Introduction to Java threads

ICS491 - Spring 2007
Concurrent and High-Performance Programming

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Threads in Programming Languages

- Several programming languages have provided constructs/abstractions for writing concurrent programs
  - Modula, Ada, etc.
- Java does it like it does everything else, by providing a Thread class
  - Note that in this class we use J2SE 1.5.0
- You create a thread object
- Then you can start the thread

Extending the Thread class

- To create a thread, you can extend the thread class and override its "run()" method

```
class MyThread extends Thread {
   public void run() {
      . . .
   }
   . . .
}

myThread t = new MyThread();
```

Example

```
public class MyThread extends Thread {
   public void run() {
     for (int i=0; i<10; i++) {
        System.out.println("Hello world #"+i);
     }
   }
   . . .
}

myThread t = new MyThread();
```

Spawning a thread

- To launch, or spawn, a thread, you just call the thread's start() method
- **WARNING**: Don't call the run() method directly to launch a thread
  - If you call the run() method directly, then you just call some method of some object, and the method executes
    - Fine, but probably not what you want
  - The start() method, which you should not override, does all the thread launching
    - It launches a thread that starts its execution by calling the run() method

Example

```
public class MyThread extends Thread {
   public void run() {
     for (int i=0; i<5; i++) {
        System.out.println("Hello world #"+i);
     }
   }
}

public class MyProgram {
  public MyProgram() {
    MyThread t = new MyThread();
    t.start();
  }
  public static void main(String args[]) {
    MyProgram p = new MyProgram();
  }
}
```

What happens

- The previous program runs as a process
  - Running inside the JVM
- In fact, the program runs as a single thread within a process
- When the start() method is called, the process creates a new thread
- We now have two threads
  - The "main", "original" thread
  - The newly created thread
- Both threads are running
  - The main thread doesn't do anything
  - The new thread prints messages to screen and exits
- When both threads are finished, then the process terminates

Example

- The previous example wasn't very interesting because the main thread did nothing
  - Admittedly, this example is not interesting because the program doesn't do anything useful, but we'll get there eventually
- In fact, we could have achieved the same result with no thread at all
- So, let's have the main thread to something

Example

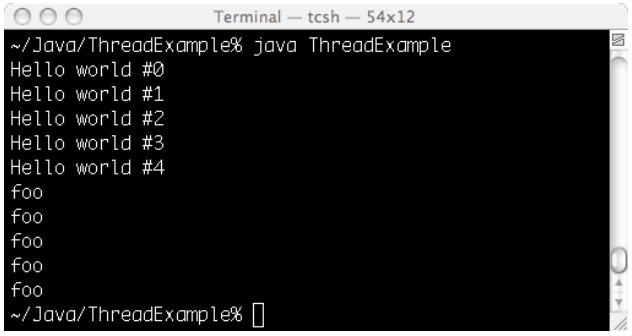
```
public class myThread extends Thread {
   public void run() {
     for (int i=0; i<5; i++)
        System.out.println("Hello world #"+i);
   }
}

public class MyProgram {
  public MyProgram() {
    MyThread t = new MyThread();
     t.start();
     for (int i=0; i<5; i++)
        System.out.println("foo");
  }
  public static void main(String args[]) {
    MyProgram p = new MyProgram();
  }
}
```

What happens?

- Now we have the main threads printing to the screen **and** the new thread printing to the screen
- Question: what will the output be?
- Answer: Impossible to tell for sure
  - If you know the implementation of the JVM on your particular machine, then you can probably tell
  - But if you write this code to be run anywhere, then you can't expect to know what happens
- Let's look at what happens on my laptop

Example Execution



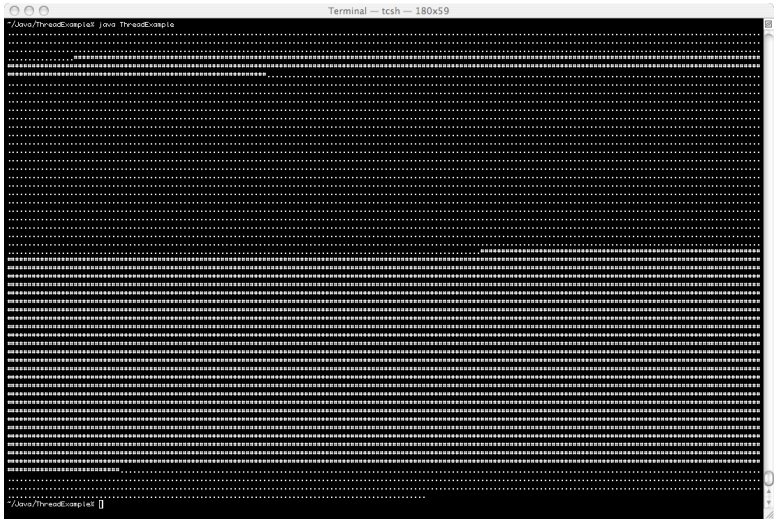
- On my laptop, with my JVM, the new thread finishes executing before the main thread moves on to doing its work

Is it really concurrent?

- One may wonder whether the execution is really concurrent
  - At least falsely concurrent
- This can be verified by having threads run for longer
- In the output that follows the new thread prints "." and the main thread prints "#"

Example Execution #1

Example Execution #2



Non-deterministic Execution

- The previous example shows what's difficult about thread programming, an especially thread debugging: it may be difficult to tell what the execution will look like
- Somebody decides when a thread runs
  - You run for a while
  - Now *you* run for a while
  - . . .
- This decision process is called scheduling
- Let's look a little bit at the Thread class to understand this better

The Thread class

```
package java.lang;

public class Thread implements Runnable {
   public void start();
   public void run();

   public boolean isAlive();
    public Thread.State getState();

   public static void sleep(long millis);
   public static void sleep(long millis,
                            long nanos);

  // A bunch of other things we'll discuss later
   ...
}
```

The isAlive() Method

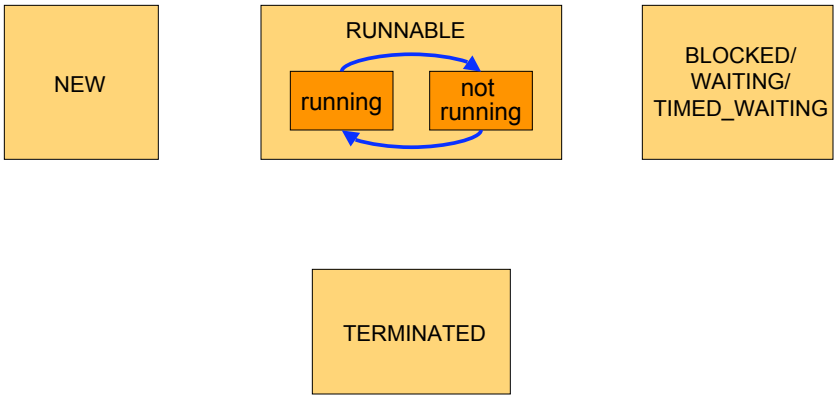
- When you spawn a thread you may not really know when or how it is going to terminate
- It may be useful to know
  - To see if the thread's work is done for instance
- The isAlive() method returns true is the thread is running, false otherwise
- Could be useful to restart a thread

```
if (!t.isAlive()) {
  t.start();
}
```

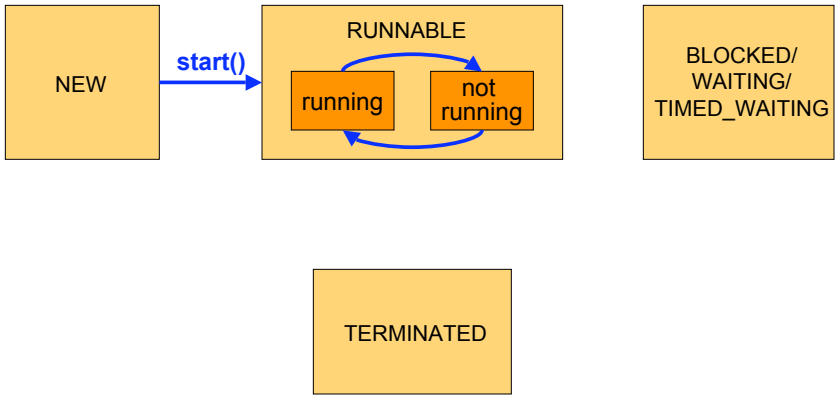
The getState() method

- The possible thread states are
  - NEW: A thread that hasn't been started yet
  - RUNNABLE: The thread can be run, and may be running as we speak
    - It may not because another runnable thread could be running
  - BLOCKED: The thread is blocked on a *monitor*
    - See future lecture
  - WAITING: The thread is waiting for another thread to do something
    - See future lecture
  - TIMED_WAITING: The thread is waiting for another thread to do something, but will give up after a specified time out
    - See future lecture
  - TERMINATED: The thread's run method has returned

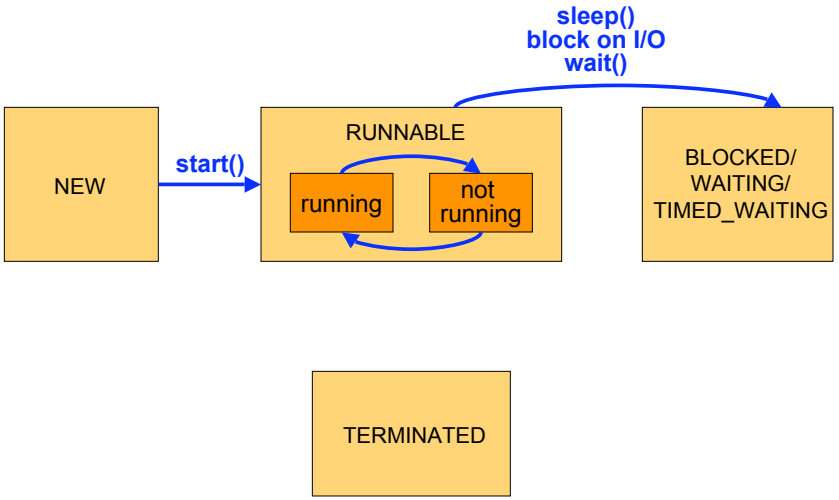
Thread Lifecycle: 4 states



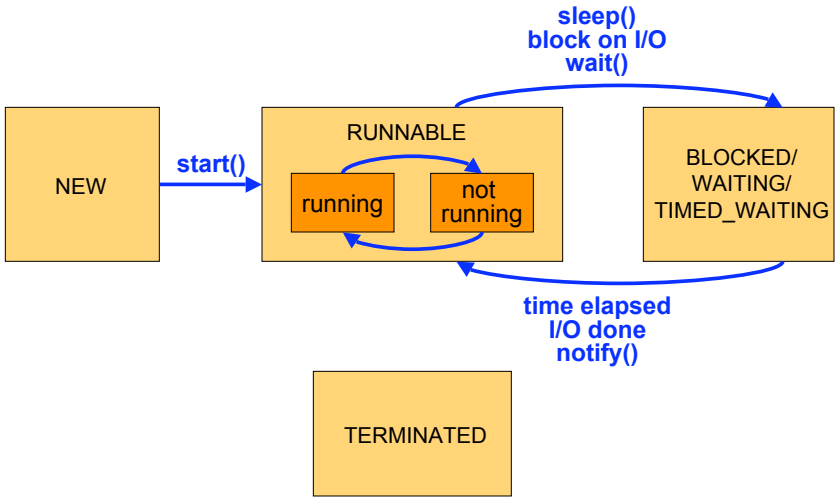
Thread Lifecycle: 4 states



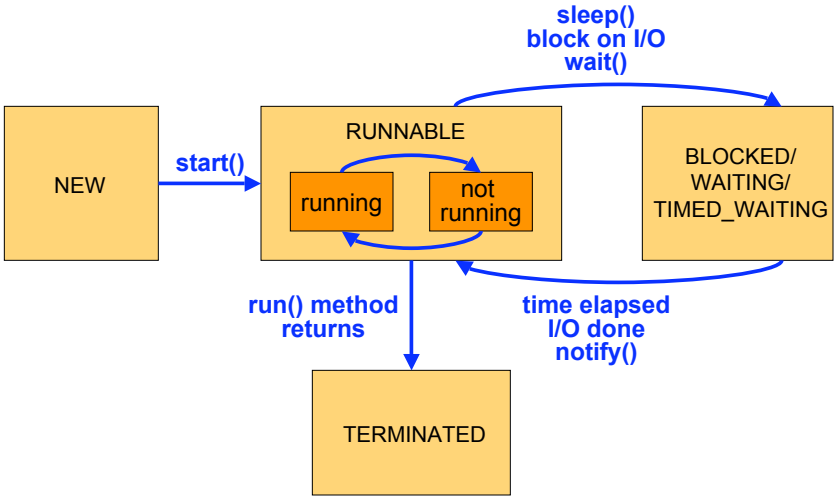
Thread Lifecycle: 4 states



Thread Lifecycle: 4 states

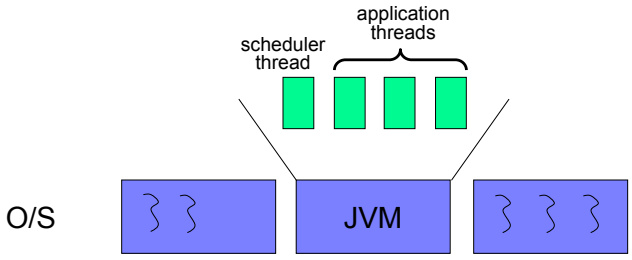


Thread Lifecycle: 4 states



Thread Scheduling

- The JVM keeps track of threads, enacts the thread state transition diagram
- Question: who decides which runnable thread to run?
- Old versions of the JVM used Green Threads
  - User-level threads implemented by the JVM
  - Invisible to the O/S

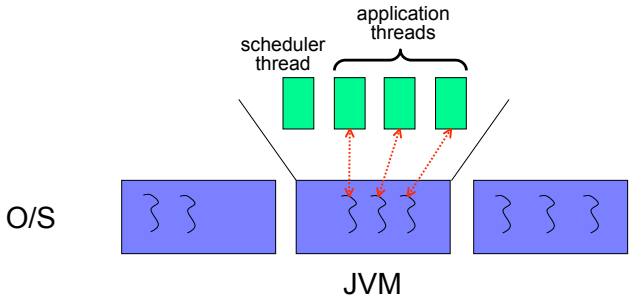


Beyond Green Threads

- Green threads have all the disadvantage of user-level threads (see previous set of lecture notes)
  - Most importantly: Cannot exploit multi-core, multi-processor architectures
- Later, the JVM provided native threads
  - Green threads are typically not available anymore
  - you can try to use “java -green” and see what your system says

Java Threads / Kernel Threads

- In modern JVMs, application threads are *mapped* to kernel threads

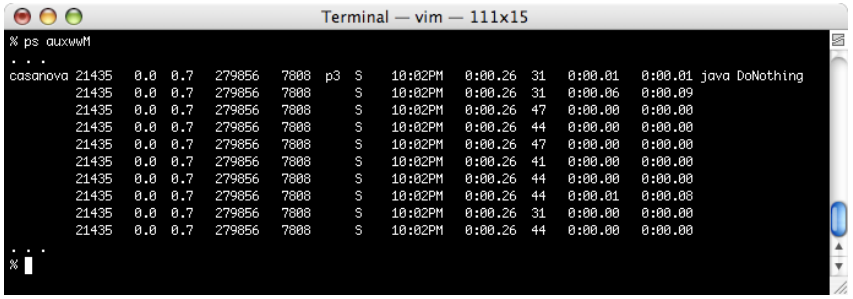


Java Threads / Kernel Threads

- This gets a bit complicated
  - The JVM has a thread scheduler for application threads, which are mapped to kernel threads
  - The O/S also has a thread scheduler for kernel threads
  - Several application threads could be mapped to the same kernel thread!
- The JVM is itself multithreaded!
- We have threads everywhere
  - Application threads in the JVM
  - Kernel threads that run application threads
  - Threads in the JVM that do some work for the JVM
- Let’s look at a running JVM

A Running JVM

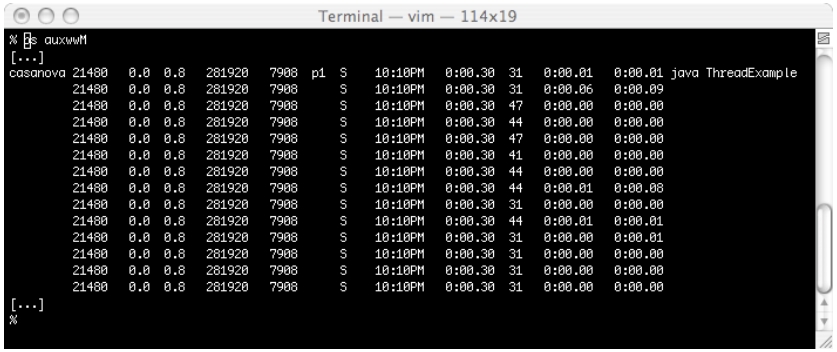
- On my laptop, a Java program that does nothing



- 10 threads!

A Running JVM

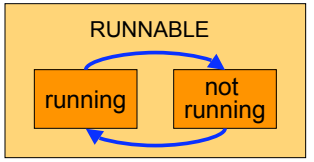
- On my laptop, a Java program that creates 4 threads



- 14 threads!
  - 10 from before, one for each application thread

So what?

- At this point, it seems that we throw a bunch of threads in, and we don't really know what happens
- To some extent it's true, but we have ways to have some control
- In particular, what happens in the RUNNABLE state?



- Can we control how multiple RUNNABLE threads become running or not running?

The yield() method: example

- With the yield() method, a thread will pause and give other RUNNABLE threads the opportunity to execute for a while

```
public class MyThread extends Thread {
   public void run() {
      for (int i=0; i<5; i++) {
         System.out.println("Hello world #"+i);
         Thread.yield();
      }
   }
}

public class MyProgram {
  public MyProgram() {
     MyThread t = new MyThread();
     t.start();
     for (int i=0; i<5; i++) {
        System.out.println("foo");
        Thread.yield();
     }
  }
  public static void main(String args[]) {
     MyProgram p = new MyProgram();
  }
}
```

Example Execution

- The use of yield made the threads' executions more interleaved
  - Switching between threads is more frequent
- But it's still not deterministic!
- Programs should NEVER rely on yield() for correctness
  - yield() is really a "hint" to the JVM

Thread Priorities

- The Thread class has a setPriority() and a getPriority() method
  - A new Thread inherits the priority of the thread that created it
- Thread priorities are integers ranging between Thread.MIN_PRIORITY and Thread.MAX_PRIORITY
  - The higher the integer, the higher the priority

Thread Priorities and Scheduling

- Whenever there is a choice between multiple runnable threads, the JVM picks the higher priority one
  - High priority threads may yield to prevent starvation of low-priority threads
- The JVM is preemptive
  - If a higher priority thread is started, it gets to run
- Modern JVMs (post green threads) use time slicing
  - Threads of the highest priorities get chosen in a round-robin fashion
  - The use of yield() isn't required but, as we saw, it can increase the frequency of switching between threads
- In spite of all this:
  - The JVM can only *influence* the way in which threads are scheduled
  - Ultimately, the decision is left to the O/S

So what?

- It is important to know the basics of thread scheduling to understand the behavior of concurrent programs
- One should NEVER rely on scheduling aspects to ensure correctness of the program
  - Since scheduling depends on the JVM and on the O/S, correctness due to scheduling is not portable

The join() method

- The join() method causes a thread to wait for another thread's termination
- This is useful for "dispatching" work to a worker thread and waiting for it to be done
- Let's see it used on an example

Terminal — vim — 70x25

```
public class JoinExample {

  public JoinExample() {
    Thread t1 = new Thread1();
    t1.start();
    System.out.println("Parent thread: waiting for child to finish");
    try { t1.join(); } catch (InterruptedException e) {}
    System.out.println("Parent thread: child has finished");
  }

  public static void main(String args[]) {
    JoinExample j = new JoinExample();
  }

  private class Thread1 extends Thread {
    public void run() {
      for (int i=0; i<5; i++) {
        System.out.println("Child thread: iteration"+i);
        try { Thread.sleep(1000); } catch (InterruptedException e) {}
      }
    }
  }
}
```

The Runnable Interface

- What if you want to create a thread that extends some other class?
  - e.g., a multi-threaded applet is at the same time a Thread and an Applet
- Java does not allow for double inheritance
- Which is why it has the concept of interfaces
- So another way to create a thread is to have runnable objects
- It's actually the most common approach
  - Allows to add inheritance in a slightly easier way after the fact
- Let's see this on an example

Runnable Example

```
public class MyTask implements Runnable {
   public void run() {
     for (int i=0; i<5; i++)
        System.out.println("Hello world #"+i);
   }
}

public class MyProgram {
  public MyProgram() {
    Thread t = new Thread(new MyTask());
    t.start();
    for (int i=0; i<5; i++)
       System.out.println("foo");
  }
  public static void main(String args[]) {
    MyProgram p = new MyProgram();
  }
}
```

Conclusion

- Two ways to create threads
  - extends Thread
  - implements Runnable
- Thread Scheduling is complex, not fully deterministic, and should not be counted on to guarantee program correctness