CS/ENGRD 2110
Object-Oriented Programming and Data Structures

Spring 2011
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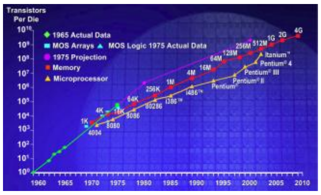
Lecture 21: Threads and Concurrency

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.

Concurrency (aka Multitasking)

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

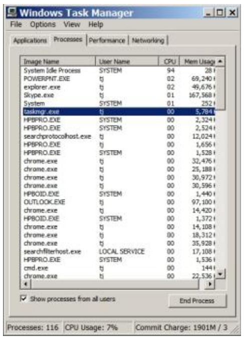


Image Name	User Name	CPU	Mem Usage
System Idle Process	SYSTEM	94	28
POWERPNT.EXE	tj	02	69,240
explorer.exe	tj	02	49,676
Skype.exe	tj	01	167,568
System	SYSTEM	01	252
taskmgr.exe	tj	00	5,784
HPBPRO.EXE	SYSTEM	00	2,324
HPBPRO.EXE	SYSTEM	00	2,524
searchprotocolhost.exe	tj	00	12,024
HPBPRO.EXE	tj	00	1,656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

☑ Show processes from all users

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

What is a Thread?

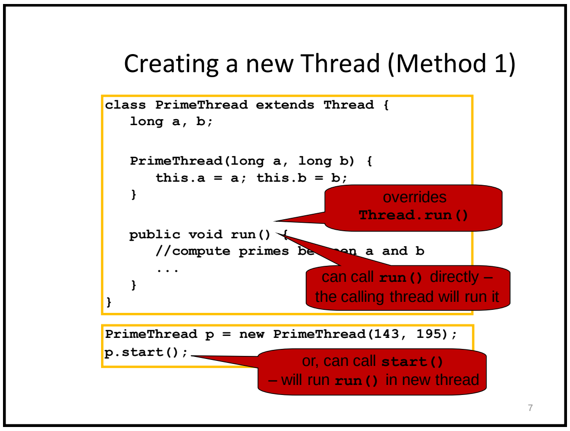
- A separate process that can perform a computational task independently and concurrently with other threads
  – Most programs have only one thread
  – GUIs have a separate thread, the event dispatching thread
  – A program can have many threads
  – You can create new threads in Java

What is a Thread?

- # Threads ≠ # Processors ≠ # Cores
  – The processor cores distributes 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

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)

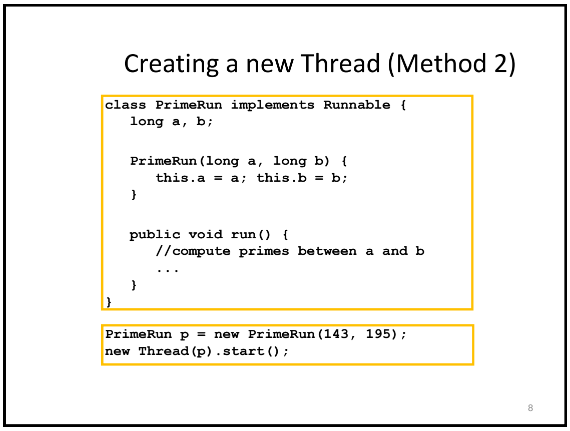
```
class PrimeThread extends Thread {
   long a, b;

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

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

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

overrides `Thread.run()`

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

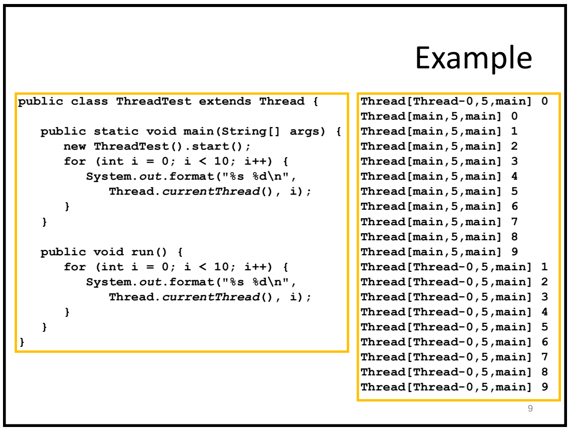
or, can call `start()` – will run `run()` in new thread



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
      ...
   }
}
```

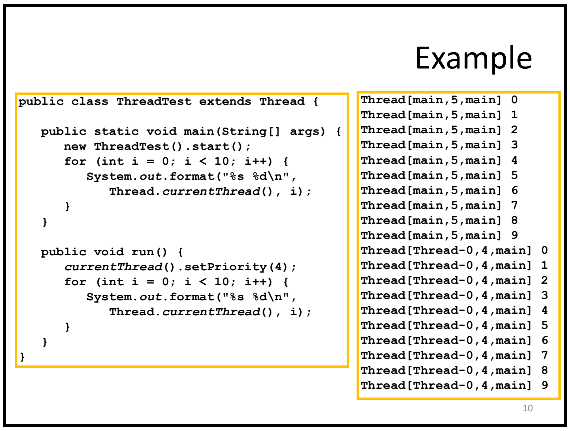
```
PrimeRun p = new PrimeRun(143, 195);
new Thread(p).start();
```



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);
      }
   }
}
```

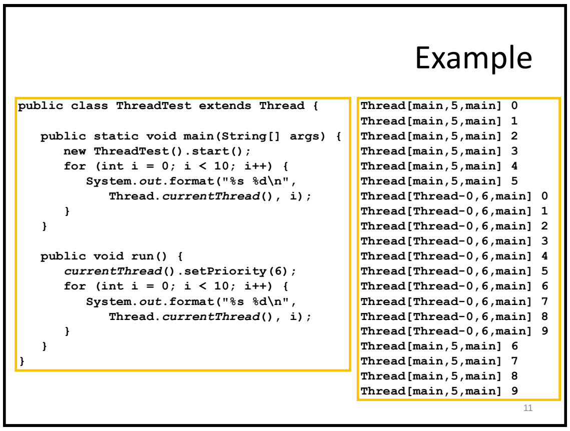
```
Thread[Thread-0,5,main] 0
Thread[main,5,main] 0
Thread[main,5,main] 1
Thread[main,5,main] 2
Thread[main,5,main] 3
Thread[main,5,main] 4
Thread[main,5,main] 5
Thread[main,5,main] 6
Thread[main,5,main] 7
Thread[main,5,main] 8
Thread[main,5,main] 9
Thread[Thread-0,5,main] 1
Thread[Thread-0,5,main] 2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

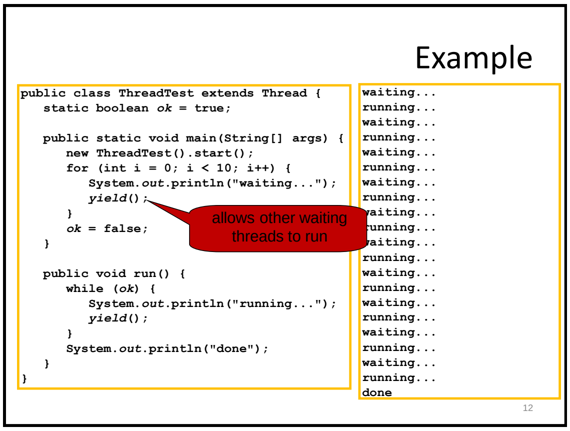
```
Thread[main,5,main] 0
Thread[main,5,main] 1
Thread[main,5,main] 2
Thread[main,5,main] 3
Thread[main,5,main] 4
Thread[main,5,main] 5
Thread[main,5,main] 6
Thread[main,5,main] 7
Thread[main,5,main] 8
Thread[main,5,main] 9
Thread[Thread-0,4,main] 0
Thread[Thread-0,4,main] 1
Thread[Thread-0,4,main] 2
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...
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 if its creating thread is
  - but this can be changed via setDemon(boolean on)
- 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

- 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 be in it
- 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

Solution – Locking

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

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

is equivalent to

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

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”

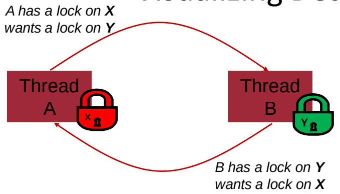
File Locking

- 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 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

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.

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)

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

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

producer

shelves

consumer

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
   }
}
```

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"

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