Reminders

- Homework 3 due next Monday
  - Synchronization
- Project 2 parts 1,2,3 due next Wednesday
  - Threads, synchronization
- Office hour at 3:30, not 4:30 today

- Today:
  - Project 2 continued (parts 2,3)
  - Synchronization

Project 2 Part 1 Questions

- Any questions about part 1?
- Some common issues:
  - sthread_create doesn't immediately run the new thread
  - sthread_exit can ignore its ret argument
  - How do you clean up an exiting thread?
    - Must switch to another thread
    - Clean up in all places after sthread_switch()
    - Have a special GC thread

Synchronization Solutions

High-level
- Monitors
- Java synchronized method

OS-level support
- Special variables – mutexes, semaphores, condition vars
- Message passing primitives

Low-level support
- Disable/enable interrupts
- Atomic instructions

Disabling/Enabling Interrupts

```
Thread A:
        disable_interrupts()
        critical_section()
        enable_interrupts()
```

```
Thread B:
        disable_interrupts()
        critical_section()
        enable_interrupts()
```

- Prevents context-switches during execution of CS
- Sometimes necessary
  - E.g. to prevent further interrupts during interrupt handling
- Many problems

Hardware support

- Atomic instructions:
  - Test and set
  - Swap
  - Compare-exchange (x86)
  - Load-linked store conditional (MIPS, Alpha, PowerPC)
- Use these to implement higher-level primitives
  - E.g. test-and-set on x86 (given to you for part 4) is written using compare-exchange.
    - compare_exchange(lock_t *x,int y,int z):

```
if(*x == y)
      *x = z;
      return y;
else
      return *x;
```

    - test_and_set(lock_t *l) {

```
}
```


Looking ahead: preemption

- You can start inserting synchronization code
  - disable/enable interrupts
  - atomic_test_and_set
- Where would you use these?

  - Example:

```
...
nextTCB = sthread_dequeue(readyQ);
switch to nextTCB;
...
```

Semaphore review

- Semaphore = a special *variable*
  - Manipulated atomically via two operations:
    - P (wait)
    - V (signal)
- Has a counter = number of available resources
  - P decrements it
  - V increments it
- Has a queue of waiting threads
  - If execute wait() and semaphore is free, continue
  - If not, block on that waiting queue
- signal() unblocks a thread if it's waiting

Synchronization in Project 2

- Part 2: write two synchronization primitives
- Implement mutex (binary semaphore)
  - How is it different from spinlock?
  - Need to keep track of lock state
  - Need to keep waiting threads on a queue
  - In **lock**(), may need to block current thread
    - Don't put on ready queue
    - Do run some other thread
  - For **unlock**(), need to take a thread off the waiting queue if available

Condition Variable

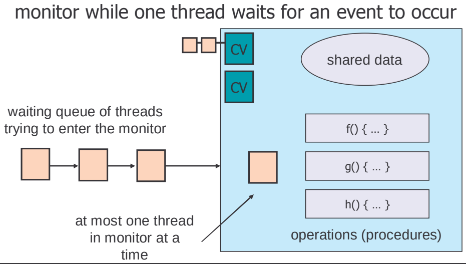
- A "place" to let threads wait for a certain event to occur while holding a lock (often a monitor lock).
- It has:
  - Wait queue
  - Three functions: *wait*, *signal*, and *broadcast*
    - *wait* – sleep until the event happens
    - *signal* – event/condition has occurred. If wait queue nonempty, wake up *one* thread, otherwise *do nothing*
      - Do not run the woken up thread right away
      - FIFO determines who wakes up
    - *broadcast* – just like *signal*, except wake up all threads
  - In part 2, you implement all of these

Condition Variables 2

- How are CVs different from semaphores?
- More about
  `cond_wait(sthread_cond_t cond, sthread_mutex_t lock)`
  - Called while holding **`lock`**!
  - Should do the following atomically:
    - Release the lock (to allow someone else to get in)
    - Add current thread to the waiters for `cond`
    - Block thread until awoken
  - After woken up, a thread should reacquire its lock before continuing
- Good explanation: **`man pthread_cond_wait`**
  - We follow the same spec for wait, signal, bcast

Monitors: preview

- One thread inside at a time
- Lock + a bunch of condition variables (CVs)
- CVs used to allow other threads to access the monitor while one thread waits for an event to occur



Part 3 problem

- N cooks produce burgers & place on stack
- M students grab burgers and eat them
- Provide correct synchronization
  - Check with your threads and pthreads!
- Print out what happens!
- sample output (rough draft):

```
…
cook 2 produces burger #5
cook 2 produces burger #6
cook 3 produces burger #7
student 1 eats burger #7
student 2 eats burger #6
cook 1 produces burger #8
student 1 eats burger #8
student 1 eats burger #5
…
```

Miscellaneous

- Synchronization is necessary when multiple threads access the same shared data
- Can't use some primitives in interrupt handlers
  - Why? Which ones?
- Don't forget to release lock, semaphore, etc
  - **Check all paths**
- Synchronization bugs can be very difficult to find
  - Read your code

Sample synchronization problem

Late-Night Pizza

- A group of students study for cse451 exam
- Can only study while eating pizza
- Each student thread executes the following:
  - ```
    while (1) {
      pick up a piece of pizza;
      study while eating the pizza;
    }
    ```
- If a student finds pizza is gone, the student goes to sleep until another pizza arrives
- First student to discover pizza is gone orders a new one.
- Each pizza has S slices.

Late-Night Pizza

- Synchronize student threads and pizza delivery thread
- Avoid deadlock
- When out of pizza, order it exactly once
- No piece of pizza may be consumed by more than one student

Semaphore solution

```
shared data:
    semaphore pizza;  (counting sema, init to 0, represent
                       number of available pizza resources)
    semaphore deliver; (init to 1)
    int num_slices = 0;
    semaphore mutex; (init to 1) // guard updating of num_slices
```

```
Student {
   while (diligent) {
       P(pizza);
       P(mutex);
       num_slices--;
       if (num_slices==0)
         // took last slice
         V(deliver);
       V(mutex);
       study();
   }
}
```

```
DeliveryGuy {
   while(employed) {
      P(deliver);
      make_pizza();
      P(mutex);
      num_slices=S;
      V(mutex);
      for (int i=0,i<S,i++) {
         V(pizza);
      }
   }
}
```


Condition Variable Solution

```
int slices=0;
Condition order, deliver;
Lock mutex;
bool first = true;
```

```
Student() {
  while(diligent) {
    mutex.lock();
    if( slices > 0 ) {
      slices--;
    }
    else {
      if(first) {
        order.signal(mutex);
        first = false;
      }
      deliver.wait(mutex);
    }
    mutex.unlock();
    Study();
  }
}
```

```
DeliveryGuy() {
  while(employed) {
    mutex.lock();
    order.wait(mutex);
    makePizza();
    slices = S;
    first=true;
    mutex.unlock();
    deliver.broadcast();
  }
}
```
```