CSE 451: Operating Systems

Section 5

Synchronization

Project 1 Recap

* Tips:
  * Check flags with &, not ==
  * Use constants for printed strings
    `#define PROMPT "CSE451Shell>"`
  * Use errno/perror(3) for error detection
* To make grading easier:
  * Preserve the build hierarchy/commands
  * Check your files before turnin!

Project 2.a is almost due

* Remember to write more test cases!
* Writeups:
  * Design decisions & alternative implementations: give them some real thought
  * Be mindful of what you use as a resource (and how much)
    * We expect you to research, but we expect you to fumble around a little too

Synchronization

Synchronization support

* Processor level:
  * Disable/enable interrupts
  * Atomic instructions (test-and-set)
* Operating system 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 4) is written using compare-exchange

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);
}
```


Project 2: preemption

* Think about where synchronization is needed
* Start inserting synchronization code
  * disable/enable timer interrupts
  * atomic_test_and_set

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

*

Mutexes

* A binary semaphore (semaphore initialized with value 1)
* A lock that waits by blocking, rather than spinning

Aside: kernel locking

* Can we use mutexes inside our kernel?

Aside: kernel locking

* Can we use mutexes inside our kernel?
  * Sometimes…
  * Spinlocks more common than semaphores/ mutexes in Linux
* Reader-writer locks (rwlocks):
  * Allow multiple readers or single writer
  * Good idea?
    * http://lwn.net/Articles/364583/

Condition variables

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

```
while (x <= y) {
   sthread_user_cond_wait(cond, lock)
}
```


Condition variables

* Operations:
  * wait: sleep on wait queue until event happens
  * signal: wake up *one* thread on wait queue
    * Explicitly called when event/condition has occurred
  * broadcast: wake up *all* threads on wait queue

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, 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

* 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;        //guards updating of
                      //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
```



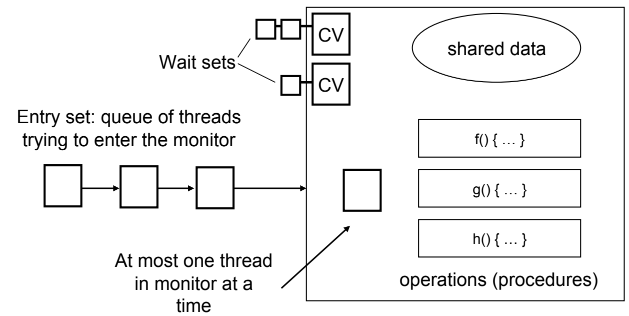
```
Student() {
  while(diligent) {
    mutex.lock();
    if (slices > 0) {
      slices--;
    }
    else {
      if (!has_been_ordered){
        order.signal(mutex);
        has_been_ordered =
          true;
      }
      deliver.wait(mutex);
    }
    mutex.unlock();
    Study();
  }
}
```

```
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



Monitors in Java

* Each object has its own monitor
```
Object o
```
* The Java monitor supports two types of synchronization:
  * Mutual exclusion
```
synchronized(o) { … }
```
  * Cooperation
```
synchronized(o) { O.wait(); }
synchronized(o) { O.notify(); }
```


Semaphores vs. CVs

Semaphores	Condition variables
* Used in apps	* Typically used in monitors
* wait() does not always block the caller	* wait() always blocks caller
* signal() either releases a blocked thread, if any, or increases semaphore counter	* signal() either releases a blocked thread, if any, or the signal is lost forever