CS/ENGRD 2110 Object-Oriented Programming and Data Structures

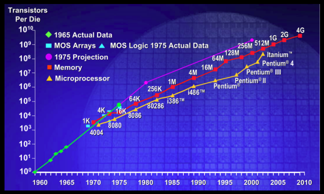
Fall 2012

Doug James

Lecture 21: Threads and Concurrency

Computer Processor Trends

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



– Multicore: use additional transistors to put more CPUs (cores) on one chip.

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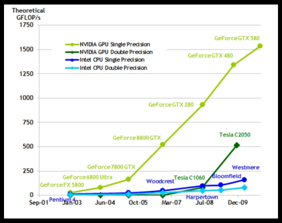
Computer Processor Trends



- Graphics Processing Units (GPUs)
  – Highly parallel processors
  – Massively multi-threaded programs

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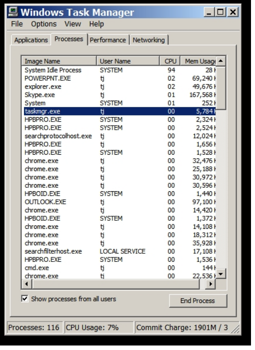
Concurrency (aka Multitasking)

- Multiple processes
  – Multiple independently running programs
- Multiple threads
  – Same program has multiple streams of execution
- Special problems arise
  – race conditions
  – deadlock



```
Image Name               User Name       CPU  Mem Usage
System Idle Process      SYSTEM          94       28 K
POWERPNT.EXE             tj              02   69,240 K
explorer.exe             tj              02   49,676 K
Skype.exe                tj              01  167,568 K
System                   SYSTEM          01      252 K
taskmgr.exe              tj              00    5,784 K
HPBPRO.EXE               SYSTEM          00    2,324 K
HPBPRO.EXE               SYSTEM          00    2,524 K
searchprotocolhost.exe   tj              00   12,024 K
HPBPRO.EXE               tj              00    1,656 K
HPBPRO.EXE               SYSTEM          00    1,528 K
chrome.exe               tj              00   32,476 K
chrome.exe               tj              00   25,188 K
chrome.exe               tj              00   30,972 K
chrome.exe               tj              00   30,596 K
HPBOID.EXE               SYSTEM          00    1,440 K
OUTLOOK.EXE              tj              00   97,100 K
chrome.exe               tj              00   14,420 K
HPBOID.EXE               SYSTEM          00    1,372 K
chrome.exe               tj              00   14,108 K
chrome.exe               tj              00   18,312 K
chrome.exe               tj              00   35,928 K
searchfilterhost.exe     LOCAL SERVICE   00   17,108 K
HPBPRO.EXE               SYSTEM          00    1,536 K
cmd.exe                  tj              00      144 K
chrome.exe               tj              00   22,536 K

☑ Show processes from all users

Processes: 116    CPU Usage: 7%    Commit Charge: 1901M / 3
```

What is a Thread?

- A separate stream of execution 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

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What is a Thread?

- # Threads ≠ # Processors ≠ # Cores
  – The processor cores distribute their time over all the active threads
  – Implemented with support from underlying operating system or virtual machine
  – Gives the illusion of many threads running simultaneously, even if more threads than processors / cores

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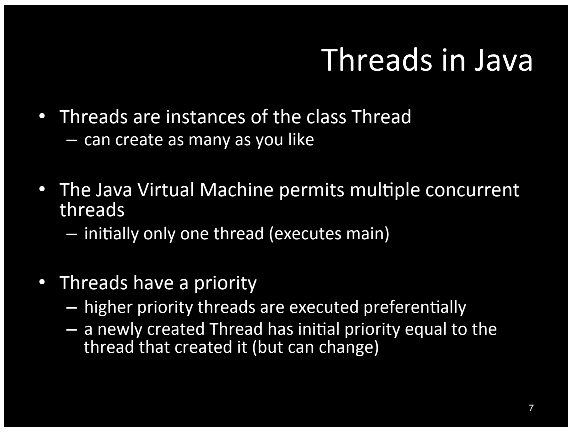

Threads in Java

- 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)

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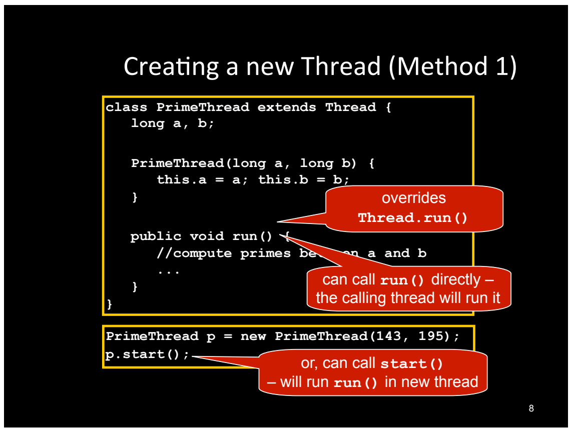

Creating a new Thread (Method 1)

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

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

   public void run() {
      //compute primes be    en 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

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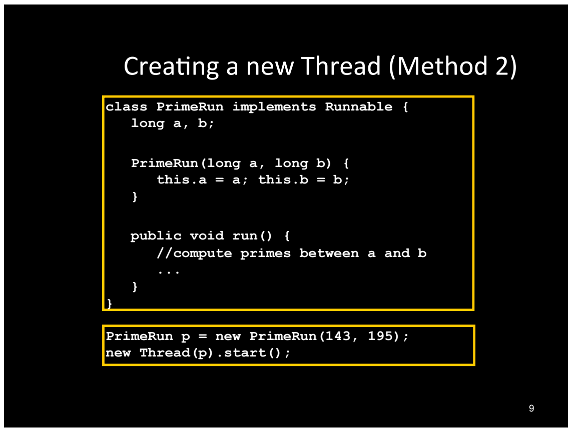

Creating a new Thread (Method 2)

```
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();
```

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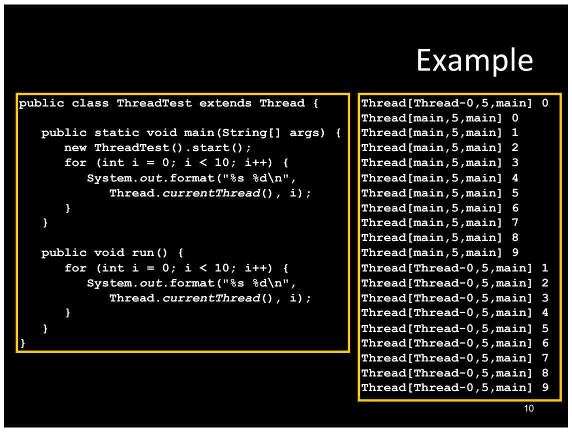

Example

```
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
```

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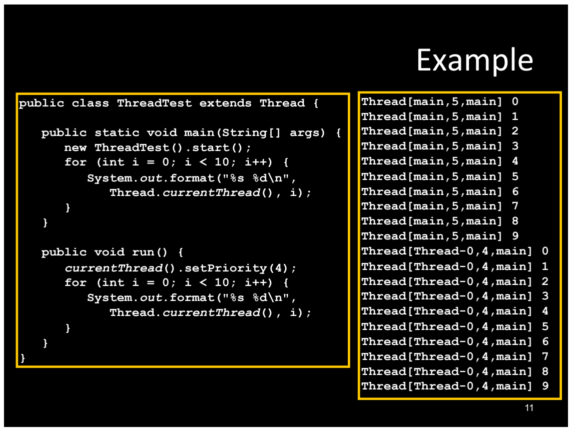

Example

```
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
```

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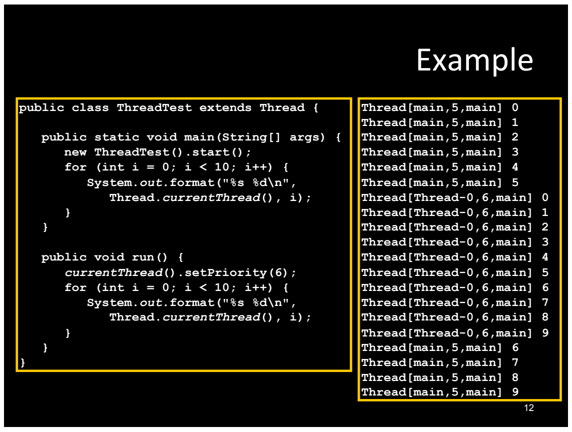

Example

```
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
```

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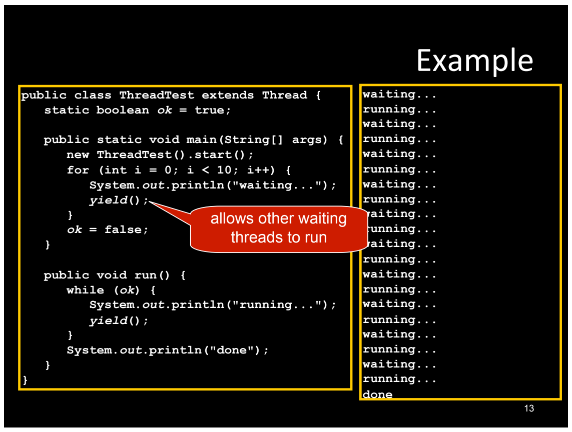

Example

```
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");
   }
}
```

```
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
aiting...
unning...
aiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
waiting...
running...
done
```

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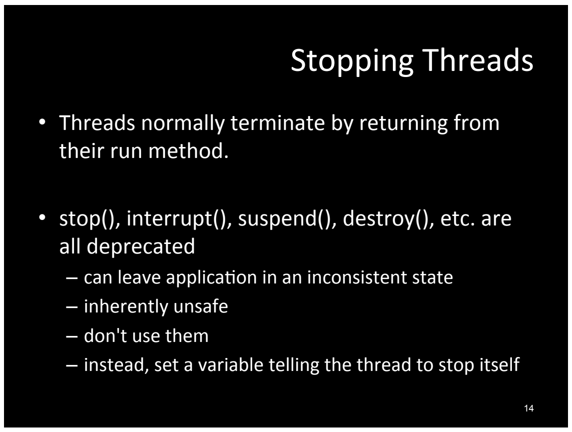

Stopping Threads

- 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

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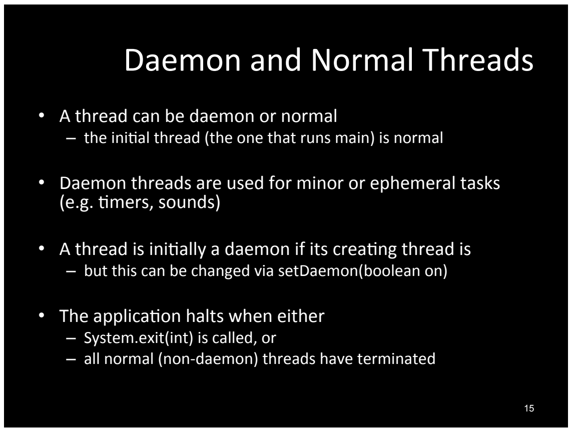

Daemon and Normal Threads

- 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 if its creating thread is
  - but this can be changed via setDaemon(boolean on)
- The application halts when either
  - System.exit(int) is called, or
  - all normal (non-daemon) threads have terminated

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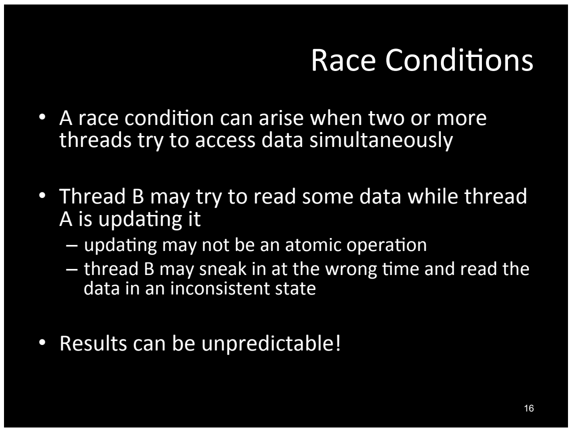

Race Conditions

- 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!

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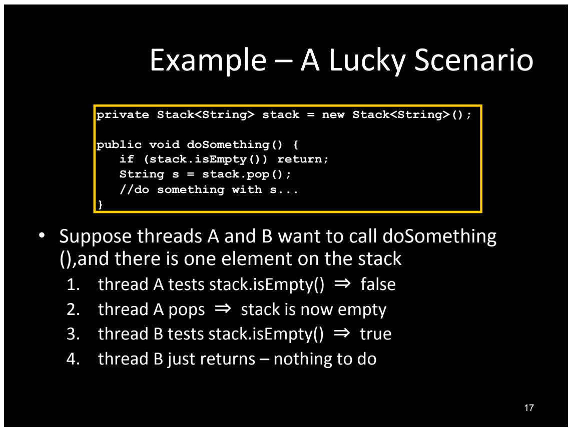

Example – A Lucky Scenario

```
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

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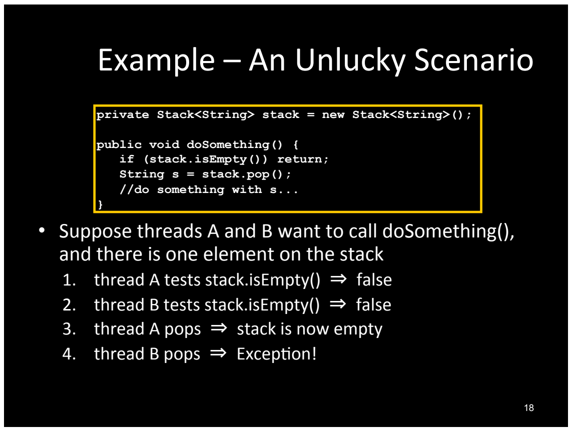

Example – An Unlucky Scenario

```
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!

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Solution: Locking

- A thread can “lock” an object for exclusive access
  - Only one thread can “hold” a lock at a time
  - If several request the same lock, Java somehow decides which will get it
- The lock is released when the thread leaves the synchronization block
  - synchronized(someObject) { *protected code* }
  - The protected code has a *mutual exclusion* guarantee: At most one thread can hold the lock at any time
- When released, some other thread can acquire the lock

Locking in Java

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

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

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

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Solution – Locking

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

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

is equivalent to

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

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Locks are Associated with Objects

- Every Object has its own built-in lock
  - Just the same, some applications prefer to create special classes of objects to use just for locking
  - This is a stylistic decision and you should agree on it with your teammates or learn the company policy if you work at a company
- Code is “thread safe” if it can handle multiple threads using it… otherwise it is “unsafe”

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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

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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 lock object X, then object Y
  - thread B tries to lock object Y, then object X
  - A gets X, B gets Y
  - Each is waiting for the other forever

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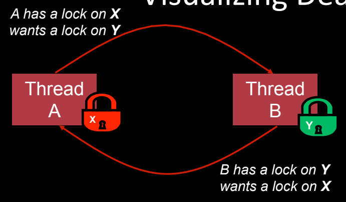
Visualizing Deadlock



- Some Strategies for Avoiding Deadlocks
  - If possible, do not acquire more than one lock.
  - If possible, always lock objects in the same order.

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wait/notify

- A mechanism for event-driven activation of threads
  - For example, animation threads and the GUI event-dispatching thread in can interact via wait/notify
- How does it work?
  - A thread that has a lock on an object can call wait() to go to sleep and give up lock.
  - Other thread gets the lock, executes some code, and then calls notify()/notifyAll() to wake other thread
    - notify(): wakes up one of the sleeping threads for this object (roughly according to priority and sleep time)
    - notifyAll(): wakes up all sleeping thread in order (roughly)

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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) {
      // do stuff to animator
      animator.notify();
   }
}
```

notifies processes waiting for **animator** lock

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A producer/consumer example

- Thread A produces loaves of bread and puts them on a shelf with capacity K
  - For example, maybe K=10
- Thread B consumes the loaves by taking them off the shelf
  - Thread A doesn't want to overload the shelf
  - Thread B doesn't wait to leave with empty arms

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Producer/Consumer example

```
class Bakery {
    int nLoaves = 0;   // Current number of waiting loaves
    final int K = 10;  // Shelf capacity

   public synchronized void produce() {
      while(nLoaves == K) this.wait();  // Wait until not full
      ++nLoaves;
      this.notifyall();                 // Signal: shelf not empty
   }

   public synchronized void consume() {
      while(nLoaves == 0) this.wait();  // Wait until not empty
      --nLoaves;
      this.notifyall();                 // Signal: shelf not full
   }
}
```

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Things to notice

- Wait needs to wait on the same Object that you used for synchronizing (in our example, "this", which is this instance of the Bakery)
- Notify wakes up just one waiting thread, notifyall wakes all of them up
- We used a while loop because we can't predict exactly which thread will wake up "next"

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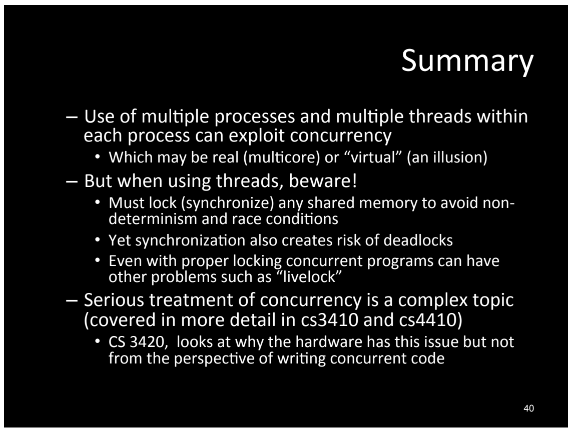

Summary

- 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)
  - CS 3420, looks at why the hardware has this issue but not from the perspective of writing concurrent code

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