Multi-Object Synchronization

Main Points

- Problems with synchronizing multiple objects
- Definition of deadlock
  - Circular waiting for resources
- Conditions for its occurrence
- Solutions for avoiding and breaking deadlock

Large Programs

- What happens when we try to synchronize across multiple objects in a large program?
  - Each object with its own lock, condition variables
  - Is concurrency modular?
- Deadlock
- Performance
- Semantics/correctness

Deadlock Definition

- Resource: any (passive) thing needed by a thread to do its job (CPU, disk space, memory, lock)
  - Preemptable: can be taken away by OS
  - Non-preemptable: must leave with thread
- Starvation: thread waits indefinitely
- Deadlock: circular waiting for resources
  - Deadlock => starvation, but not vice versa

Example: two locks

Thread A	Thread B
lock1.acquire();	lock2.acquire();
lock2.acquire();	lock1.acquire();
lock2.release();	lock1.release();
lock1.release();	lock2.release();

Bidirectional Bounded Buffer

Thread A	Thread B
buffer1.put(data);	buffer2.put(data);
buffer1.put(data);	buffer2.put(data);
buffer2.get();	Buffer1.get();
buffer2.get();	Buffer1.get();

Two locks and a condition variable

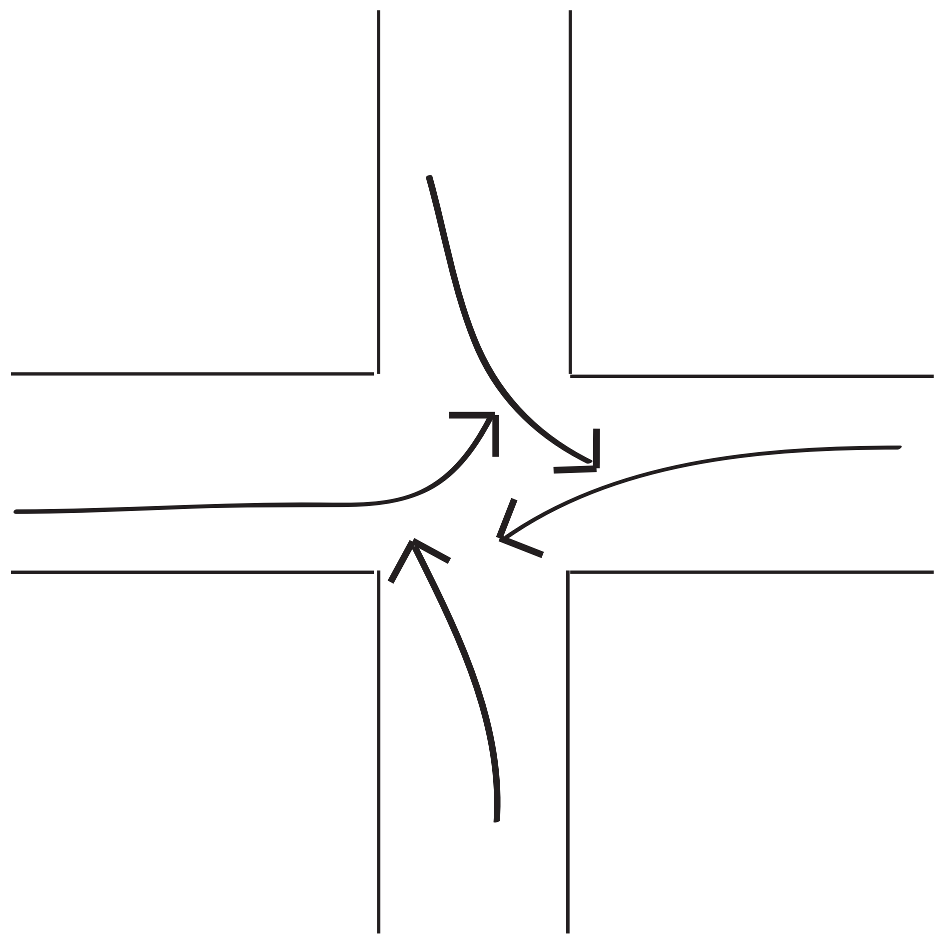
Thread A

```
lock1.acquire();
…
lock2.acquire();
while (need to wait)
  condition.wait(lock2);
lock2.release();
…
lock1.release();
```

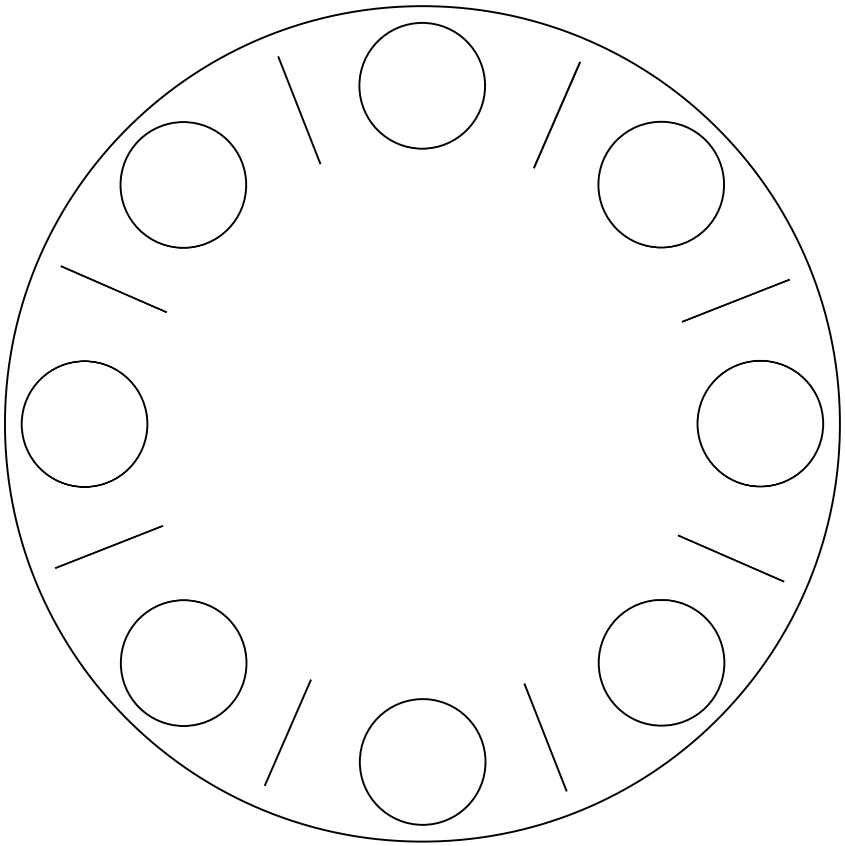
Thread B

```
lock1.acquire();
…
lock2.acquire();
….
condition.signal(lock2);
lock2.release();
…
lock1.release();
```

Yet another Example



Dining Lawyers

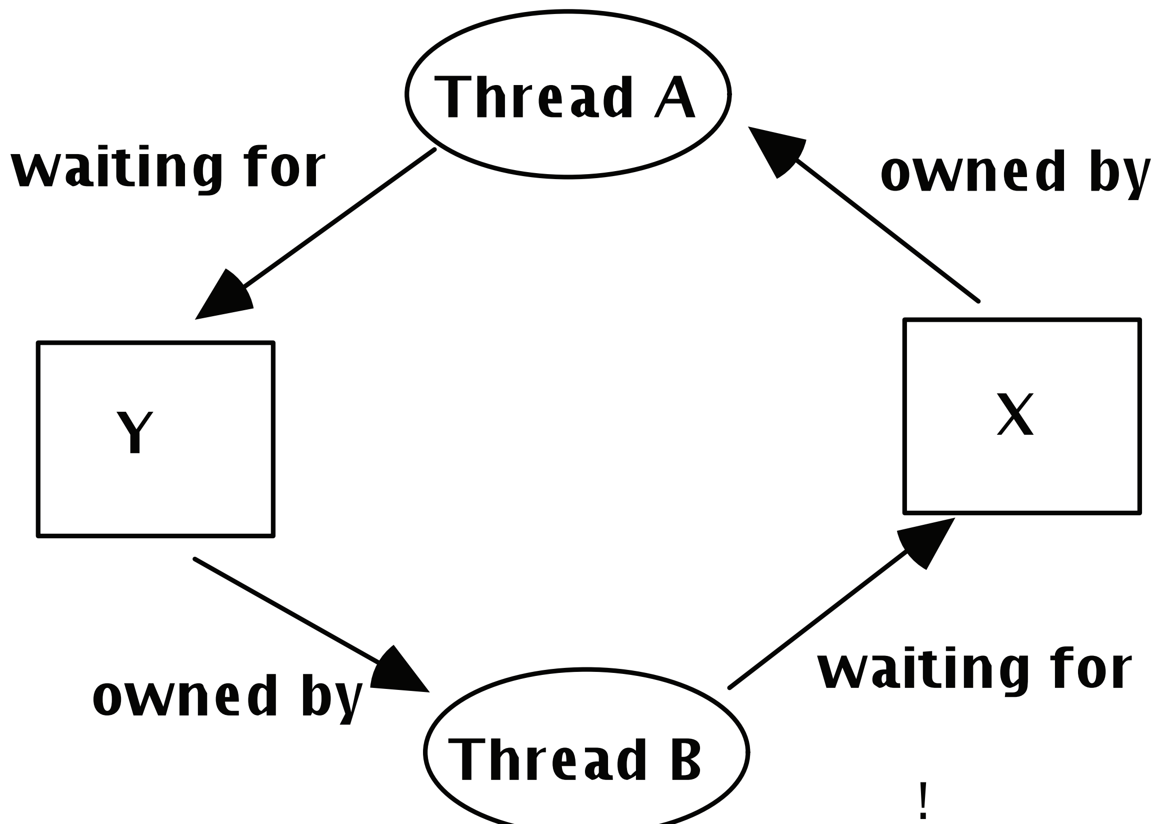


Each lawyer needs two chopsticks to eat.
Each grabs chopstick on the right first.

Conditions for Deadlock

- Limited access to resources
  - If infinite resources, no deadlock!
- No preemption
  - If resources are virtual, can break deadlock
- Multiple independent requests
  - “wait while holding”
- Circular chain of requests

Circular Waiting



Solution #1: Detect and Fix

- Algorithm
  - Scan wait for graph
  - Detect cycles
  - Fix cycles
- How?
  - Remove one thread, reassign its resources
    - Requires exception handling code to be very robust
  - Roll back actions of one thread
    - Databases: all actions are provisional until committed

Solution #2: Deadlock Prevention

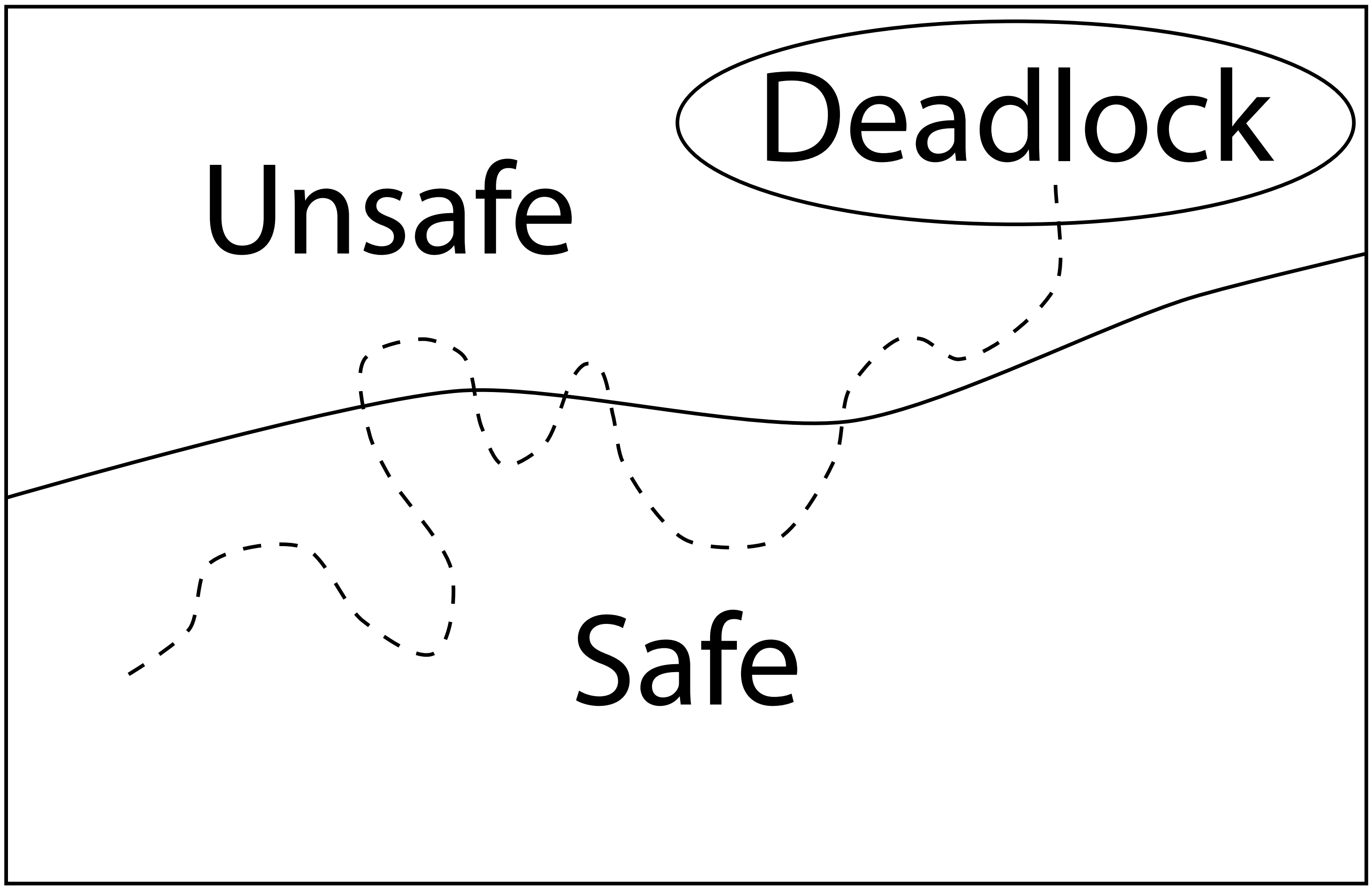
Eliminate one of the four conditions for deadlock

- Lock ordering
  - Always acquire locks in the same order
  - Example: move file from one directory to another
  - Widely used in OS kernels
- Design system to release resources and retry if need to wait
  - No “wait while holding”
  - Example: telephone circuit setup
- Infinite resources?
  - Ex: UNIX reserves a process for the sysadmin to run “kill”
- Acquire all needed resources in advance

Solution #3: Banker's Algorithm

- Banker's algorithm
  - State maximum resource needs in advance
  - Allocate resources dynamically when resource is needed -- wait if granting request would lead to deadlock
  - Request can be granted if some sequential ordering of threads is deadlock free

Possible System States



Definitions

- Safe state:
  - For any possible sequence of future resource requests, it is possible to eventually grant all requests
  - May require waiting even when resources are available!
- Unsafe state:
  - Some sequence of resource requests can result in deadlock
- Doomed state:
  - All possible computations lead to deadlock

Banker's Algorithm

- Grant request iff result is a safe state
- Sum of maximum resource needs of current threads can be greater than the total resources
  - Provided there is some way for all the threads to finish without getting into deadlock
- Example: proceed iff
  - total available resources - # allocated >= max remaining that might be needed by this thread in order to finish
  - Guarantees this thread can finish

Lock-Free Data Structures

- Assume compare and swap atomic instruction
  - Limitation: swap a single memory location
  - Only supported on some processor architectures
- Rewrite critical section
  - Create copy of data structure
  - Modify copy
  - Swap in pointer to copy iff no one else has
  - Restart if pointer has changed

Lock-Free Bounded Buffer

```
get() {
  do {
    mine = ConsistentCopy(p);
    if (mine.front == mine.last)
      mine.queue.Add(self);
    else {
      item = mine.buf[
             mine.front % size];
      mine.front++;
     }
   while ((compare&swap(mine, p) != p);
   wake up waiter if needed
   return item.
}
```