CONCURRENCY: DEADLOCK

Shivaram Venkataraman

CS 537, Spring 2019

ADMINISTRIVIA

Midterm is on Wednesday 3/13 at 5.15pm, details on Piazza

Venue: If your last name starts with A-L, go to [VanVleck B102]

else (last name starts with M-Z), go to [VanVleck B130]

Bring your ID! Calculators allowed, no cheat sheet

Review session, Office hours at 5.30pm at Noland Hall, Room 132

Fill out mid semester course evaluation? https://aefis.wisc.edu/

AGENDA / LEARNING OUTCOMES

- Concurrency
  - What are common pitfalls with concurrent execution?

RECAP

CONCURRENCY OBJECTIVES

Mutual exclusion (e.g., A and B don’t run at same time)

solved with *locks*

Ordering (e.g., B runs after A does something)

solved with *condition variables* and *semaphores*

SUMMARY: CONDITION VARIABLES

wait(cond_t *cv, mutex_t *lock)

- assumes the lock is held when wait() is called
- puts caller to sleep + releases the lock (atomically)
- when awoken, reacquires lock before returning

signal(cond_t *cv)

- wake a single waiting thread (if >= 1 thread is waiting)
- if there is no waiting thread, just return, doing nothing

SUMMARY: SEMAPHORES

Semaphores are equivalent to locks + condition variables

- Can be used for both mutual exclusion and ordering

Semaphores contain **state**

- How they are initialized depends on how they will be used
- Init to 0: Join (1 thread must arrive first, then other)
- Init to N: Number of available resources

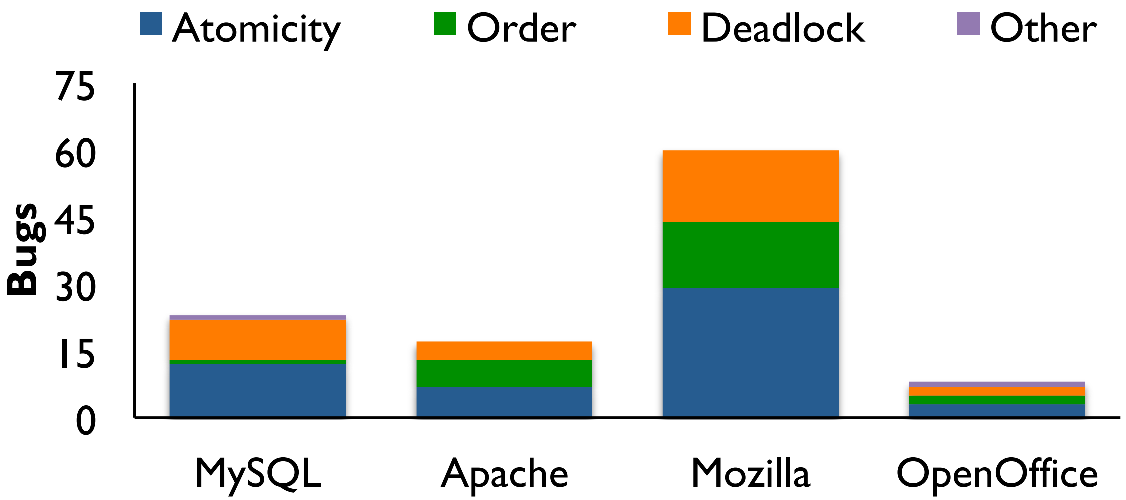
sem_wait(): Decrement and waits IF value < 0

sem_post() or sem_signal(): Increment value, then wake a single waiter (atomic)

Can use semaphores in producer/consumer and for reader/writer locks

CONCURRENCY BUGS

CONCURRENCY STUDY



Lu *etal.* [ASPLOS 2008]:

For four major projects, search for concurrency bugs among >500K bug reports. Analyze small sample to identify common types of concurrency bugs.

FIX ATOMICITY BUGS WITH LOCKS

Thread 1:

```
pthread_mutex_lock(&lock);
if (thd->proc_info) {
   …
   fputs(thd->proc_info, …);
   …
}
pthread_mutex_unlock(&lock);
```

Thread 2:

```
pthread_mutex_lock(&lock);
thd->proc_info = NULL;
pthread_mutex_unlock(&lock);
```

FIX ORDERING BUGS WITH CONDITION VARIABLES

Thread 1:

```
void init() {
    …

    mThread =
    PR_CreateThread(mMain, …);

    pthread_mutex_lock(&mtLock);
    mtInit = 1;
    pthread_cond_signal(&mtCond);
    pthread_mutex_unlock(&mtLock);

    …
}
```

Thread 2:

```
void mMain(…) {
  …

  mutex_lock(&mtLock);
  while (mtInit == 0)
    Cond_wait(&mtCond, &mtLock);
  Mutex_unlock(&mtLock);

  mState = mThread->State;
  …
}
```

DEADLOCK

No progress can be made because two or more threads are waiting for the other to take some action and thus neither ever does

CODE EXAMPLE

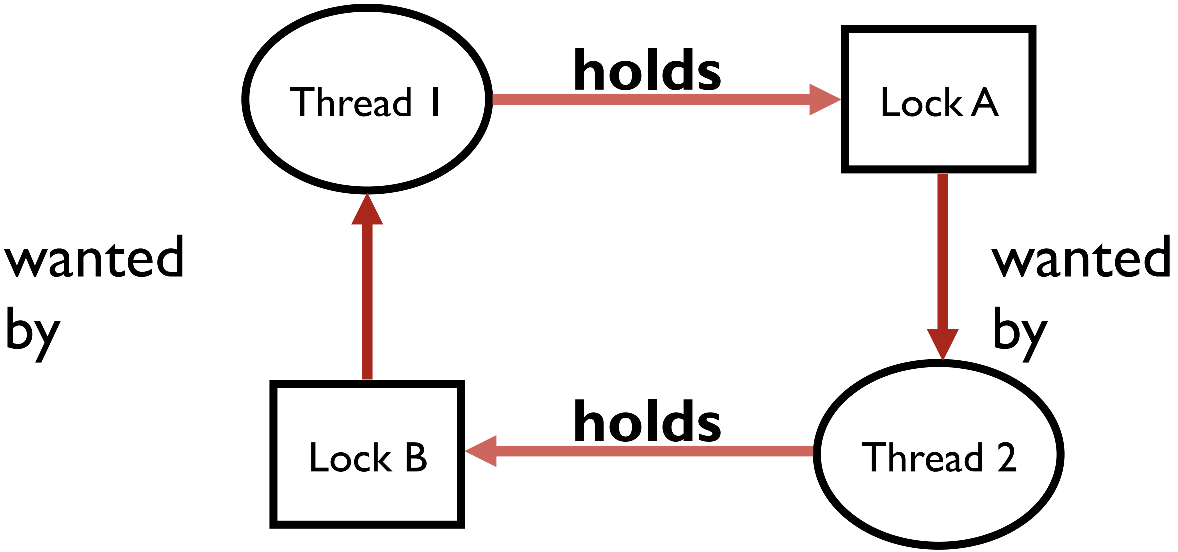
Thread 1:

```
lock(&A);
lock(&B);
```

Thread 2:

```
lock(&B);
lock(&A);
```

CIRCULAR DEPENDENCY



FIX DEADLOCKED CODE

```
Thread 1:

lock(&A);
lock(&B);
```

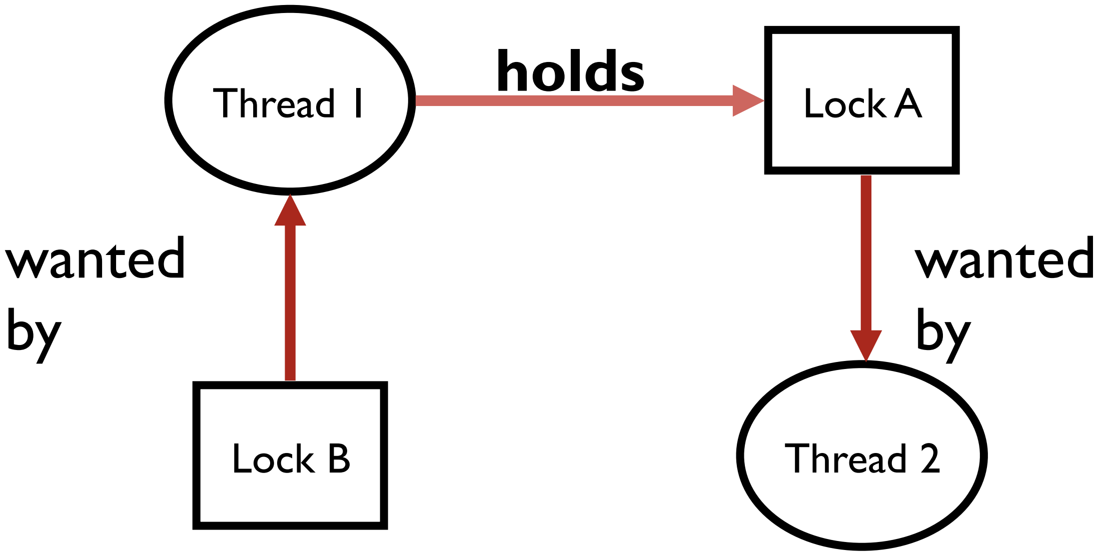
```
Thread 2:

lock(&B);
lock(&A);
```

```
Thread 1
```

```
Thread 2
```

NON-CIRCULAR DEPENDENCY



```c
set_t *set_intersection (set_t *s1, set_t *s2) {
    set_t *rv = malloc(sizeof(*rv));
    mutex_lock(&s1->lock);
    mutex_lock(&s2->lock);
    for(int i=0; i<s1->len; i++) {
        if(set_contains(s2, s1->items[i])
            set_add(rv, s1->items[i]);
    mutex_unlock(&s2->lock);
    mutex_unlock(&s1->lock);
}
```

Thread 1: `rv = set_intersection(setA, setB);`

Thread 2: `rv = set_intersection(setB, setA);`

ENCAPSULATION

Modularity can make it harder to see deadlocks

Solution?

```
if (m1 > m2) {
    // grab locks in high-to-low address order
    pthread_mutex_lock(m1);
    pthread_mutex_lock(m2);
} else {
    pthread_mutex_lock(m2);
    pthread_mutex_lock(m1);
}
```

Any other problems?

DEADLOCK THEORY

Deadlocks can only happen with these four conditions:

1. mutual exclusion
2. hold-and-wait
3. no preemption
4. circular wait

Can eliminate deadlock by eliminating any one condition

1. MUTUAL EXCLUSION

Problem: Threads claim exclusive control of resources that they require

Strategy: Eliminate locks!

Try to replace locks with atomic primitive:

```
int CompareAndSwap(int *address, int expected, int new) {
   if (*address == expected) {
      *address = new;
      return 1; // success
   }
   return 0; // failure
}
```


https://tinyurl.com/cs537-sp19-bunny9
BUNNY

BUNNY

https://tinyurl.com/cs537-sp19-bunny9

```
void add (int *val, int amt) {
    Mutex_lock(&m);
    *val += amt;
    Mutex_unlock(&m);
}
```

```
int CompareAndSwap(int *address,
     int expected, int new) {
  if (*address == expected) {
     *address = new;
     return 1; // success
   }
   return 0; // failure
}
```

```
void add (int *val, int amt) {
                          do {
                 int old = *value;
} while(!CompAndSwap(___, ___,___);
                                 }
```

WAIT-FREE ALGORITHM: LINKED LIST INSERT

```
void insert (int val) {
    node_t *n = Malloc(sizeof(*n));
    n->val = val;
    lock(&m);
    n->next = head;
    head = n;
    unlock(&m);
}
```

```
void insert (int val) {
    node_t *n = Malloc(sizeof(*n));
    n->val = val;
    do {
        n->next = head;
    } while (!CompAndSwap(&head,
                     n->next, n));
}
```

2. HOLD-AND-WAIT

Problem: Threads hold resources allocated to them while waiting for additional resources

Strategy: Acquire all locks atomically **once.** Can release locks over time, but cannot acquire again until all have been released

How to do this? Use a meta lock:

Disadvantages?

3. NO PREEMPTION

Problem: Resources (e.g., locks) cannot be forcibly removed from threads that are

Strategy: if thread can't get what it wants, release what it holds

```
top:
    lock(A);
    if (trylock(B) == -1) {
        unlock(A);
        goto top;
    }
    …
```

Disadvantages?

4. CIRCULAR WAIT

Circular chain of threads such that each thread holds a resource (e.g., lock) being requested by next thread in the chain.

Strategy:

- decide which locks should be acquired before others
- if A before B, never acquire A if B is already held!
- document this, and write code accordingly

Works well if system has distinct layers

CONCURRENCY SUMMARY SO FAR

Motivation: Parallel programming patterns, multi-core machines

Abstractions, Mechanisms

- Spin Locks, Ticket locks
- Queue locks
- Condition variables
- Semaphores

Concurrency Bugs

MIDTERM REVIEW