Section 5

Synchronization primitives

(Many slides taken from Winter 2006)

1

Announcements

- Assignment grades online
  - Please check them and report bugs to TAs
- Mailing list for TAs:
  - cse451-tas@cs.washington.edu
  - Faster response time
- Late project 0s were not downgraded
  - Next ones will!
- Hand homework 2 back
- Any questions?? (project 2, class, midterm)

2

Synchronization

High-level
- Monitors
- Java synchronized method

OS-level support
- Special variables – mutex, futex, semaphor, condition var
- Message passing primitives

Low-level support
- Disable/enable interrupts
- Atomic instructions (test_and_set)

3

Disabling/Enabling Interrupts

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

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

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

4

Disabling/Enabling Interrupts

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

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

- Prevents context-switches during execution of critical sections
- Sometimes necessary
  - E.g. to prevent further interrupts during interrupt handling
- Many problems
  - E.g., an interrupt may be shared
  - How does it work on multi-processors?

5

Hardware 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:
    - 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) {
```
      ?
}
```

6

Looking ahead: preemption

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

7

Synchronization

High-level
- Monitors
- Java synchronized method

OS-level support
- Special variables – mutex, futex, semaphor, condition var
- Message passing primitives

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

- Used to implement higher-level sync primitives (in the kernel typically)
- Why not use in apps?

8

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
- Mutex is bi-value semaphore (capacity 1)

9

Condition Variable

- A "place" to let threads wait for a certain event to occur while holding a 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
- Typically associated with some logical condition in program

10

Condition Variable (2)

- **`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
  - Read man page for **`pthread_cond_[wait|signal|broadcast]`**
  - Must be called while holding **`lock`**! -- Why?

11

Semaphores vs. CVs

12

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 sem. counter.	Signal() either releases blocked thread(s), if any, or the signal is lost forever.

13

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 (must_study) {
   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.

14

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

15

Semaphore / mutex solution

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

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

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

16

Condition Variable Solution

```
int slices=0;
Condition order, deliver;
Lock mutex;
bool has_been_ordered = false;
```

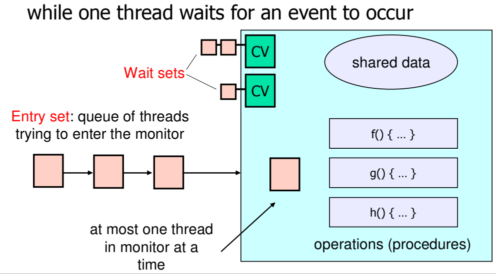
```
Student() {
  while(diligent) {
    mutex.lock();
    if( slices > 0 ) {
      slices--;
    }
    else {
      if( !has_been_ordered ) {
        order.signal(mutex);
        has_been_ordered = true;
      }
      deliver.wait(mutex);
    }
    mutex.unlock();
    Study();
  }
}
```

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

17

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



18

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(); }
    ```