THREADS AND CONCURRENCY

Lecture 20 – CS2110 – Fall 2009

Prelim 2 Reminder

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- Prelim 2
  - Tuesday 16 Nov, 7:30-9pm
  - Uris G01 Auditorium
  - Ten days from today!
  - Topics: all material up to and including this week's lectures
  - Includes graphs
- Exam conflicts
  - You'll take the exam early, at 6pm, in the same place

Prelim 2 Topics

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- 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

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- 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

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- 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)

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- 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?

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- 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?

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- On many machines, threads are an illusion
  - Not all machines have multiple processors
  - But a single processor can share 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
- But modern computers often have "multicore" architectures: multiple CPUs on one chip

Why Multicore?

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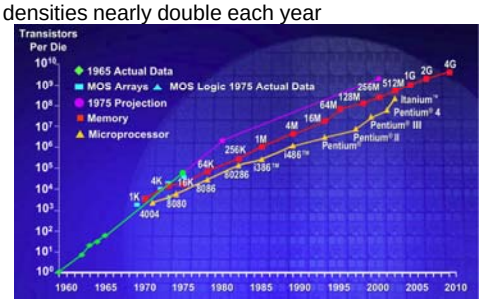
- Moore's Law: Computer speeds and memory densities nearly double each year



But a fast computer runs hot

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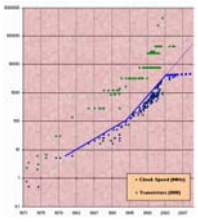
- Power dissipation rises as the square of the CPU clock rate
- Chips were heading towards melting down!
- Multicore: with four CPUs (cores) on one chip, even if we run each at half speed we get more overall performance!



Concurrency (aka Multitasking)

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

Task Manager

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- The operating system provides support for multiple "processes"
- In reality there there may be fewer processors than processes
- Processes are an illusion too – at the hardware level, lots of multitasking
  - memory subsystem
  - video controller
  - buses
  - instruction prefetching

Threads in Java

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- 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)

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```
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)

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```
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

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```
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

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```
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

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```
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

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```
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...
done
```

Stopping Threads

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- 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

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- 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

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- 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

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```
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

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```
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

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```
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

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

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

is equivalent to

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

File Locking

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- 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

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- 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

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

wait/notify

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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

Summary

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- Use of multiple processes and multiple threads within each process can exploit concurrency
  - Which may be real (multicore) or “virtual” (an illusion)
- But when using threads, beware!
  - Must lock (synchronize) any shared memory to avoid non-determinism and race conditions
  - Yet synchronization also creates risk of deadlocks
  - Even with proper locking concurrent programs can have other problems such as “livelock”
- Serious treatment of concurrency is a complex topic (covered in more detail in cs3410 and cs4410)