Threads and Concurrency

Lecture 20 – CS2110 – Fall 2008

Prelim 2 Reminder

- Prelim 2
  - Tuesday 18 Nov, 7:30-9pm
  - Uris Auditorium
  - One week from today!
  - Topics: all material up to and including this week's lectures
  - Includes graphs
- Exam conflicts
  - Email Kelly Patwell (ASAP)
- Prelim 2 Review Session
  - Sunday 4/15,1:30-3pm
  - Upson B17
  - Individual appointments are available if you cannot attend the review session (email *one* TA to arrange appointment)
- Old exams are available for review on the course website

Prelim 2 Topics

- Asymptotic complexity
- Searching and sorting
- Basic ADTs
  - stacks
  - queues
  - sets
  - dictionaries
  - priority queues
- Basic data structures used to implement these ADTs
  - arrays
  - linked lists
  - hash tables
  - binary search trees
  - heaps
- Know and understand the sorting algorithms
  - From lecture
  - From text (not Shell Sort)
- Know the algorithms associated with the various data structures
  - Know BST algorithms, but don't need to memorize *balanced* BST algorithms
- Know the runtime tradeoffs among data structures
- Don't worry about details of API
  - But should have basic understanding of what's available

Prelim 2 Topics

- Language features
  - inheritance
  - inner classes
  - anonymous inner classes
  - types & subtypes
  - iteration & iterators
- GUI statics
  - layout managers
  - components
  - containers
- GUI dynamics
  - events
  - listeners
  - adapters

Data Structure Runtime Summary

- Stack [ops = put & get]
  - O(1) worst-case time
    - Array (but can overflow)
    - Linked list
  - O(1) time/operation
    - Array with doubling
- Queue [ops = put & get]
  - O(1) worst-case time
    - Array (but can overflow)
    - Linked list (need to keep track of both head & last)
  - O(1) time/operation
    - Array with doubling
- Priority Queue [ops = insert & getMin]
  - O(1) worst-case time if set of priorities is bounded
    - One queue for each priority
  - O(log n) worst-case time
    - Heap (but can overflow)
  - O(log n) time/operation
    - Heap (with doubling)
  - O(n) worst-case time
    - Unsorted linked list
    - Sorted linked list (O(1) for getMin)
    - Unsorted array (but can overflow)
    - Sorted array (O(1) for getMin, but can overflow)

Data Structure Runtime Summary (Cont'd)

- Set [ops = insert & remove & contains]
  - O(1) worst-case time
    - Bit-vector (can also do union and intersect in O(1) time)
  - O(1) expected time
    - Hash table (with doubling & chaining)
  - O(log n) worst-case time
    - Balanced BST
  - O(n) worst-case time
    - Linked list
    - Unsorted array
    - Sorted array (O(log n) for contains)
- Dictionary [ops = insert(k,v) & get(k) & remove(k)]
  - O(1) expected time
    - Hash table (with doubling & chaining)
  - O(log n) worst-case time
    - Balanced BST
  - O(log n) expected time
    - Unbalanced BST (if data is sufficiently random)
  - O(n) worst-case time
    - Linked list
    - Unsorted array
    - Sorted array (O(log n) for contains)

What is a Thread?

- A separate process that can perform a computational task independently and concurrently with other threads
  - Most programs have only one thread
  - GUIs have a separate thread, the *event dispatching thread*
  - A program can have many threads
  - You can create new threads in Java

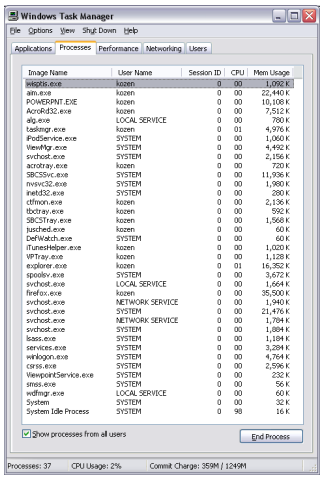
What is a Thread?

- In reality, threads are an illusion
  - The processor shares its time among all the active threads
  - Implemented with support from underlying operating system or virtual machine
  - Gives the illusion of several threads running simultaneously

Concurrency (aka Multitasking)

- Refers to situations in which several threads are running simultaneously
- Special problems arise
  - race conditions
  - deadlock

- The operating system provides support for multitasking
- In reality there is one processor doing all this
- But this is an illusion too – at the hardware level, lots of multitasking
  - memory subsystem
  - video controller
  - buses
  - instruction prefetching



Threads in Java

- Threads are instances of the class **`Thread`**
  - can create as many as you like
- The Java Virtual Machine permits multiple concurrent threads
  - initially only one thread (executes **`main`**)
- Threads have a priority
  - higher priority threads are executed preferentially
  - a newly created **`Thread`** has initial priority equal to the thread that created it (but can change)

Creating a new Thread (Method 1)

```
class PrimeThread extends Thread {
   long a, b;

   PrimeThread(long a, long b) {
      this.a = a; this.b = b;
   }

   public void run() {
      //compute primes between a and b
      ...
   }
}
```

overrides **`Thread.run()`**

can call **`run()`** directly – the calling thread will run it

```
PrimeThread p = new PrimeThread(143, 195);
p.start();
```

or, can call **`start()`** – will run **`run()`** in new thread

Creating a new Thread (Method 2)

```
class PrimeRun implements Runnable {
   long a, b;

   PrimeRun(long a, long b) {
      this.a = a; this.b = b;
   }

   public void run() {
      //compute primes between a and b
      ...
   }
}
```

```
PrimeRun p = new PrimeRun(143, 195);
new Thread(p).start();
```


Example

```
public class ThreadTest extends Thread {

   public static void main(String[] args) {
      new ThreadTest().start();
      for (int i = 0; i < 10; i++) {
         System.out.format("%s %d\n",
            Thread.currentThread(), i);
      }
   }

   public void run() {
      for (int i = 0; i < 10; i++) {
         System.out.format("%s %d\n",
            Thread.currentThread(), i);
      }
   }
}
```

```
Thread[Thread-0,5,main] 0
Thread[main,5,main] 0
Thread[main,5,main] 1
Thread[main,5,main] 2
Thread[main,5,main] 3
Thread[main,5,main] 4
Thread[main,5,main] 5
Thread[main,5,main] 6
Thread[main,5,main] 7
Thread[main,5,main] 8
Thread[main,5,main] 9
Thread[Thread-0,5,main] 1
Thread[Thread-0,5,main] 2
Thread[Thread-0,5,main] 3
Thread[Thread-0,5,main] 4
Thread[Thread-0,5,main] 5
Thread[Thread-0,5,main] 6
Thread[Thread-0,5,main] 7
Thread[Thread-0,5,main] 8
Thread[Thread-0,5,main] 9
```


Example

```
public class ThreadTest extends Thread {

   public static void main(String[] args) {
      new ThreadTest().start();
      for (int i = 0; i < 10; i++) {
         System.out.format("%s %d\n",
            Thread.currentThread(), i);
      }
   }

   public void run() {
      currentThread().setPriority(4);
      for (int i = 0; i < 10; i++) {
         System.out.format("%s %d\n",
            Thread.currentThread(), i);
      }
   }
}
```

```
Thread[main,5,main] 0
Thread[main,5,main] 1
Thread[main,5,main] 2
Thread[main,5,main] 3
Thread[main,5,main] 4
Thread[main,5,main] 5
Thread[main,5,main] 6
Thread[main,5,main] 7
Thread[main,5,main] 8
Thread[main,5,main] 9
Thread[Thread-0,4,main] 0
Thread[Thread-0,4,main] 1
Thread[Thread-0,4,main] 2
Thread[Thread-0,4,main] 3
Thread[Thread-0,4,main] 4
Thread[Thread-0,4,main] 5
Thread[Thread-0,4,main] 6
Thread[Thread-0,4,main] 7
Thread[Thread-0,4,main] 8
Thread[Thread-0,4,main] 9
```


Example

```
public class ThreadTest extends Thread {

   public static void main(String[] args) {
      new ThreadTest().start();
      for (int i = 0; i < 10; i++) {
         System.out.format("%s %d\n",
            Thread.currentThread(), i);
      }
   }

   public void run() {
      currentThread().setPriority(6);
      for (int i = 0; i < 10; i++) {
         System.out.format("%s %d\n",
            Thread.currentThread(), i);
      }
   }
}
```

```
Thread[main,5,main] 0
Thread[main,5,main] 1
Thread[main,5,main] 2
Thread[main,5,main] 3
Thread[main,5,main] 4
Thread[main,5,main] 5
Thread[Thread-0,6,main] 0
Thread[Thread-0,6,main] 1
Thread[Thread-0,6,main] 2
Thread[Thread-0,6,main] 3
Thread[Thread-0,6,main] 4
Thread[Thread-0,6,main] 5
Thread[Thread-0,6,main] 6
Thread[Thread-0,6,main] 7
Thread[Thread-0,6,main] 8
Thread[Thread-0,6,main] 9
Thread[main,5,main] 6
Thread[main,5,main] 7
Thread[main,5,main] 8
Thread[main,5,main] 9
```


Example

```
public class ThreadTest extends Thread {
   static boolean ok = true;

   public static void main(String[] args) {
      new ThreadTest().start();
      for (int i = 0; i < 10; i++) {
         System.out.println("waiting...");
         yield();
      }
      ok = false;
   }

   public void run() {
      while (ok) {
         System.out.println("running...");
         yield();
      }
      System.out.println("done");
   }
}
```

allows other waiting threads to run

```
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
done
```


Stopping Threads

- Threads normally terminate by returning from their run method
- `stop()`, `interrupt()`, `suspend()`, `destroy()`, etc. are all deprecated
  - can leave application in an inconsistent state
  - inherently unsafe
  - don't use them
  - instead, set a variable telling the thread to stop itself

Daemon and Normal Threads

- A thread can be *daemon* or *normal*
  - the initial thread (the one that runs `main`) is normal
- Daemon threads are used for minor or ephemeral tasks (e.g. timers, sounds)
- A thread is initially a daemon iff its creating thread is
  - but this can be changed
- The application halts when either
  - `System.exit(int)` is called, or
  - all normal (non-daemon) threads have terminated

Race Conditions

- A *race condition* can arise when two or more threads try to access data simultaneously
- Thread B may try to read some data while thread A is updating it
  - updating may not be an atomic operation
  - thread B may sneak in at the wrong time and read the data in an inconsistent state
- Results can be unpredictable!

Example – A Lucky Scenario

```
private Stack<String> stack = new Stack<String>();

public void doSomething() {
   if (stack.isEmpty()) return;
   String s = stack.pop();
   //do something with s...
}
```

Suppose threads A and B want to call `doSomething()`, and there is one element on the stack

1. thread A tests `stack.isEmpty()` ⇒ false
2. thread A pops ⇒ stack is now empty
3. thread B tests `stack.isEmpty()` ⇒ true
4. thread B just returns – nothing to do

Example – An Unlucky Scenario

```
private Stack<String> stack = new Stack<String>();

public void doSomething() {
   if (stack.isEmpty()) return;
   String s = stack.pop();
   //do something with s...
}
```

Suppose threads A and B want to call `doSomething()`, and there is one element on the stack

1. thread A tests `stack.isEmpty()` ⇒ false
2. thread B tests `stack.isEmpty()` ⇒ false
3. thread A pops ⇒ stack is now empty
4. thread B pops ⇒ Exception!

Solution – Locking

```
private Stack<String> stack = new Stack<String>();

public void doSomething() {
   synchronized (stack) {
      if (stack.isEmpty()) return;
      String s = stack.pop();
   }
   //do something with s...
}
```

`synchronized` block

- Put critical operations in a `synchronized` block
- The `stack` object acts as a lock
- Only one thread can own the lock at a time

Solution – Locking

- You can lock on any object, including `this`

```
public synchronized void doSomething() {
   ...
}
```

is equivalent to

```
public void doSomething() {
   synchronized (this) {
      ...
   }
}
```

File Locking

- In file systems, if two or more processes could access a file simultaneously, this could result in data corruption
- A process must *open* a file to use it – gives exclusive access until it is *closed*
- This is called *file locking* – enforced by the operating system
- Same concept as **`synchronized(obj)`** in Java

Deadlock

- The downside of locking – *deadlock*
- A *deadlock* occurs when two or more competing threads are waiting for the other to relinquish a lock, so neither ever does
- Example:
  - thread A tries to open file X, then file Y
  - thread B tries to open file Y, then file X
  - A gets X, B gets Y
  - Each is waiting for the other forever

`wait/notify`

- A mechanism for event-driven activation of threads
- Animation threads and the **`GUI`** event-dispatching thread in can interact via **`wait/notify`**

`wait/notify`

`animator:`

```
boolean isRunning = true;

public synchronized void run() {
   while (true) {
      while (isRunning) {
         //do one step of simulation
      }
      try {
         wait();
      } catch (InterruptedException ie) {}
      isRunning = true;
   }
}
```

relinquishes lock on **`animator`** – awaits notification

```
public void stopAnimation() {
   animator.isRunning = false;
}

public void restartAnimation() {
   synchronized(animator) {
      animator.notify();
   }
}
```

notifies processes waiting for **`animator`** lock