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Examples where threads are useful: Windowing systems, Web browsers, Servers and Clients

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*How can you be in two place at once when you're not anywhere at all?*  
—Firesign Theater.

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- ▶ The other way to create a thread is to declare a class that implements the `Runnable` interface. That class then implements the `run` method. An instance of the class can then be allocated, passed as an argument when creating `Thread`, and started.

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- ▶ Example 2: Shows how to create a thread by implementing the `Runnable` interface.  
`threads/RunnableExample.java`
- ▶ Example 3: Create a thread quagmire!  
`threads/MaxThreads.java`

In Java, each thread is an object!

# Relevant Java Classes/Interfaces

- ▶ See documentation for basic classes: `java.lang.Thread`, `java.lang.ThreadGroup` and `java.lang.Runnable` interface.
- ▶ See the `java.lang.Object` class for synchronization methods.
- ▶ For automatic management of threads, see: `Executor` interface from `java.util.concurrent` package.

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- ▶ Example: `threads/InterruptTest.java`

# A Thread's Life

A thread continues to execute until one of the following thing happens.

- ▶ it returns from its target `run()` method.
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What happens if the `run()` method never terminates, and the application that started the thread never calls the `stop()` method?

*The thread remains alive even after the application has finished!*  
(so the Java interpreter has to keep on running...)

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- ▶ Code snippet:

```
class Devil extends Thread {  
    Devil() {  
        setDaemon( true);  
        start();  
    }  
    public void run() {  
        //perform evil tasks  
        ...  
    }  
}
```



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- ▶ Example of a race condition: **Account.java**, **TestAccount.java**

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// the class.
synchronized void update() { //... }

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- ▶ Every Java object has an implicit monitor associated with it to implement the synchronized keyword. Inner class has a separate monitor than the containing outer class.
- ▶ Java allows **Reentrant Synchronization**, that is, a thread can reacquire a lock it already owns. For example, a synchronized method can call another synchronized method.

# Synchronization Example 1

- ▶ Example of a race condition: `Account.java`, `TestAccount.java`
- ▶ Thread safe version using `synchronized` keyword:  
`SynchronizedAccount.java`

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- ▶ The method `notifyAll()` wakes up all waiting threads instead of just one waiting thread.

## Example with `wait()/notify()`

```
class MyThing {  
    synchronized void waiterMethod() {  
        // do something  
        // we need to wait for the notifier to do something  
        // give up the lock, put calling thread to sleep  
        wait();  
        // continue where we left off  
    }  
  
    synchronized void notifierMethod() {  
        // do something  
        // notifier the waiter that we've done it  
        notify();  
        //do more things  
    }  
  
    synchronized void relatedMethod() {  
        // do some related stuff  
    }  
}
```

## Synchronization Example 2: Producer/Consumer Problem

- ▶ A *producer* thread produces objects and places them into a queue, while a *consumer* thread removes objects and consumes them.

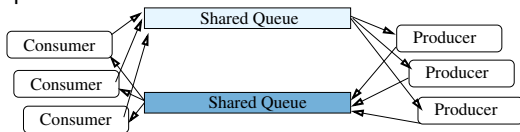
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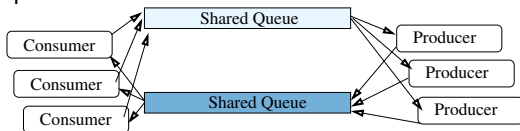
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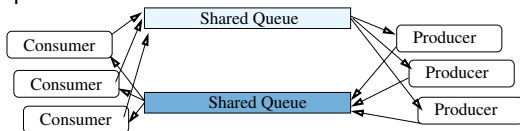
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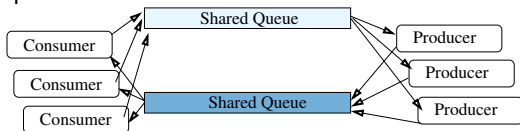
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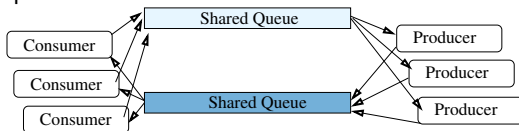
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- ▶ Example: `SharedQueue.java`, `Producer.java`, `Consumer.java`, `PC.java`
- ▶ The **Producer/Consumer** or a **Thread Pool pattern** is a widely used one for multi-threaded applications as well as in servers and clients.

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- ▶ Are the threads really simulating ping pong? We need them to exchange an object over the network!



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- ▶ **Thread Pool**: A number of threads are created to perform a number of tasks, which are organized in a queue. Typically, there are many more tasks than threads.
- ▶ Java provides a thread pool via the **Executor** interface in the `java.util.concurrent` package.

```
public interface Executor {  
    void execute (Runnable command);  
}
```



## Thread Pool: Executor (2)

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A collection created in this fashion is every bit as thread-safe as a normally synchronized collection, such as a `Vector`.

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- ▶ If an explicit iterator is used, the iterator method must be called from within the synchronized block. Failure to follow this advice may result in nondeterministic behavior.

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For more details, see:

<http://docs.oracle.com/javase/tutorial/collections/implementations/wrapper.html>

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- ▶ Javadocs for `java.lang.Thread`, `java.lang.Runnable`, `java.util.concurrent`
- ▶ Brian Goetz, Tim Peierls, Joshua Bloch and Joseph Bowbeer: *Java Concurrency in Practice*
- ▶ Lewis and Berg: *Multithreaded Programming with Java Technology*