



Multithreaded Programming Part I: General Techniques

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Topics in This Section

- **Why threads?**
- **Basic approach**
 - Make a task list with `Executors.newFixedThreadPool`
 - Add tasks to list with `taskList.execute(someRunnable)`
- **Three variations on the theme**
 - Separate classes that implement `Runnable`
 - Main Activity implements `Runnable`
 - Inner classes that implement `Runnable`
- **Related topics**
 - Race conditions and synchronization
 - Helpful Thread-related methods
 - Advanced topics in concurrency



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Overview

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Motivation for Concurrent Programming

- **Pros**

- Advantages even on single-processor systems
 - Efficiency
 - Downloading image files
 - Convenience
 - A clock icon
 - Responsiveness
 - If you block the main thread, event handlers will not respond
- Some devices have multiple cpus or cores
 - Find out via `Runtime.getRuntime().availableProcessors()`

- **Cons**

- Significantly harder to debug and maintain than single-threaded apps

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Steps for Concurrent Programming

- **First, make a task list**

`ExecutorService taskList =`

`Executors.newFixedThreadPool(poolSize);`

- The `poolSize` is the maximum number of *simultaneous* threads. For many apps, it is higher than the number of tasks, so each task has a separate thread.
- There are other types of thread pools, but this is simplest

- **Second, add tasks to the list (three options)**

- Make a separate class that implements `Runnable`.
 - Make instances of this class and start threading via `taskList.execute(new MySeparateRunnableClass(...))`
- Have your existing class implement `Runnable`.
 - Start threading via `taskList.execute(this)`
- Use an inner class.
 - `taskList.execute(new MyInnerRunnableClass(...))`

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Approach One: Separate Classes that Implement Runnable

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Thread Mechanism One: Separate Runnable Class

- **Make class that implements Runnable**
 - No import statements needed: Runnable is in java.lang
- **Put actions to be performed in run method**
 - `public class MyRunnableClass implements Runnable {
 public void run() { ... }
}`
- **Create instance of your class**
 - Or lots of instances if you want lots of threads
- **Pass instance to `ExecutorService.execute`**
 - `taskList.execute(new MyRunnableClass(...));`
 - The number of simultaneous threads won't exceed the maximum size of the pool.

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Separate Runnable Class: Template Code

```
public class MainClass extends Activity {
    ...
    public void startSomeThreads() {
        int poolSize = ...;
        ExecutorService taskList =
            Executors.newFixedThreadPool(poolSize);
        for(int i=0; i<something; i++) {
            taskList.execute(new SomeTask(...));
        }
    }
}

public class SomeTask implements Runnable {
    public void run() {
        // Code to run in the background
    }
}
```

This code should not update the UI. If you need to update UI, see the post method and AsyncTask class covered in the next tutorial section.

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Thread Mechanism One: Example

```
public class ThreadingBasicsActivity extends Activity {
    @Override
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.threading_basics);
    }

    public void separateClass(View clickedButton) {
        ExecutorService taskList =
            Executors.newFixedThreadPool(50);
        taskList.execute(new SeparateCounter(6));
        taskList.execute(new SeparateCounter(5));
        taskList.execute(new SeparateCounter(4));
    }
}
```

This method is associated with a Button via the android:onClick attribute in the layout file.

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Thread Mechanism One: Example (Continued)

```
public class SeparateCounter implements Runnable {
    private final int mLoopLimit;

    public SeparateCounter(int loopLimit) {
        this.mLoopLimit = loopLimit;
    }

    public void run() {
        for (int i = 0; i < mLoopLimit; i++) {
            String threadName =
                Thread.currentThread().getName();
            System.out.printf("%s: %s\n", threadName, i);
            // Sleep for up to 1 second
            ThreadUtils.pause(Math.random());
        }
    }
}
```

This example is just for testing, so the output will go in the DDMS window. The next tutorial section will talk about what to do if the results of the background threads directly affect the user interface.

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Helper Class

```
public class ThreadUtils {
    public static void pause(double seconds) {
        try {
            Thread.sleep(Math.round(1000.0 * seconds));
        } catch (InterruptedException ie) {}
    }

    // Uninstantiable class: static methods only
    private ThreadUtils() {}
}
```

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Thread Mechanism One: Results

```
pool-2-thread-1: 0
pool-2-thread-2: 0
pool-2-thread-3: 0
pool-2-thread-1: 1
pool-2-thread-3: 1
pool-2-thread-3: 2
pool-2-thread-2: 1
pool-2-thread-3: 3
pool-2-thread-1: 2
pool-2-thread-2: 2
pool-2-thread-2: 3
pool-2-thread-1: 3
pool-2-thread-1: 4
pool-2-thread-1: 5
pool-2-thread-2: 4
```

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Pros and Cons of Approach

- **Advantages**

- Loose coupling
 - Can change pieces independently
 - Can reuse Runnable class in more than one application
- Passing arguments
 - If you want different threads to do different things, you pass args to constructor, which stores them in instance variables that run method uses
- Little danger of race conditions
 - You usually use this approach when there is no data shared among threads, so no need to synchronize.

- **Disadvantages**

- Hard to access main Activity
 - If you want to call methods in main app, you must
 - Pass reference to main app to the Runnable's constructor, which stores it
 - Make methods in main app be public

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Approach Two: Main App Implements Runnable

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Review of Interfaces: Syntax

- **Shape interface**

```
public interface Shape {  
    public double getArea(); // No body, just specification  
}
```
- **Circle class**

```
public class Circle implements Shape {  
    public double getArea() { some real code }  
}
```
- **Note**
 - You can implement many interfaces
 - `public class MyClass implements Foo, Bar, Baz { ... }`

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Review of Interfaces: Benefits

- **Class can be treated as interface type**

- public interface Shape {
 public double getArea();
}
- public class Circle implements Shape { ... }
- public class Rectangle implements Shape { ... }

```
Shape[] shapes =  
    { new Circle(...), new Rectangle(...) ... };  
double sum = 0;  
for(Shape s: shapes) {  
    sum = sum + s.getArea(); // All Shapes have getArea  
}
```

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Thread Mechanism Two: Main App Implements Runnable

- **Have main class implement Runnable**

- Put actions in run method of existing class
 - public class MyClass extends Activity implements Runnable {
 ...
 public void run() { ... }
}

- **Pass the instance of main class to execute**

- taskList.execute(this);

- **Main differences from previous approach**

- Good
 - run can easily call methods in main class, since it is *in* that class
- Bad
 - If run accesses any shared data (instance variables), you have to worry about conflicts (race conditions)
 - Very hard to pass arguments, so each task starts off the same

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Main App Implements Runnable: Template Code

```
public class ThreadedActivity extends Activity
                                implements Runnable {
    public void run() {
        // Code to run in background. Don't update UI.
    }

    public void startSomeThreads() {
        int poolSize = ...;
        ExecutorService taskList =
            Executors.newFixedThreadPool(poolSize);
        for(int i=0; i<someSize; i++) {
            taskList.execute(this);
        }
    }
    ...
}
```

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Thread Mechanism Two: Example

```
public class ThreadingBasicsActivity extends Activity
                                implements Runnable {
    private final static int LOOP_LIMIT = 5;

    public void implementsInterface(View clickedButton) {
        ExecutorService taskList =
            Executors.newFixedThreadPool(50);
        taskList.execute(this);
        taskList.execute(this);
        taskList.execute(this);
    }

    @Override
    public void run() {
        for (int i = 0; i < LOOP_LIMIT; i++) {
            String threadName = Thread.currentThread().getName();
            System.out.printf("%s: %s\n", threadName, i);
            ThreadUtils.pause(Math.random());
        }
    }
}
```

← This method is associated with a Button via the android:onClick attribute in the layout file.

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Thread Mechanism Two: Results

```
pool-3-thread-1: 0
pool-3-thread-2: 0
pool-3-thread-3: 0
pool-3-thread-3: 1
pool-3-thread-1: 1
pool-3-thread-2: 1
pool-3-thread-1: 2
pool-3-thread-3: 2
pool-3-thread-2: 2
pool-3-thread-3: 3
pool-3-thread-1: 3
pool-3-thread-3: 4
pool-3-thread-2: 3
pool-3-thread-1: 4
pool-3-thread-2: 4
```

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Pros and Cons of Approach

- **Advantages**

- Easy to access main app.
 - The run method is already inside main app. Can access any public or private methods or instance variables.

- **Disadvantages**

- Tight coupling
 - run method tied closely to this application
- Cannot pass arguments to run
 - So, you either start a single thread only (quite common), or all the threads do very similar tasks
- Danger of race conditions
 - You usually use this approach specifically because you want to access data in main application. So, if run modifies some shared data, you must synchronize.

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Approach Three: Inner Class that Implements Runnable

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Review of Inner Classes

- **Class can be defined inside another class**
 - Methods in the inner class can access all methods and instance variables of surrounding class
 - Even private methods and variables

- **Example**

```
public class OuterClass {  
    private int count = ...;  
  
    public void foo(...) {  
        InnerClass inner = new InnerClass();  
        inner.bar();  
    }  
  
    private class InnerClass {  
        public void bar() {  
            doSomethingWith(count);  
        }  
    }  
}
```

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Thread Mechanism Three: Runnable Inner Class

- **Have inner class implement Runnable**
 - Put actions in run method of inner class
 - ```
public class MyClass extends Activity {
 ...
 private class SomeInnerClass implements Runnable {
 public void run() { ... }
 }
}
```
- **Pass instances of inner class to execute**
  - ```
taskList.execute(new SomeInnerClass(...));
```

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Inner Class Implements Runnable: Template Code


```
public class MainClass extends Activity {  
    public void startSomeThreads() {  
        int poolSize = ...;  
        ExecutorService taskList =  
            Executors.newFixedThreadPool(poolSize);  
        for(int i=0; i<someSize; i++) {  
            taskList.execute(new RunnableClass(...));  
        }  
    }  
    ...  
    private class RunnableClass implements Runnable {  
        public void run() {  
            // Code to run in background. Don't change UI.  
        }  
    }  
}
```

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Thread Mechanism Three: Example

```
public class ThreadingBasicsActivity extends Activity {
    @Override
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.threading_basics);
    }

    public void innerClass(View clickedButton) {
        ExecutorService taskList =
            Executors.newFixedThreadPool(50);
        taskList.execute(new InnerCounter(6));
        taskList.execute(new InnerCounter(5));
        taskList.execute(new InnerCounter(4));
    }
}
```

 This method is associated with a Button via the android:onClick attribute in the layout file. Note also that the class is not yet finished – inner class on next page is still inside this class.

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Thread Mechanism Three: Example (Continued)

```
private class InnerCounter implements Runnable {
    private final int mLoopLimit;

    public InnerCounter(int loopLimit) {
        this.mLoopLimit = loopLimit;
    }

    public void run() {
        for (int i = 0; i < mLoopLimit; i++) {
            String threadName =
                Thread.currentThread().getName();
            System.out.printf("%s: %s%n", threadName, i);
            ThreadUtils.pause(Math.random());
        }
    }
}
```

You can also use anonymous inner classes. This is not different enough to warrant a separate example here, especially since we showed examples in the section on Widget event handling.

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Thread Mechanism Three: Results

```
pool-5-thread-1: 0
pool-5-thread-2: 0
pool-5-thread-3: 0
pool-5-thread-3: 1
pool-5-thread-1: 1
pool-5-thread-2: 1
pool-5-thread-1: 2
pool-5-thread-1: 3
pool-5-thread-3: 2
pool-5-thread-2: 2
pool-5-thread-2: 3
pool-5-thread-3: 3
pool-5-thread-1: 4
pool-5-thread-2: 4
pool-5-thread-1: 5
```

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Pros and Cons of Approach

- **Advantages**

- Easy to access main app.
 - Methods in inner classes can access any public or private methods or instance variables of outer class.
- Can pass arguments to run
 - As with separate classes, you pass args to constructor, which stores them in instance variables that run uses

- **Disadvantages**

- Tight coupling
 - run method tied closely to this application
- Danger of race conditions
 - You usually use this approach specifically because you want to access data from main application. So, if run modifies some shared data, you must synchronize.

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Summary of Approaches

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Pros and Cons

- **Separate class that implements Runnable**
 - Can pass args to run
 - Cannot easily access data in main class
 - Usually no worry about race conditions
- **Main class implements Runnable**
 - Can easily access data in main class
 - Cannot pass args to run
 - Must worry about race conditions
- **Inner class implements Runnable**
 - Can easily access data in main class
 - Can pass args to run
 - Must worry about race conditions

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Race Conditions and Synchronization

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Race Conditions

- **Idea**
 - You write code that assumes no other threads run between certain steps. But, if your thread is interrupted in the wrong place and another thread changes some data, you get the wrong answer.
- **Typical scenarios**
 - You modify shared data & assume next thread sees new result.
 - You read a value and then increment it. You assume no thread runs between when you read it and when you increment it.
 - You read shared data and then use it, forgetting that it could change between when you read it and when you use it
 - You look up size of a List, then loop from 0 to size-1. But, another thread could remove elements in between.

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Race Conditions: Example

```
public class RaceConditionsActivity extends Activity
    implements Runnable {
    private final static int LOOP_LIMIT = 3;
    private final static int POOL_SIZE = 4;
    private int mLatestThreadNum = 0;

    @Override
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.race_conditions);
    }

    public void tryRace(View clickedButton) {
        ExecutorService taskList =
            Executors.newFixedThreadPool(POOL_SIZE);
        for(int i=0; i<POOL_SIZE; i++) {
            taskList.execute(this);
        }
    }
}
```

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Race Conditions: Example (Continued)

```
public void run() {
    int currentThreadNum = mLatestThreadNum;
    System.out.printf("Setting currentNum to %s\n",
        currentThreadNum);
    mLatestThreadNum = mLatestThreadNum + 1;
    for (int i = 0; i < LOOP_LIMIT; i++) {
        System.out.printf("I am Counter %s; i is %s\n",
            currentThreadNum, i);
        ThreadUtils.pause(0.5 * Math.random());
    }
}
}
```

- What's wrong with this code?

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Race Conditions: Result

- Usual Output

```
Setting currentNum to 0
I am Counter 0; i is 0
Setting currentNum to 1
I am Counter 1; i is 0
Setting currentNum to 2
I am Counter 2; i is 0
Setting currentNum to 3
I am Counter 3; i is 0
I am Counter 0; i is 1
I am Counter 2; i is 1
I am Counter 3; i is 1
I am Counter 1; i is 1
I am Counter 0; i is 2
I am Counter 1; i is 2
I am Counter 3; i is 2
I am Counter 2; i is 2
```

- Occasional Output

```
Setting currentNum to 36
I am Counter 36; i is 0
Setting currentNum to 37
I am Counter 37; i is 0
Setting currentNum to 38
Setting currentNum to 38
I am Counter 38; i is 0
I am Counter 38; i is 0
I am Counter 36; i is 1
I am Counter 38; i is 1
I am Counter 37; i is 1
I am Counter 38; i is 1
I am Counter 36; i is 2
I am Counter 38; i is 2
I am Counter 37; i is 2
I am Counter 38; i is 2
```

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Race Conditions: Solution?

- Do things in a single step

```
public void run() {
    int currentThreadNum = mLatestThreadNum++;
    System.out.printf("Setting currentNum to %s\n",
        currentThreadNum);
    for (int i = 0; i < LOOP_LIMIT; i++) {
        System.out.printf("I am Counter %s; i is %s\n",
            currentThreadNum, i);
        ThreadUtils.pause(0.5 * Math.random());
    }
}
```

This "solution" does not fix the problem. In some ways, it makes it worse!

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Arbitrating Contention for Shared Resources

- **Synchronizing a section of code**

```
synchronized(someObject) {  
    code  
}
```

- **Fixing the previous race condition**

```
public void run() {  
    int currentThreadNum;  
    synchronized(this) {  
        currentThreadNum = mLatestThreadNum;  
        System.out.printf("Setting currentNum to %s%n",  
                           currentThreadNum);  
        mLatestThreadNum = mLatestThreadNum + 1;  
    }  
    for (int i = 0; i < LOOP_LIMIT; i++) {  
        ...  
    }  
}
```

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Arbitrating Contention for Shared Resources

- **Synchronizing a section of code**

```
synchronized(someObject) {  
    code  
}
```

- **Simplistic interpretation**

- Once a thread enters the code, no other thread can enter until the first thread exits.

- **Stronger interpretation**

- Once a thread enters the code, no other thread can enter any section of code that is synchronized using the same “lock” object
 - If two pieces of code say “synchronized(blah)”, the question is if the blah’s are the same object *instance*.

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Arbitrating Contention for Shared Resources

- Synchronizing an entire method

```
public synchronized void someMethod() {  
    body  
}
```

- Note that this is equivalent to

```
public void someMethod() {  
    synchronized(this) {  
        body  
    }  
}
```

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Helpful Thread-Related Methods

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Methods in Thread Class

- **Thread.currentThread()**
 - Gives instance of Thread that is running current code
- **Thread.sleep(milliseconds)**
 - Puts calling code to sleep. Useful for non-busy waiting in all kinds of code, not just multithreaded code. You must catch InterruptedException, but you can ignore it:
 - ```
try { Thread.sleep(someMilliseconds); }
 catch (InterruptedException ie) { }
```
  - See also TimeUnit.SECONDS.sleep, TimeUnit.MINUTES.sleep, etc.
    - Same idea except takes sleep time in different units.
- **someThread.getName(), someThread.getId()**
  - Useful for printing/debugging, to tell threads apart

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## Methods in ExecutorService Class

- **execute(Runnable)**
  - Adds Runnable to the queue of tasks
- **shutdown**
  - Prevents any more tasks from being added with execute (or submit), but lets current tasks finish.
- **shutdownNow**
  - Attempts to halt current tasks. But author of tasks must have them respond to interrupts (ie, catch InterruptedException), or this is no different from shutdown.
- **awaitTermination**
  - Blocks until all tasks are complete. Must shutdown() first.
- **submit, invokeAny, invokeAll**
  - Variations that use Callable instead of Runnable. See next slide on Callable.

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# Callable

- **Runnable**

- “run” method runs in background. No return values, but run can do side effects.
- Use “execute” to put in task queue

- **Callable**

- “call” method runs in background. It returns a value that can be retrieved after termination with “get”.
- Use “submit” to put in task queue.
- Use invokeAny and invokeAll to block until value or values are available
  - Example: you have a list of links from a Web page and want to check status (404 vs. good). Submit them to a task queue to run concurrently, then invokeAll will let you see return values when all links are done being checked.

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# Lower-Level Threading

- **Use Thread.start(someRunnable)**

- Implement Runnable, pass to Thread constructor, call start
  - Thread t = new Thread(someRunnable);
  - t.start();
- About same effect as taskList.execute(someRunnable), except that you cannot put bound on number of simultaneous threads.
- Mostly a carryover from pre-Java-5 days; still widely used.

- **Extend Thread**

- Put run method in Thread subclass, instantiate, call start
  - SomeThreadSubclass t = new SomeThreadSubclass(...);
  - t.start();
- A holdover from pre-Java-5; has little use in modern Java applications (Android or otherwise)

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# Advanced Topics

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## Types of Task Queues

- **Executors.newFixedThreadPool(nThreads)**
  - Simplest and most widely used type. Makes a list of tasks to be run in the background, but with caveat that there are never more than nThreads simultaneous threads running.
- **Executors.newScheduledThreadPool**
  - Lets you define tasks that run after a delay, or that run periodically. Replacement for pre-Java-5 “Timer” class.
- **Executors.newCachedThreadPool**
  - Optimized version for apps that start many short-running threads. Reuses thread instances.
- **Executors.newSingleThreadExecutor**
  - Makes queue of tasks and executes one at a time
- **ExecutorService (subclass) constructors**
  - Lets you build FIFO, LIFO, and priority queues

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# Stopping a Thread

```
public class SomeTask implements Runnable {
 private volatile boolean running;

 public void run(){
 running = true;
 while (running) {
 ...
 }
 doCleanup();
 }

 public void setRunning(boolean running) {
 this.running = running;
 }
}
```

Compilers on multicore systems often do optimizations that prevent changes to variables from one thread from being seen by another thread. To guarantee that other threads see your changes, either use synchronized methods, declare the variable "volatile", or use AtomicBoolean.

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# Nasty Synchronization Bug

```
public class Driver {
 public void startThreads() {
 ...
 for(...) {
 taskList.execute(new SomeThreadedClass());
 }
 }
}

public class SomeThreadedClass implements Runnable {
 public synchronized void doSomeOperation() {
 accessSomeSharedObject();
 }
 ...
 public void run() {
 while(someCondition) {
 doSomeOperation(); // Accesses shared data
 doSomeOtherOperation(); // No shared data
 }
 }
}
```

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# Synchronization Solution

- **Solution 1: synchronize on the shared data**

```
public void doSomeOperation() {
 synchronized(someSharedObject) {
 accessSomeSharedObject();
 }
}
```

- **Solution 2: synchronize on the class object**

```
public void doSomeOperation() {
 synchronized(SomeThreadedClass.class) {
 accessSomeSharedObject();
 }
}
```

- Note that if you synchronize a static method, the lock is the corresponding Class object, not this

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# Synchronization Solution (Continued)

- **Solution 3: synchronize on arbitrary object**

```
public class SomeThreadedClass
 implements Runnable{
 private static Object lockObject
 = new Object();
 ...
 public void doSomeOperation() {
 synchronized(lockObject) {
 accessSomeSharedObject();
 }
 }
 ...
}
```

- Why doesn't this problem usually occur with thread mechanism two (with run method in main class)?

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# Determining Maximum Thread Pool Size

- **In most apps, a reasonable guess is fine**  
`int maxThreads = 50;`  
`ExecutorService tasks =`  
`Executors.newFixedThreadPool(maxThreads);`
- **For more precision, you can use equation**  
$$\text{maxThreads} = \text{numCpus} * \text{targetUtilization} * (1 + \text{avgWaitTime}/\text{avgComputeTime})$$
  - Compute numCpus with `Runtime.getRuntime().availableProcessors()`
  - targetUtilization is from 0.0 to 1.0
  - Find ratio of wait to compute time with profiling
  - Equation taken from *Java Concurrency in Practice*

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## Other Advanced Topics

- **wait/waitForAll**
  - Releases the lock for other threads and suspends itself (placed in a wait queue associated with the lock)
  - Very important in some applications, but very, very hard to get right. Try to use the newer Executor services if possible.
- **notify/notifyAll**
  - Wakes up all threads waiting for the lock
  - A notified thread doesn't begin immediate execution, but is placed in the runnable thread queue
- **Concurrency utilities in java.util.concurrent**
  - Advanced threading utilities including semaphores, collections designed for multithreaded applications, atomic operations, etc.
- **Debugging thread problems**
  - Use JConsole (bundled with Java 5; officially part of Java 6)
    - <http://java.sun.com/developer/technicalArticles/J2SE/jconsole.html>

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# Wrap-Up

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## More Reading

- **Books**

- *Java Concurrency in Practice* (Goetz, et al)
- Chapter 10 (“Concurrency”) of *Effective Java*, 2<sup>nd</sup> Ed (Josh Bloch)
  - *Effective Java* is the alltime best Java practices book
- *Java Threads* (Oak and Wong)

- **Online references**

- Lesson: Concurrency (Oracle Java Tutorial)
  - <http://download.oracle.com/javase/tutorial/essential/concurrency/>
- Jacob Jenkov’s Concurrency Tutorial
  - <http://tutorials.jenkov.com/java-concurrency/index.html>
- Lars Vogel’s Concurrency Tutorial
  - <http://www.vogella.de/articles/JavaConcurrency/article.html>

# Summary

- **Basic approach**

```
ExecutorService taskList =
 Executors.newFixedThreadPool(poolSize);
```

- **Three variations**

- taskList.execute(new SeparateClass(...));
- taskList.execute(this);
- taskList.execute(new InnerClass(...));

- **Handling shared data**

```
synchronized(referenceSharedByThreads) {
 getSharedData();
 modifySharedData();
}
doOtherStuff();
```

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## Questions?

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