Threads

Objectives

- Understand the concept of multithreading
- Understand the life cycle of a thread
- Understand thread synchronization
- Be familiar with thread scheduling and prioritization techniques
- Get acquainted with important utility classes for concurrency in the JDK

Threads

- Provide
  - Concurrent paths of execution
  - A way to enable of parallel processing
    - Multi processor/core offer true parallelism
    - Single processor/core give the illusion
- Why Use Threads?
  - Improve program performance
  - Execute separate but coordinated tasks
  - Run background tasks

Java Programs are Multi-Threaded

- Every program uses multiple threads
  - The “main” thread executes `main()`
  - Another thread performs garbage collection
- Many library classes use threading techniques to improve perceived performance and protect data integrity

Constructs

- Two important language constructs support threading:
  - java.lang.Thread: Class that represents a thread of execution
  - Java.lang.Runnable: Interface that indicates its implementor can do something when called by a thread

java.lang.Thread

- `start()` – housekeeping, becomes runnable
- `run()` – where your code is executed
- `interrupt()` – sets interruption status
  - If blocked on `wait`, `sleep` or `join` `InterruptedException` is thrown and the status cleared
- `isInterrupted()` – returns interruption status
- `interrupted()` – returns interruption status of current thread and resets the status
- `join()` – waits till the thread terminates
- `sleep()` – sleeps for some time
- `yield()` – pause and let another execute
- `set(Default)UncaughtExceptionHandler()` – installs a handler for uncaught exception

java.lang.Thread

- `resume()` - resumes a suspended thread
- `stop()` - stops the thread
- `suspend()` - suspends the thread

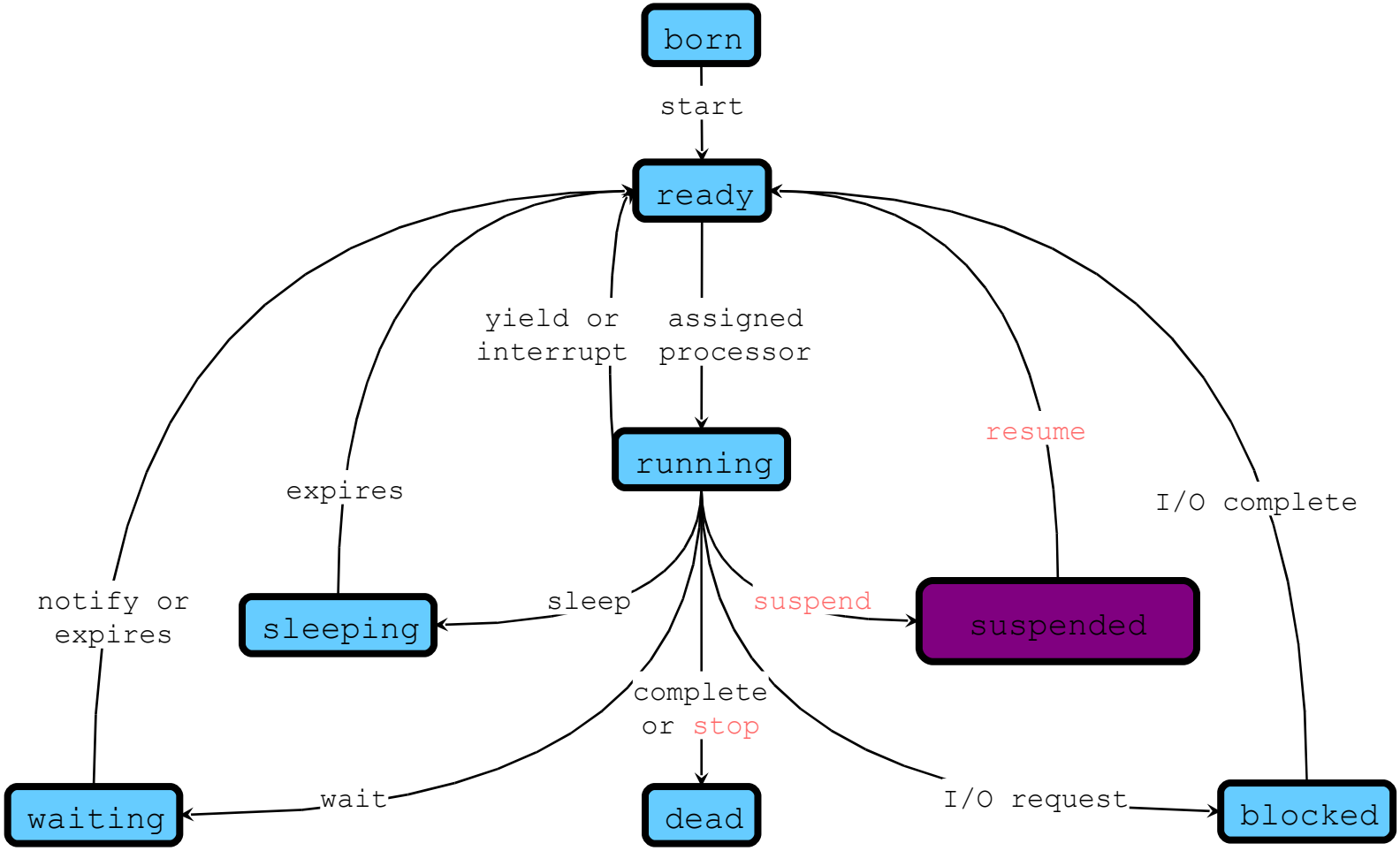
How Threads Run

- Each thread needs time to execute
  - Pre-emptive time-slicing
    - Performed at process level
  - Scheduling
    - No scheduling guarantees
    - No fairness guarantees
    - No guarantee threads will make progress

Thread Priority

- Only thread scheduler uses priority
  - Priority heuristically influences scheduler
    - 10 Crisis management
    - 7-9 Interactive, event driven
    - 4-6 IO - bound
    - 2-3 Background computation
    - 1 Run only if nothing else can
- `setPriority()`
  - `MIN_PRIORITY`, 1
  - `MAX_PRIORITY`, 10
  - `NORM_PRIORITY`, 5

Thread Lifecycle



Controlling Thread State

- Use flag to indicate if thread is running
- Don’t be selfish
- Do not use
  - `stop()`
  - `suspend()`
  - `resume()`
- Implement stop using flags, `interrupt()`, `isInterrupted()` and `interrupted()`
- Name threads (useful for debugging)

Controlling Thread State

```
volatile boolean running = true;

public void run()
{
   while( running && !Thread.interrupted() )
   {
      // run and do something in a loop
   }
}

public void stopThisThread()
{
   running = false;
   interrupt();
}
```

Non-portable Thread Features

- The use of priorities and `yield()` to “tune” concurrency should be avoided
- Behavior of `yield()` and impact of priorities vary from one VM to another
- If you have to use `yield()` for performance, it may indicate a higher level design flaw

`java.lang.Runnable`

- Interface specifying the `run()` operation
  - Implemented by `Thread`
- Using `Runnable`
  - Do not need to extend from **`Thread`**
  - Separates logic from concurrency
- Implementation
  - Define implementing class
  - Provide an instance to the `Thread` constructor
  - Start the thread

Synchronization

Reasons for Synchronization

- Example

```
int totalAmount = price * shares;
// 1. report total amount to the user
// 2. get money equal to total amount
// 3. buy shares
```

Price can be changed by other threads in between operations
Synchronize access to price

Monitor and Synchronization

- Monitor (one per object)
  - Implemented in `Object`
  - Only one thread may have ownership of objects monitor at a time
- Synchronization
  - An objects monitor is used to restrict access to guarded statements
  - `synchronized` keyword
    - Method modifier
    - Controls access to a block

`synchronized`

- A thread may not execute synchronized statements until it obtains ownership of controlling monitor
  - Class methods
    - `Class` object for the method's class
  - Instance methods
    - The object the method was invoked on
  - Synchronized block
    - The object specified in the synchronized block

`synchronized` Block

```
Object m_Lock = new Object();
public void doSomething()
{
   synchronized(m_Lock)
   {
      // current thread now has ownership of m_Lock
   }
   // current thread releases ownership of m_Lock
   ...
}
```

Atomic Assignment

- Assignment cannot be interrupted

```
foo = 50;
foo = 42;
```

  - Any thread will see either `42` or `50`, not garbage
  - No guarantee value is result of most recent assignment
    - `volatile` – value is "flushed" immediately after written
- Except... **`long`** and **`double`**
  - Bigger (64 bit) than native hardware reads/writes
  - Unless `volatile`

Assignment & Synchronization

```
private Object mFoo;
...
public void set(Object foo)
{
   mFoo = foo;
}
```

- Doesn't need to be synchronized:
  - Assignment of a reference is atomic
  - …however, different threads can change the value of mFoo frequently—is this what you want?

Assignment & Synchronization

```
private Object mFoo;
private boolean mFooAssigned;
...
public synchronized void set(Object foo)
{
   mFoo = foo;
   mFooAssigned = true;
   Syetem.out.println( foo );
}
```

- Needs to be synchronized, because:
  - Multiple related variables
  - Multiple operations

Assignment & Synchronization

```
public void set(Object foo)
{
    mFoo = foo;

    Iterator it = colListeners.iterator();
    while(it.hasNext())
    {
        ((IEventListner)it.next()).processEvent(mFoo);
    }
}
```

- Do you see a problem here?
  - Notification of listeners can be late
  - Member mFoo can be changed while updating listeners
  - Soapbox (again) be wary of setters, especially in the presence of multiple threads

Assignment & Synchronization

```
public void set(Object foo)
{
    mFoo = foo;

    Iterator it = colListeners.iterator();
    while(it.hasNext())
    {
        ((IEventListner)it.next()).processEvent(foo);
    }
}
```

- Local variables can resolve some problems
  - But spotting such subtle situations is difficult

Cooperating Threads

Monitor Methods

- `java.lang.Object`
  - `wait()`
    - Thread must have ownership of object's monitor prior to calling
    - Thread releases ownership, and waits, until...
  - `notify()`
    - Thread must own object's monitor
    - Thread wakes up any one of the threads that called `wait()` on the object
    - Awakened thread must obtain ownership of the object's monitor

Synchronization Example

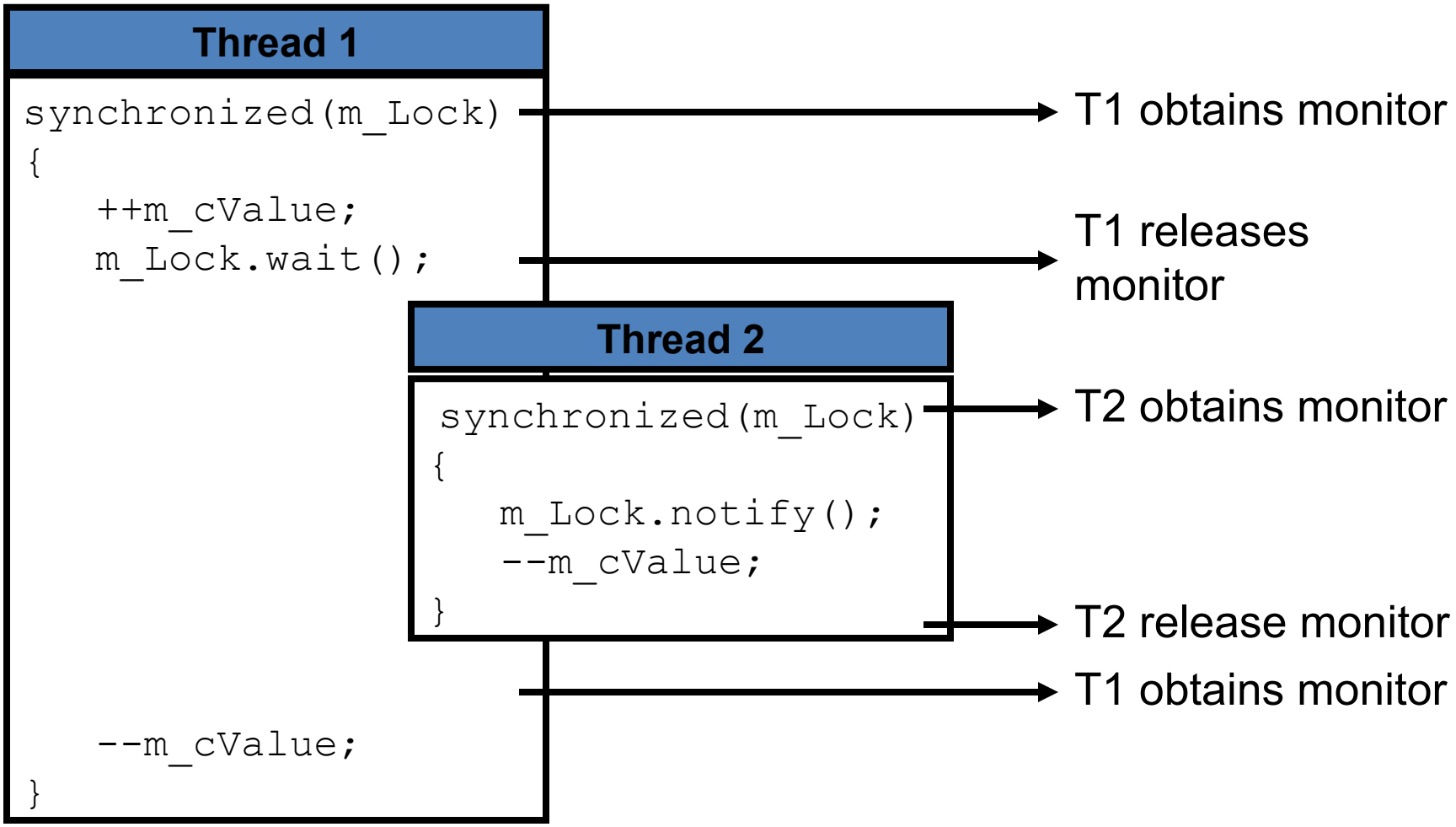
```
int m_value = 0;
Object m_lock = new Object;
void method1()
{
   synchronized(m_Lock)
   {
      ++m_value;
      try {
         m_Lock.wait();
      }
      catch(InterruptedException ie) {
         // means something called interrupt()
      }
      finally {
         --m_value;
      }
   }
}
```

Synchronization Example

```
void method2()
{
    synchronized(m_Lock)
    {
        m_Lock.notify();
        --m_value;
    }
}
```

What is a value of `m_value` going to be?

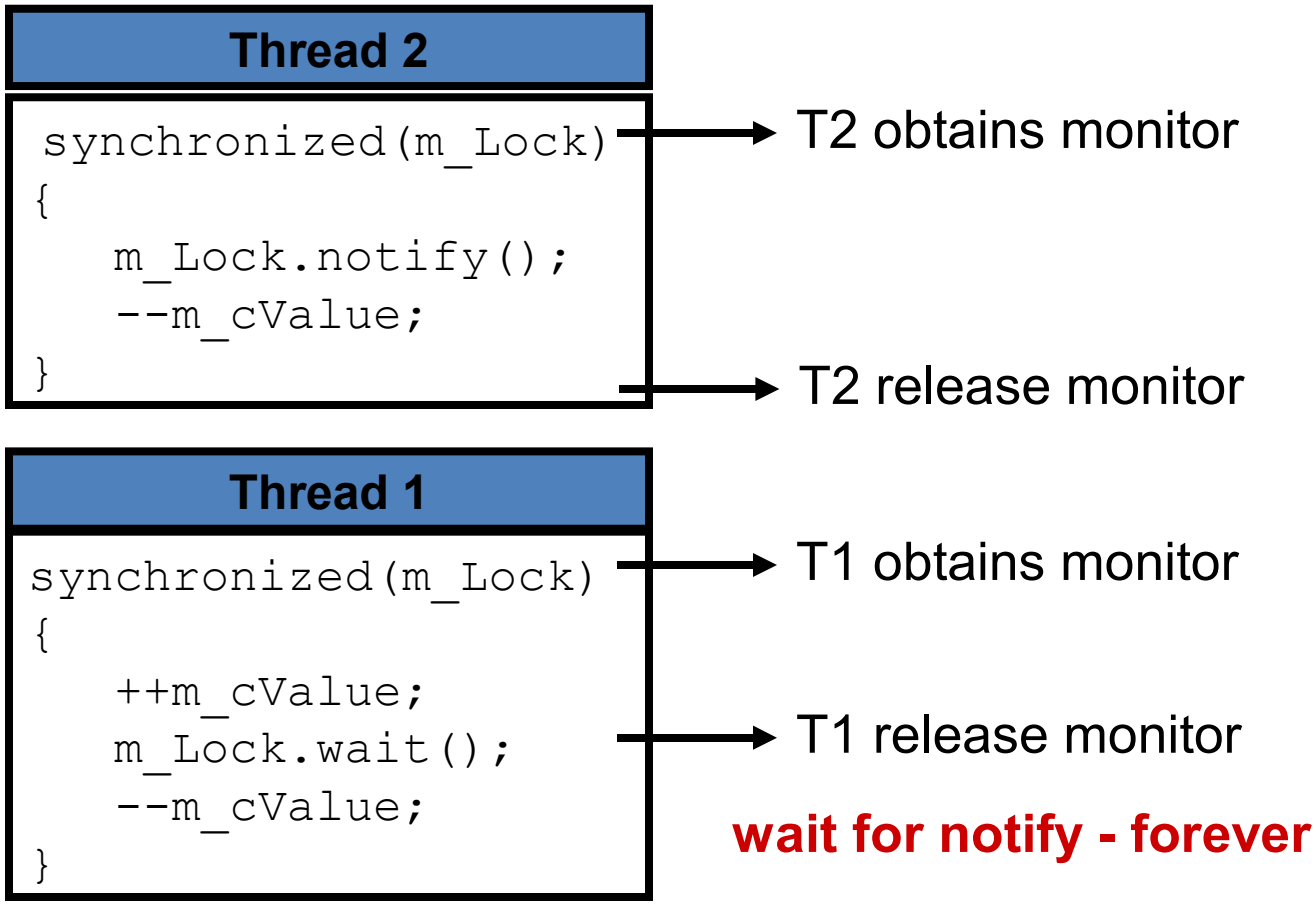
How it Works


Thread 1
synchronized(m_Lock)
{
++m_cValue;
m_Lock.wait();
--m_cValue;
}
Thread 2
synchronized(m_Lock)
{
m_Lock.notify();
--m_cValue;
}
T1 obtains monitor
T1 releases monitor
T2 obtains monitor
T2 release monitor
T1 obtains monitor

More Monitor Methods

- `java.lang.Object`
  - `notifyAll()` - awakens all *`wait()`*ing threads
    - Easy but more expensive
  - `wait(long timeout)`
    - Equivalent of **`wait()`**, but will try to re-obtain the lock and resume execution
  - `wait(long timeout, int nanos)`
    - Same as above with “higher precision”

Deadlock


Thread 2
synchronized(m_Lock)
{
m_Lock.notify();
--m_cValue;
}
T2 obtains monitor
T2 release monitor
Thread 1
synchronized(m_Lock)
{
++m_cValue;
m_Lock.wait();
--m_cValue;
}
T1 obtains monitor
T1 release monitor
wait for notify - forever

Deadlock Tips

- Call `wait()` carefully, without appropriate `notify()` we have deadlock
- Calling `notifyAll()` can help avoid deadlock
- Only good design will save you! :-)

Coordinating Worker Threads Producer - Consumer

- Both threads work on a specific task
  - Producer thread populates queue
  - Consumer picks the results

```
// consumer thread
public void run()
{
   while( true )
   {
      synchronized(list)
      {
         while(list.isEmpty())
            list.wait()
         Object task = list.getFirst();
      }
   }
```

Coordinating Worker Threads Producer - Consumer

- Producer thread
  - add
  - notify

```
// producer thread
public void run()
{
   synchronized(list)
   {
      list.addLast(task);
      list.notify();
   }
}
```

Coordinating Worker Threads AND-style

- Workers need to coordinate their work
  - Both tasks must complete prior to proceeding
  - AND-style joiner

```
Thread th1 = new Thread(runnable1);
Thread th2 = new Thread(runnable2);

th1.start();
th2.start();
// both threads running

// wait for first thread to terminate
th1.join();

// wait for second thread to terminate
th2.join();
```

Coordinating Worker Threads OR-style

- Using callback
  - Each thread knows about others
  - When thread completes notifies other threads
  - Notified threads terminate
  - All joins cease blocking
- Use same `join()` scheme

JDK Concurrency Support

- There are lots of interesting and useful classes in the JDK
  - Synchronized collections (wrapped)
  - “Concurrent” collections
  - BlockingQueue
  - Executor framework

Synchronized Collections

- You don’t have to synchronize access to a collection yourself
- The Collections class has static methods that wrap existing collections with synchronization
- Pros:
  - Easy to synchronize access to a collection
- Cons:
  - Large collection + lots of threads = performance degradation

Concurrent Collections

- java.util.concurrent has a lot of goodies for concurrency
- Classes with “Concurrent” in the name, e.g. ConcurrentHashMap are designed and implemented to support highly concurrent writes and reads:
  - Not possible to lock the entire collection
  - Uses “striped” locking, with a default value of 16 (but you can give any value you like)

BlockingQueue for Concurrency

- Traditional queue that supports four different semantics:
  - Throw an exception
  - Return a special value (boolean)
  - Block until the condition is true
  - Time out after some specified time

	Throw exception	Return value	Block	Time Out
Insert	add(e)	offer()	put(e)	offer(e, time, unit)
Remove	remove()	poll()	take()	poll(time, unit)
Examine	element()	Peek()	n/a	n/a

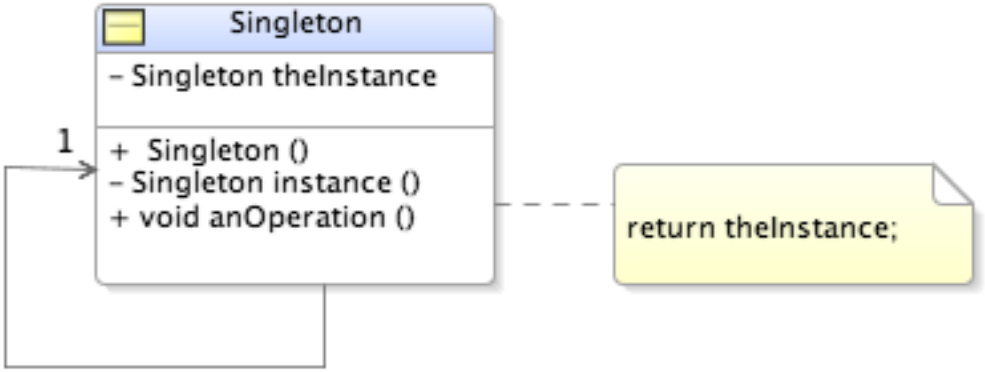
Executor Framework

- Executor is an interface
- Decouples task creation from execution
  - Allows easy abstraction of concurrency algorithms used

Advice on Threading

- It is harder than you think
- If you think you have to use concurrency, start with the prebuilt classes (java.util.concurrent)—what you need is probably already there
- Writing your own low level Thread code is a last resort (you are asking for trouble)
- Coding is half the battle; when writing concurrent code there is often much testing, debugging, and tuning to be done

Singleton Pattern



- Insures there is one instance of the class
  - Constructor is private

Singleton enum Implementation

- Use of an enum is the preferred way to implement singletons

```
public enum EnumSingleton {
     INSTANCE;

     public void anyMethod() {
          // implementation
     }
}
```

Singleton vs. Class Methods

- Benefits over a class having only class (static) methods
  - Constructors apply to instances
  - Only instances can be serialized
  - Interfaces can’t specify static methods
  - Inheritance is not useful
  - May insert an object pool if a single instance is not sufficient (non-enum implementation)

Lazy Initialization
Class Holder Idiom

- Lazily initializes a static field
  - Classes are guaranteed not to be initialized until used
  - Useful for singleton implementation pre 1.5

```
public class MySingleton {
    private static class InstanceHolder {
        static final MySingleton singleton = new MySingleton();
    }

    private MySingleton() {
    }

    public static MySingleton instance() {
        return InstanceHolder.singleton;
    }
}
```

Lazy Initialization Double-check Idiom

- Double-check idiom
  - Broke prior to 1.5, due to weak `volatile` symantics

```
public class LazyInitialization {
    private volatile LazyType lazyValue;

    public LazyType getLazyValue() {
        LazyType result = lazyValue;
        if (result == null) {
            synchronized(this) {
                if (result == null) {
                    result = lazyValue = computeInitValue();
        }   }   }
        return result;
    }
    ...
}
```

Misc

Shutting Down a Program

- To clean up and shut down a running Java program from the outside (from the command line or a script file)
- Use a *shutdownHook*
  - Simply an initialized but unstarted thread
  - *Must* extend Thread, Runnable doesn't work here
  - All shutdownHooks will be run when the Java runtime is told to stop; by a Cntl-C from the command line, for example

Shutting Down a Program (cont'd)

- Instantiate the shutdownHook
- Get the current runtime object by calling

```
Runtime.getRuntime();
```

- Register the shutdownHook by calling

```
runtime.addShutdownHook(shutdownHook);
```

- When the runtime shuts down, all the registered shutdownHooks will run