Reminders

- Homework 3 due Monday, Oct. 25
  - Synchronization
- Project 2 parts 1,2,3 due Tuesday, Oct. 26
  - Threads, synchronization
- Today:
  - Project 2 continued (parts 2,3)
  - Synchronization

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Project 2 Part 1 Questions

- Anything about writing user threads?
- Recall that:
  - stread_create doesn't immediately run the new thread
  - sthread_exit can ignore its ret argument
- Recall how stacks are allocated
  - `sthread_new_ctx` – creates a new stack and makes it ready to run after first context switch
  - `sthread_new_blank_ctx` – create new stack but don't initialize. Suitable to use as `old` parameter to switch().
- Read .h files for function specs!

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Synchronization

- Why do we need it?
  - ensure correct and efficient cooperation
  - Prevent race conditions
- How?
  - Protect code in critical sections
    - Allow at most one process/thread in critical section
    - Maintain fairness & progress
    - Don't make deadlocks

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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

+ Software algorithms …

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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
- In Linux: cli(), sti()
- Sometimes necessary
  - E.g. to prevent further interrupts during interrupt handling
- Problems?

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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:

```
int atomic_test_and_set(lock_t *l) {
  int val;
  _asm {
    mov edx, dword ptr [l]    ; Get the pointer to l
    mov ecx, 1                ; load 1 into the cmpxchg source
    mov eax, 0                ; load 0 into the accumulator
                                      ; if l == 0 then
    lock cmpxchg dword ptr [edx], ecx ;   l = 1 (and eax = 0)
                                      ; else
                                      ;   l = 1 (and eax = 1)
    mov val, eax              ; set eax to be the return val
  }
  return val;
}
```

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Software algorithms

- book, p. 193
- Example algorithm for two processes 0 and 1, P_i does this:

```
while(1) {
   while(turn != i) ;
   <critical section>
   turn = 1-i;
}
```

- What's wrong with it?

Hyman's Algorithm

```
  bool flag[2];
  int turn;
  void Protocol(int id) {
     while(true) {
1       flag[id] = true;
2       while(turn != id) {
3          while(flag[1-id])
4             ; /* Spin */
5          turn = id;
        }
6       <Critical Section>
7       flag[id] = false;
8       <rest of code>
     }
  }
```

- Two processes: P0, P1
- flag initialized to {false, false}, turn to 0
- "Elegant"
- **Wrong – why?**

Hyman's Algorithm

```
  bool flag[2];
  int turn;
  void Protocol(int id) {
     while(true) {
1       flag[id] = true;
2       while(turn != id) {
3          while(flag[1-id])
4             ; /* Spin */
5          turn = id;
        }
6       <Critical Section>
7       flag[id] = false;
8       <rest of code>
     }
  }
```

- P1 executes 1, 2, 3
- P0 executes 1, 2, 6
- P1 executes 5, 6

Timeline:

```
P1 | P0
   |
1  |       flag[1]==true
2  |
3  |
   | 1     flag[0]==true
   | 2
   | 6
5  |       turn==1
6  |  mutual exclusion
      has been violated
```


Semaphore review

- Semaphore = a special *variable*
  - Manipulated atomically via two operations:
    - P (wait)
    - V (signal)
  - To access critical section:
    - P(sema)
    - <critical section>
    - V(sema)
- Has a counter = number of available resources
- 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 condition or event to occur while holding a lock (often a monitor lock).
- It has:
  - Wait queue
  - Three functions: *wait*, *signal*, and *broadcast*
    - *wait* – sleep until condition becomes true.
    - *signal* – event/condition has occurred. If wait queue nonempty, wake up *one* thread, o.w. *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 (not just one).
  - In part 2, you implement all of these

Condition Variables 2

- 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
- How are CVs different from semaphores?
- More info: **`man pthread_cond_wait`**
  - We follow the same spec for wait, signal, bcast

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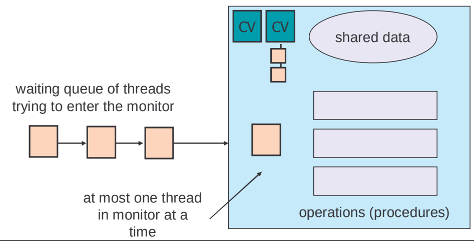
Monitors: preview

- 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



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No preemption

- You get atomic critical sections for free
- However, you should understand what to do if you had preemption
  - *Mark critical sections* with comments
  - Describe appropriate protection that might apply (e.g. spinlock).

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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
…

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Synchronization – Important Points

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

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Homework questions?

- Sleeping barber problem
- Cigarette-smoker problem

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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 student finds pizza is gone, the student goes to sleep until another pizza arrives
- First student to discover pizza is gone phones Pizza Hut and orders a new one.
- Each pizza has S slides.

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);
       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;
    deliver.broadcast(mutex);
    mutex.unlock();
  }
}
```