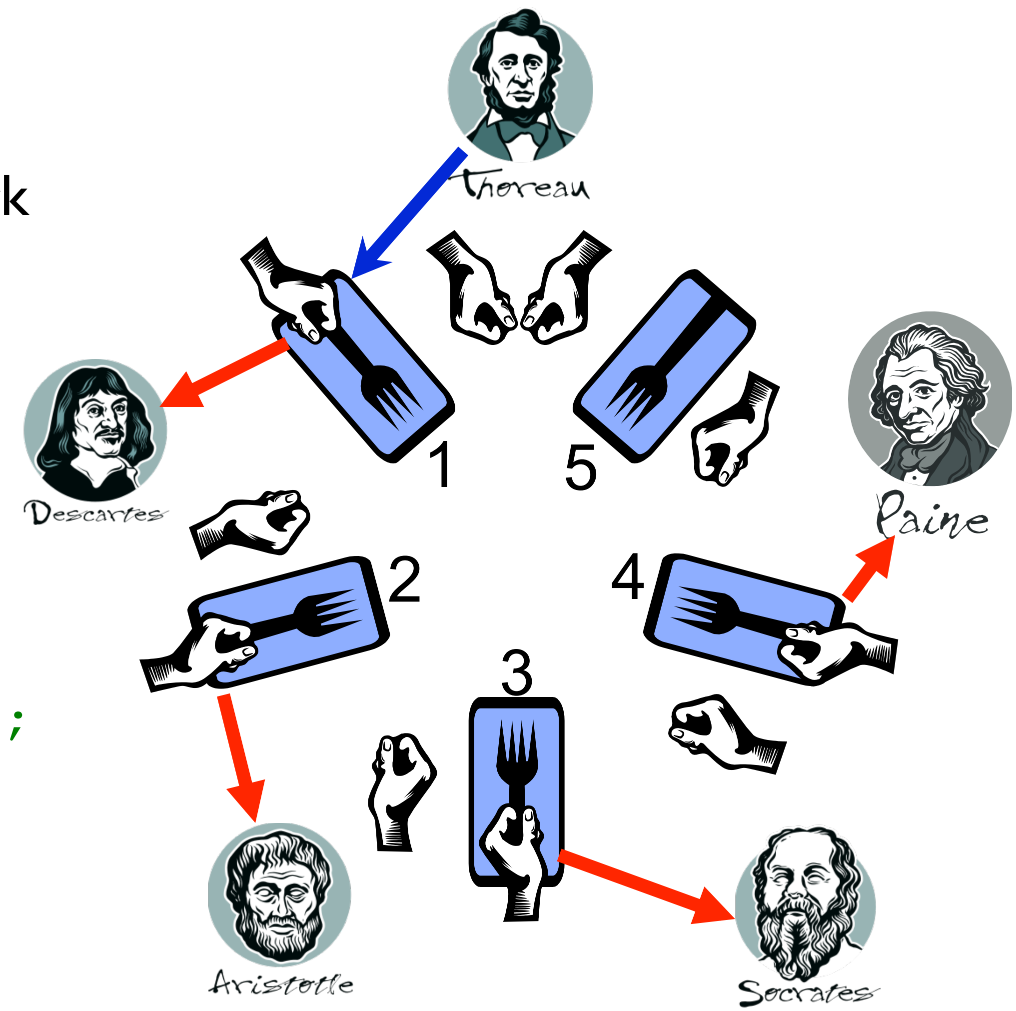

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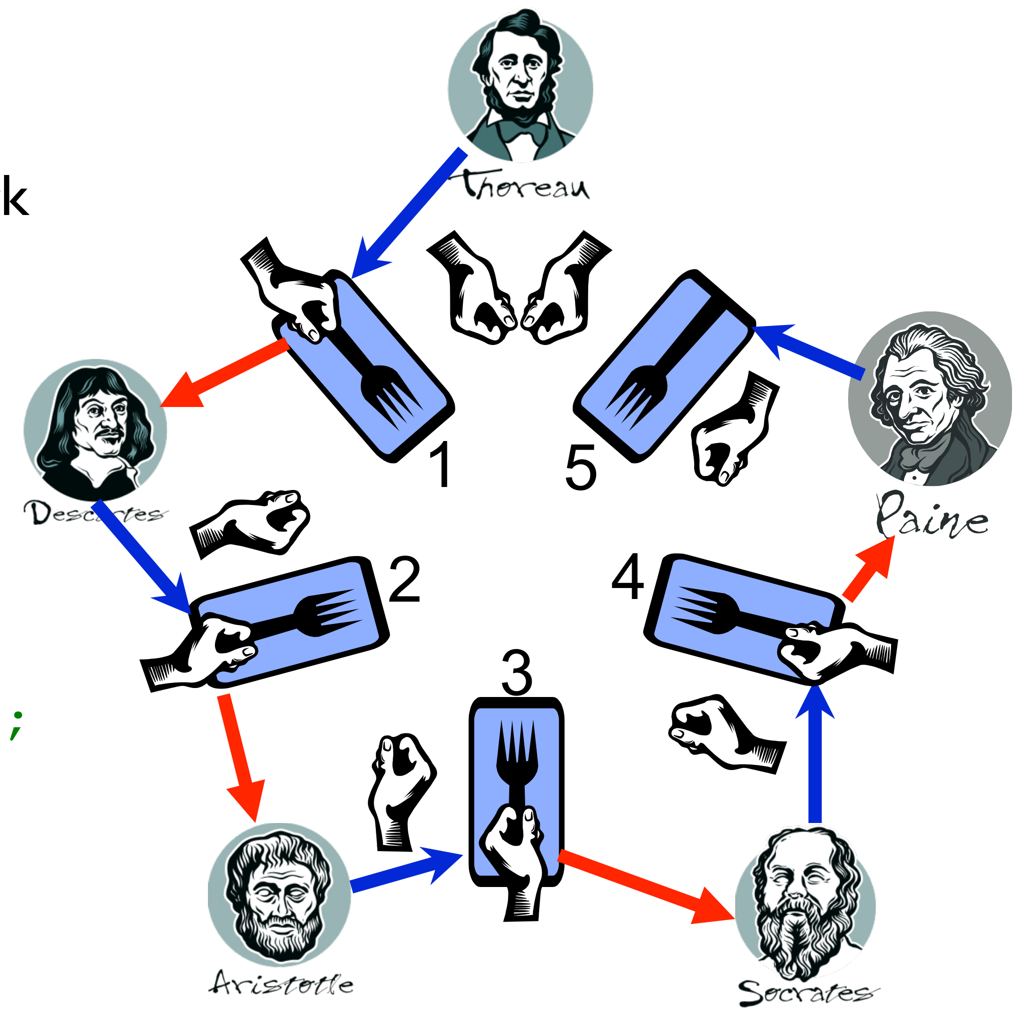

Dining Philosophers solution with numbered resources

Instead, number resources...

One philosopher can eat!

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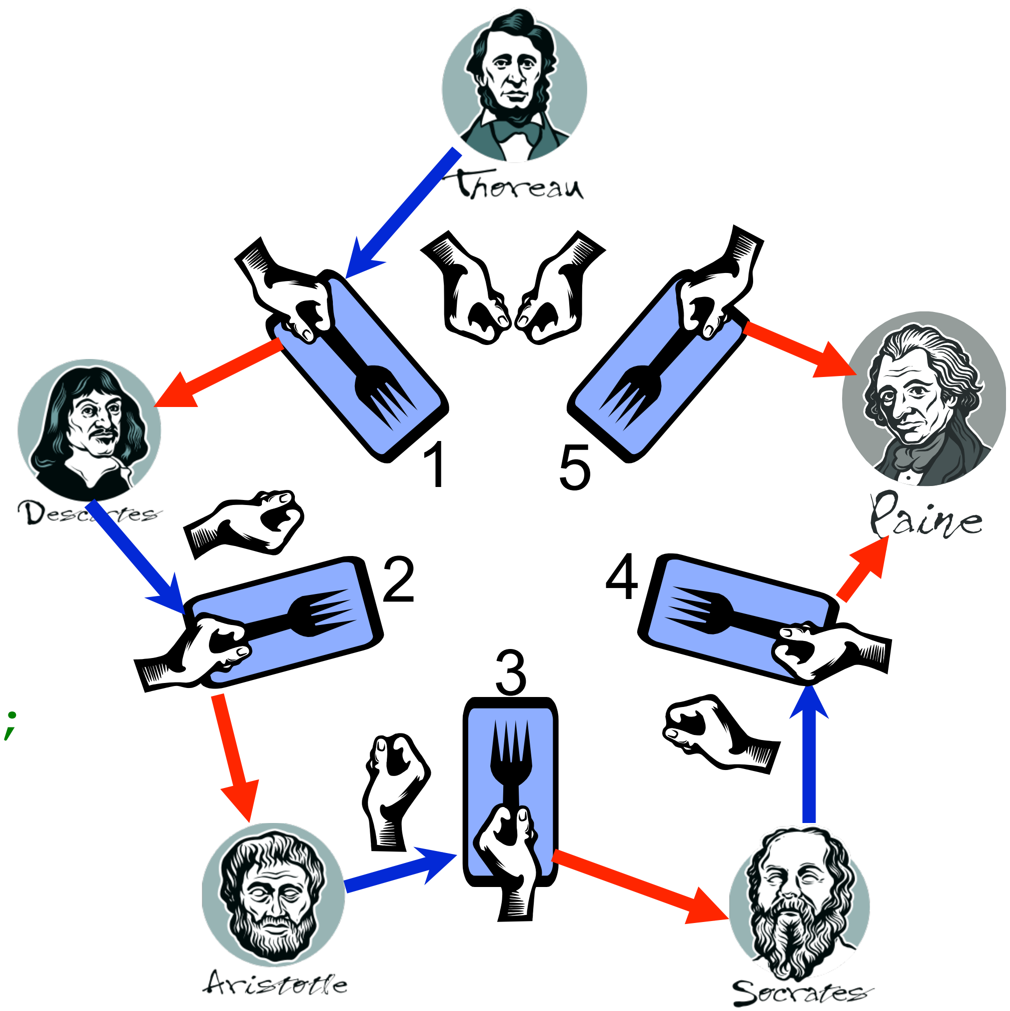
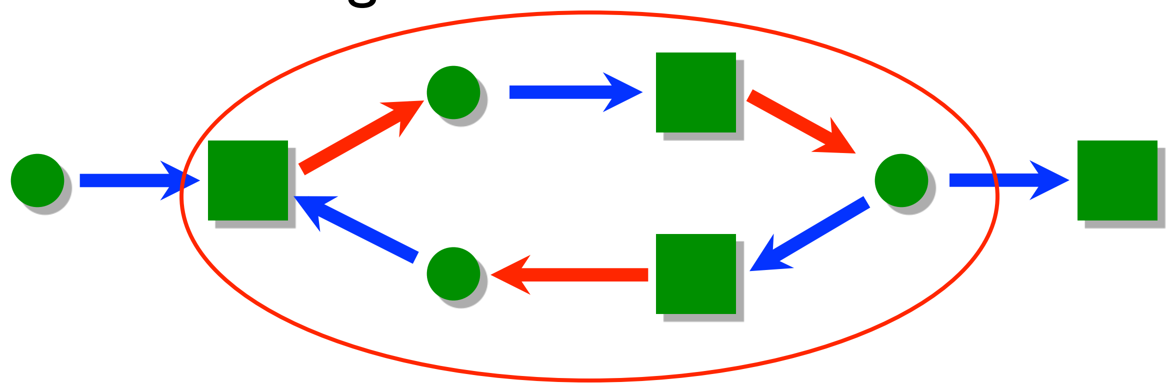


Ordered resource requests prevent deadlock

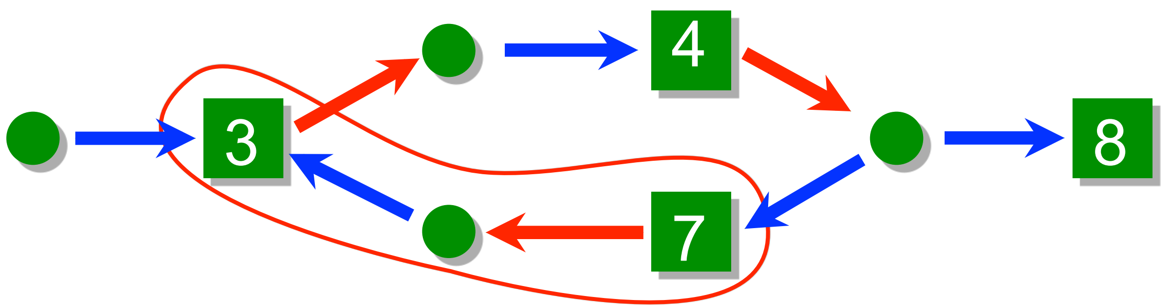
Without numbering



Cycle!

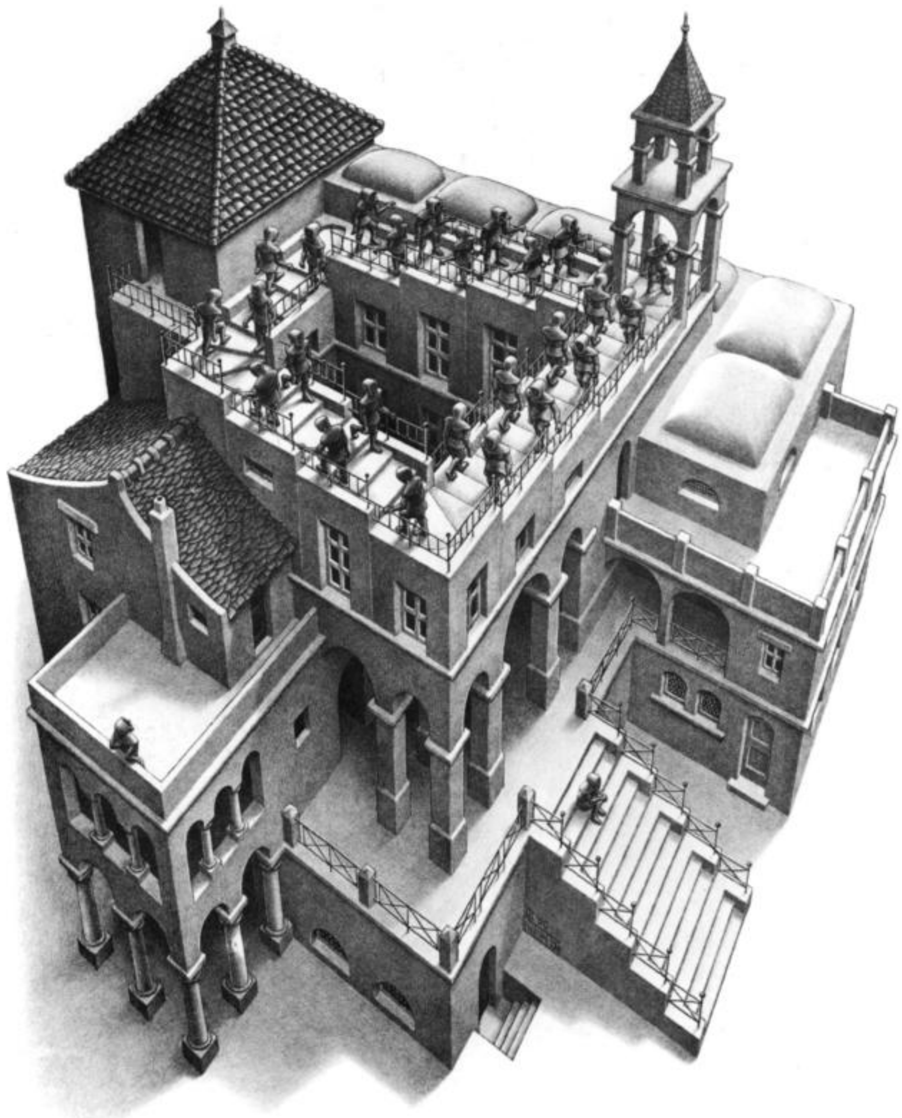
Ordered resource requests prevent deadlock

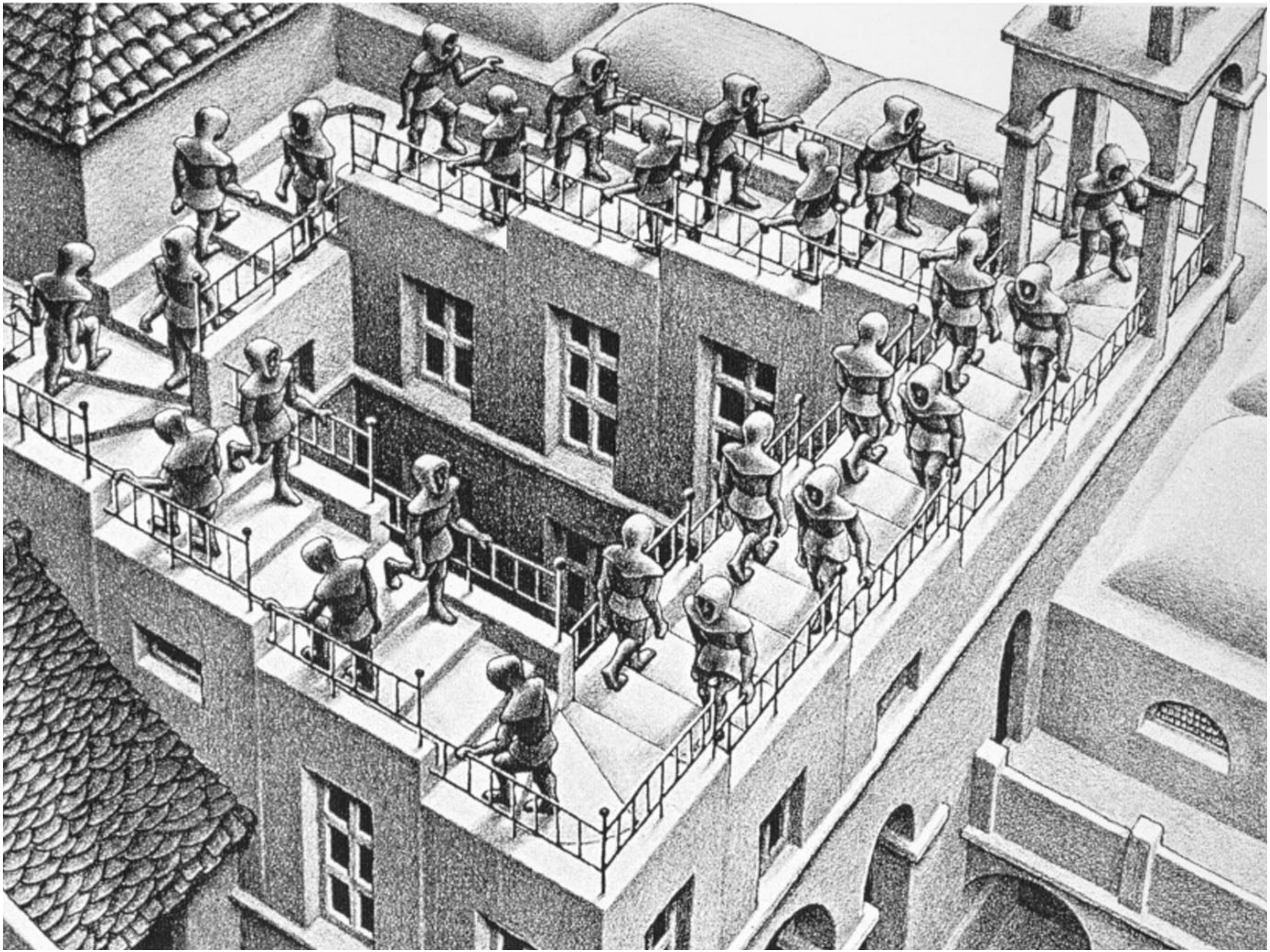
With numbering



Contradiction:
Must have requested 3 first!

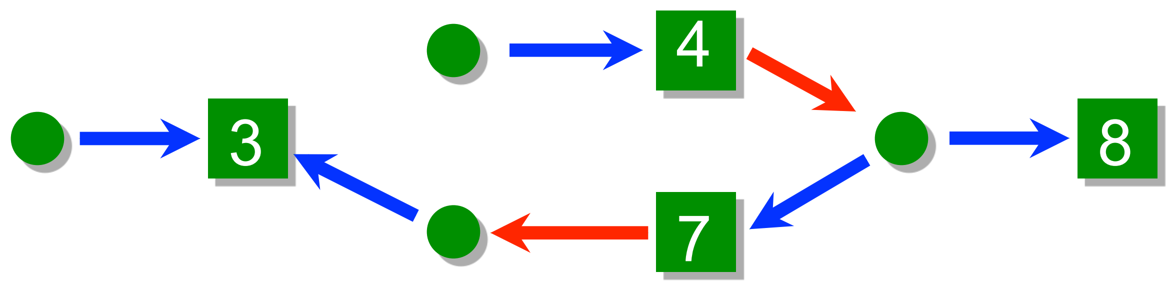
Proof by M.C. Escher





Are we always in trouble without ordering resources?

No, not always:

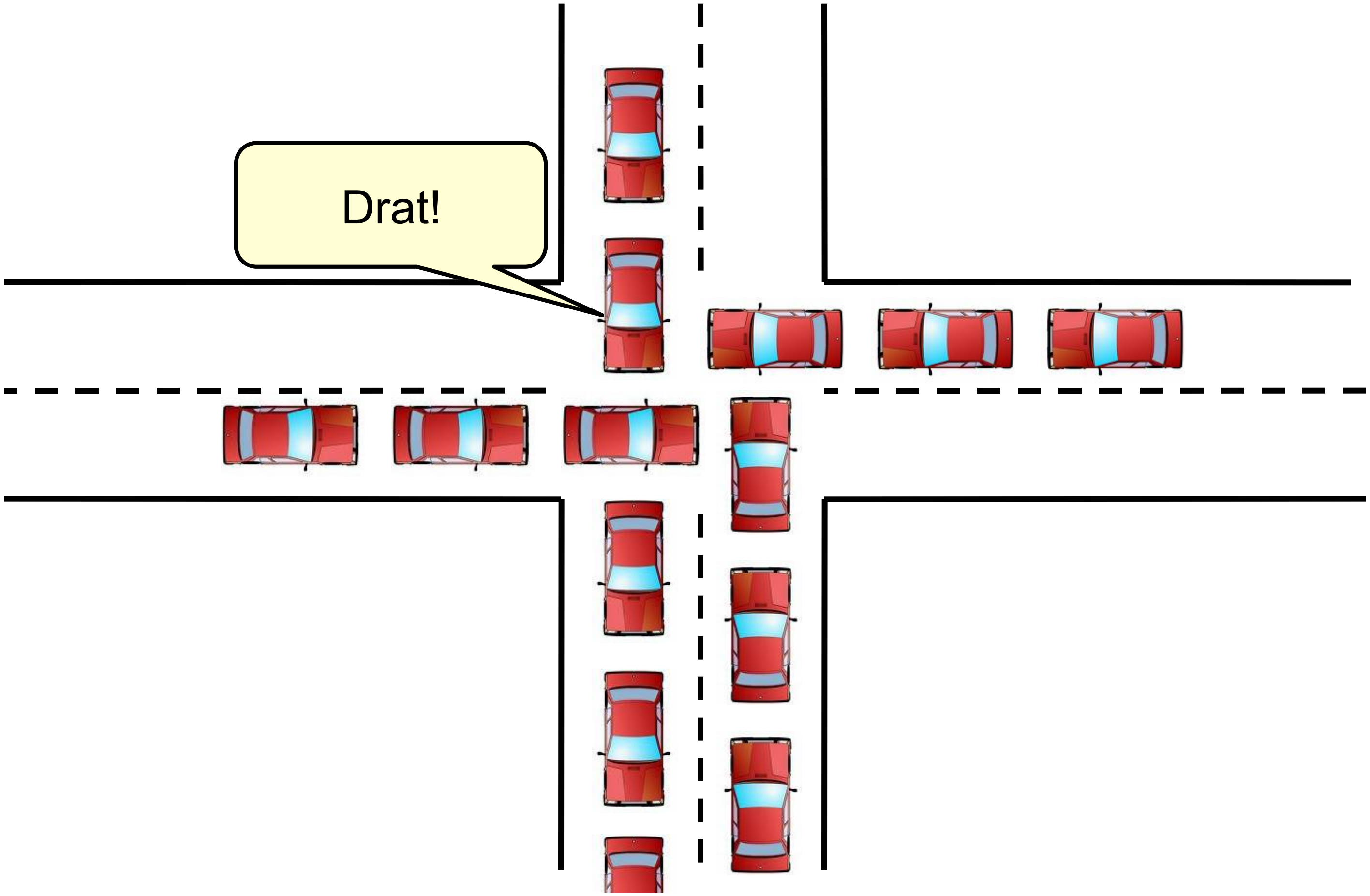


Ordered resource requests are sufficient to avoid deadlock, but not necessary

Convenient, but may be conservative

Q: What's the rule of the road?

What's the law? Does it resemble one of the rules we saw?



Summary

Deadlock prevention

- Imposes rules on what system can do
- These rules are conservative
- Most useful technique: ordered resources
- Application can do it; no special OS support

Next: dealing with deadlocks other ways

- Avoidance
- Detection & recovery