CSE 451: Operating Systems

Section 5:
Synchronization

Project 2a is due on Wednesday

* Review the `sthread` code that we give you
  * If a function is there, then there is probably a good reason why
* Remember to write more test cases
* `test-burgers`: your shell may limit the number of threads you can run
  * **ulimit –u**
* Has anybody found bugs in the 64-bit code yet?

Synchronization

Synchronization support

* Processor level:
  * Disable / enable interrupts
  * Atomic instructions
* Operating system / library level:
  * Special variables: mutexes, semaphores, condition variables
* Programming language level:
  * Monitors, Java synchronized methods

Disabling / enabling interrupts

```
Thread A:                Thread B:
  disable_irq()            disable_irq()
  critical_section()       critical_section()
  enable_irq()             enable_irq()
```

- Prevents context-switches during execution of critical sections
- Sometimes necessary
- Many pitfalls

Processor support

- Atomic instructions:
  - test-and-set
  - compare-exchange (x86)
- Use these to implement higher-level primitives
  - E.g. test-and-set on x86 (given to you for part 5) is written using compare-exchange
  - You'll use test-and-set when implementing mutexes and condition variables (part 5)

Processor support

- Test-and-set 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 *lock) {
  ???
}
```


Processor support

- Test-and-set 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 *lock) {
  compare_exchange(lock, 0, 1);
}
```

Preemption

- You will need to use test-and-set and interrupt disabling in part 5 of project 2 (preemption)
  - You can start thinking about this while completing the code for the first 2 parts: where are the critical sections where I shouldn't be interrupted?

Semaphores

- Semaphore = a special variable
  - Manipulated atomically via two operations
    - P (wait): tries to decrement semaphore
    - V (signal): increments semaphore
  - Has a *queue* of waiting threads
    - If execute wait() and semaphore is available, continue
    - If not, block on the waiting queue
    - signal() unblocks a thread on queue

Mutexes

- What is a mutex?
  - A binary semaphore (semaphore initialized with value 1)
- Why use a mutex rather than a low-level lock?
  - Threads wait on a mutex by *blocking*, rather than *spinning*

How *not* to implement mutexes

- Definitely not like this:

```
void sthread_user_mutex_lock(
          sthread_mutex_t lock) {
  while (lock->held) { ; }
  lock->held = true;
}
```

- And also not like this:

```
void sthread_user_mutex_lock(
          sthread_mutex_t lock) {
  while (lock->held) {
    yield();
  }
  lock->held = true;
}
```

Condition variables

- Let threads block until a certain *event* or *condition* occurs (rather than polling)
- Associated with some logical *condition* in a program:

```
sthread_mutex_lock(lock);
while (x <= y) {
  sthread_cond_wait(cond, lock);
}
sthread_mutex_unlock(lock);
```


Condition variables

- Operations:
  - `wait`: sleep on wait queue until event happens
  - `signal`: wake up *one* thread on wait queue
  - `broadcast`: wake up *all* threads on wait queue
- `signal` or `broadcast` is called explicitly by the application when the event / condition occurs

Condition variables

```
sthread_user_cond_wait(sthread_cond_t cond,
  sthread_mutex_t 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 (by signal/broadcast)
- So, application must acquire `lock` before calling `wait()`!
- Read man page for
  `pthread_cond_[wait|signal|broadcast]`

Example synchronization problem

- Late-Night Pizza
  - A group of students study for CSE 451 exam
  - Can only study while eating 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

* Each student thread executes the following:

```
while (must_study) {
  pick up a piece of pizza;
  study while eating the pizza;
}
```


Late-night pizza

* Need to *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 / mutex solution

* Shared data:

```
semaphore_t pizza;    //Number of
                      //available pizza
                      //resources;
                      //init to 0

semaphore_t deliver;  //init to 1

int num_slices = 0;

mutex_t mutex;        //protects accesses
                      //to num_slices
```



```
student_thread {
  while (must_study) {
    wait(pizza);

    acquire(mutex);
    num_slices--;
    if (num_slices==0)
      signal(deliver);
    release(mutex);

    study();
  }
}
```

```
delivery_guy_thread {
  while (employed) {
    wait(deliver);

    make_pizza();

    acquire(mutex);
    num_slices=S;
    release(mutex);

    for (i=0;i<S;i++)
      signal(pizza);
  }
}
```

Condition variable solution

∗ Shared data:

```
int slices=0;
bool has_been_ordered;
Condition order;        //an order has
                        //been placed

Condition deliver;      //a delivery has
                        //been made

Lock mutex;             //protects
                        //"slices";
                        //associated with
                        //both Condition
                        //variables
```



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

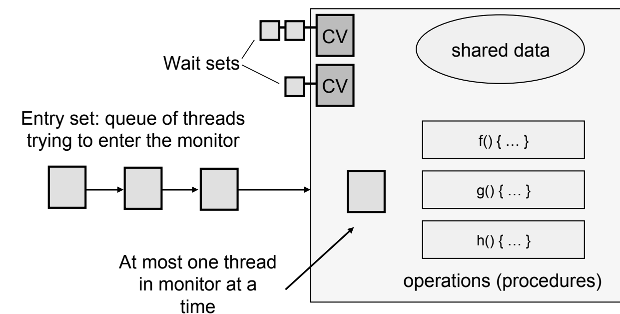
```
DeliveryGuy() {
  while(employed) {
    mutex.lock();
    order.wait(mutex);
    makePizza();
    slices = S;
    has_been_ordered =
      false;
    mutex.unlock();
    deliver.broadcast();
  }
}
```


Monitors

∗ An object that allows one thread inside at a time

∗ Contain a lock and some condition variables
  ∗ Condition variables used to allow other threads to access the monitor while one thread waits for an event to occur

Monitors



Midterm!

The kernel

- Kernel mode vs user mode
  - How these modes differ conceptually and from the CPU's point of view
  - How we switch between the two
- Interrupts

System calls

- What they are
- What they do
- How they do it
- What hardware is involved
- Who uses them and when

Processes and threads

- Kernel processes, kernel threads, and user threads
  - How these differ from one another
- Context switching
- Process and thread states
- fork, exec, wait

Synchronization

* Critical sections
* Locks and atomic instructions
* Mutexes, semaphores, and condition variables
* Monitors and how they are implemented
* Ways to detect / avoid deadlock

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Scheduling

* Different scheduling algorithms and their tradeoffs
* Average response time, various "laws"
* Starvation
* Cooperative vs. preemptive scheduling

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Tips

* Focus on lecture slides
* Review textbook, section slides and project writeups to emphasize key concepts and fill in gaps
* On Monday, when taking the exam:
  * Arrive early
  * Focus on key points
  * Work quickly; finish easy problems first

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