CSc 360
Operating Systems
Mutual Exclusion

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1st Practice Exam Released!
Solution will release this Thur.

Plz join the shared teams!
Emails me bonus request and cc TAs: Johnathan and Clark.

Review: threads

- Thread vs process
  - easy to share info btw threads in one process
    - share and protect!
- Create and terminate threads
  - start routine, argument passing
    - threads are executed “in parallel”
- Join and detach threads
  - synchronization
    - “wait”

Shared or not shared?

- E.g., increment a **counter** (shared variable)
  - read the counter (from memory)
  - increment by one (at CPU)
  - write the counter
- How about two threads?
  - *sharing* only one counter
    - non-deterministic result: $R_1W_1R_2W_2$; $R_1R_2W_1W_2$
- "There is something not to be (always) shared"

* producer-consumer problem with a buffer and counter

What will be the final answer?

```
pthread_t tid[2];
int counter = 0;
void* doSomething(void *arg) {
  unsigned long i = 0;
  for (int i = 0 ; i < 1000 ; i++) {
    counter += 1;
  }
  return NULL;
}
int main(void) {
  for(int i = 0; i < 2; i++) {
    pthread_create(&(tid[i]), NULL, &doSomething, NULL);
  }
  pthread_join(tid[0], NULL);
  pthread_join(tid[1], NULL);
  printf("Counter %d \n", counter);
  return 0;
}
```

```
 matei@laptop> gcc concurrency.c -o
concurrency –pthread
```

```
 matei@laptop> ./concurrency
```

```
Counter 2000
```

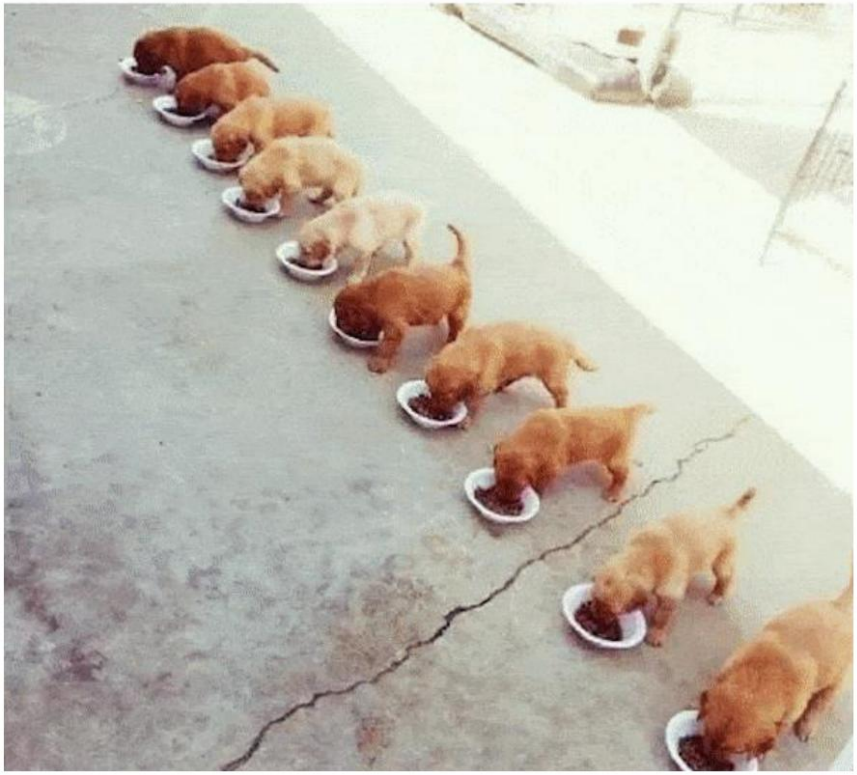
```
 matei@laptop> ./concurrency
```

```
Counter 1937
```

```
 matei@laptop> ./concurrency
```

```
Counter 1899
```

Multi-threaded programming in theory:



Multi-threaded programming in reality:

Why?

- Protection is at the process level.
- Threads not isolated.
  - Share an address space and data (e.g., counter).

So interleaving of threads is non-deterministic, and thus inconsistent outputs.

Definitions

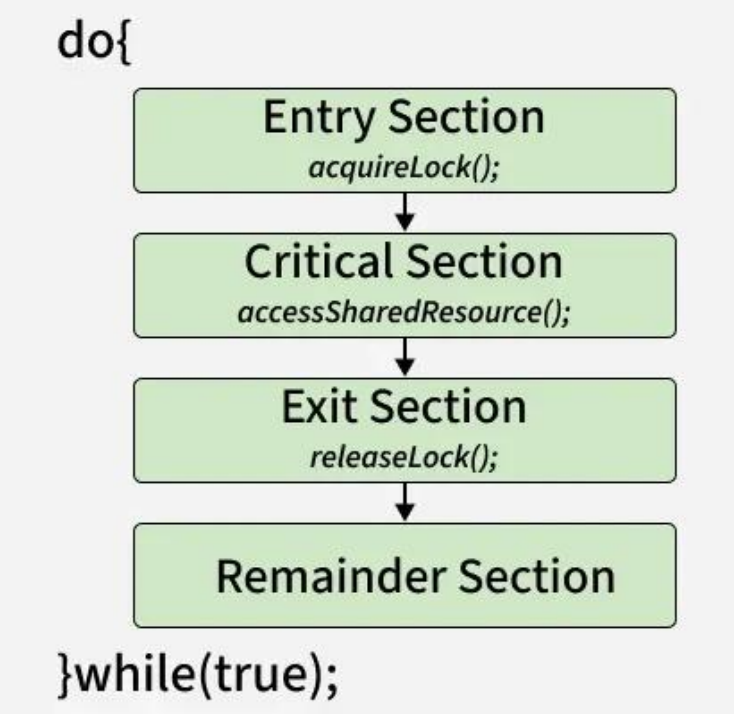
- Synchronization
  - Using atomic operations to ensure cooperation between threads
- Critical Section
  - Piece of code that only one thread can execute at once. Only one thread at a time will get into this section of code
- Mutual Exclusion
  - Ensuring that only one thread does a particular thing at a time

Atomic Operations

- An operation that always runs to completion, or not at all
- It is indivisible: it cannot be stopped in the middle, and state cannot be modified by someone else in the middle
- Fundamental building block
  - If no atomic operations, then have no way for threads to work together
- On most machines, memory references and assignments (i.e. loads and stores) of words are atomic
- Many instructions are not atomic, e.g., double-precision floating point store

Critical section

- Critical section
  - code section accessing shared data
  - only one thread executing in critical section
  - choose the **right** (size of) critical section!



Critical section

- Approach: exclusion (lock)
  - Prevents someone from doing something
  - **Lock()** before entering critical section and before accessing shared data
  - **Unlock()** when leaving, after accessing shared data
  - **Wait** if locked

Mutual exclusion

- Mutual exclusion (mutex)
  - only two states
    - unlocked: there is no thread in critical section
    - locked: there is one thread in critical section
  - state change is atomic
    - if it is unlocked, it can be locked by **at most one** thread when entering the critical section
    - if it is locked, it can “only” be unlocked by the locking thread when leaving the critical section

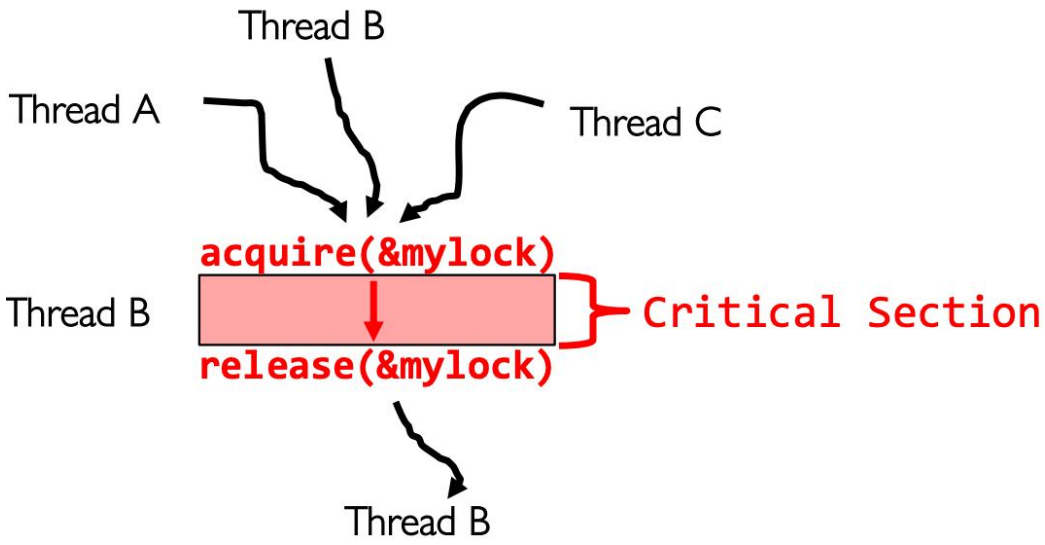
Example: Bank deposit with locks

- Identify critical sections (atomic instruction sequences) and add locking

```
Deposit(acctId, amount) {
  acquire(&mylock)          // Wait if someone else in critical section!
  acct = GetAccount(actId);
  acct->balance += amount;
  StoreAccount(acct);
  release(&mylock)          // Release someone into critical section
}
```

Critical Section

Example: Bank deposit with locks



Threads serialized by lock through critical section

Only one thread at a time

Example:“Too Much Milk”

Time	Person A	Person B
3:00	Look in Fridge. Out of milk	
3:05	Leave for store	
3:10	Arrive at store	Look in Fridge. Out of milk
3:15	Buy milk	Leave for store
3:20	Arrive home, put milk away	Arrive at store
3:25		Buy milk
3:30		Arrive home, put milk away

Too Much Milk: Correctness Properties

What are the correctness properties for the “Too much milk” problem???

- Never more than one person buys
- Someone buys if needed

First attempt: Restrict ourselves to use only atomic load and store operations as building blocks

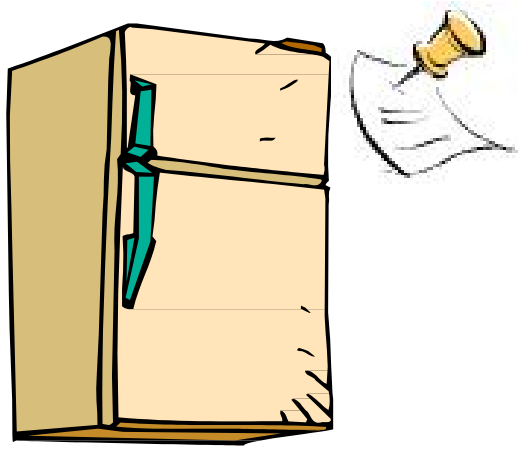
Too Much Milk: Solution #1

Use a note to avoid buying too much milk:

- Leave a note before buying (kind of “lock”)
- Remove note after buying (kind of “unlock”)
- Don’t buy if note (wait)

Suppose a computer tries this
(remember, only memory read/write are atomic)

```
if   (noMilk)   {
     if   (noNote)
     {
          leave   Note;
          buy  milk;
          remove note;
     }
}
```



Too Much Milk: Solution #1

Thread A

```
if  (noMilk) {
    if  (noNote) {
        leave Note;

        buy Milk;
        remove Note;
}   }
```

Thread B

```
if  (noMilk) {
    if  (noNote) {

        leave Note;
        buy Milk;
        remove Note;
    }
}
```

Too Much Milk: Solution #1

Still too much milk but only occasionally!

Thread can get context switched after checking milk and note but before leaving notes!

Too Much Milk: Solution #2

Let's try to fix this by placing note first

```
leave  Note;
if  (noMilk)  {
    if  (noNote)  {
        buy  milk;
    }
}
remove Note;
```

What happens here?

– Well, with human, probably nothing bad

– With computer: no one ever buys milk

Too Much Milk: Solution #3

Recall our target lock interface:
- acquire(&milklock) – wait until lock is free, then grab
- release(&milklock) – Unlock, waking up anyone waiting
– These must be atomic operations – if two threads are waiting for the lock and both see it's free, only one succeeds to grab the lock

Then, our milk problem is easy:

```
acquire(&milklock);
if (nomilk)
    buy milk;
release(&milklock);
```

Mutex: more

- Mutex procedures
  - create a mutex variable (initially unlocked)
  - (some threads) attempt to lock the mutex
    - only one can lock the mutex
      - others may be blocked and waiting
    - the one with the mutex
      - execute the critical section
      - unlock the mutex variable eventually
  - destroy the mutex variable

Mutex with pthread

- Create mutex
  - int pthread_mutex_init (mutex, attributes);
- Attempt to lock
  - int pthread_mutex_lock (mutex);
    - if unlocked, lock and return immediately
    - if locked
      - “fast” lock: blocked until the mutex is unlocked
      - “test” lock: return immediately with error
      - “recursive” lock: “over”-lock
        - » multiple pthread_mutex_unlock() to unlock

https://computing.llnl.gov/tutorials/pthreads/

Mutex with pthread: more

- Try to lock
  - int pthread_mutex_trylock (mutex);
    - if locked, return immediately with error code
- Unlock
  - int pthread_mutex_unlock (mutex);
    - if “recursive” lock, multiple pthread_mutex_unlock necessary to fully unlock the mutex
- Destroy mutex
  - int pthread_mutex_destroy (mutex);

Condition variable

- Used **together** with mutex
  - mutex: control access to shared data
  - condition: synchronize by condition “predict”
- Wait for condition
  - pthread_cond_wait (condition, mutex);
    - automatically unlock and wait for signal
    - on signal, wake up and automatically lock
- Signal or broadcast
  - pthread_cond_signal (condition);

Example: mutex and condition

- Main thread
  - global variable
  - create mutex and condition variable

- Wait to be signaled
  - pthread_mutex_lock();
  - pthread_cond_wait();
  - … /* run me next */
  - pthread_mutex_unlock();

- Send the signal
  - pthread_mutex_lock();
  - … /* run me first */
  - pthread_cond_signal();
  - pthread_mutex_unlock();

This lecture

- Mutex and condition
  - mutex: binary access control
    - locked or unlocked
  - condition: access control by condition
    - used together with mutex
- Explore further
  - more details in

    http://computing.llnl.gov/tutorials/pthreads/

    * also a tutorial coming soon

Next half of the lecture

- CPU scheduling
  - Another chapter in the textbook