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Multithreaded Programming

Agenda

- **Why threads?**
- **Approaches for starting threads**
 - Separate class approach
 - Callback approach
- **Solving common thread problems**
- **Synchronizing access to shared resources**
- **Thread life cycle**
- **Stopping threads**

Concurrent Programming Using Java Threads

- **Motivation**

- Efficiency
 - Downloading network data files
- Convenience
 - A clock icon
- Multi-client applications
 - HTTP Server, SMTP Server

- **Caution**

- Significantly harder to debug and maintain

- **Two Main Approaches:**

- Make a self-contained subclass of `Thread` with the behavior you want
- Implement the `Runnable` interface and put behavior in the `run` method of that object

Thread Mechanism One: Making a Thread Subclass

- **Create a separate subclass of Thread**
 - No import statements needed: Thread is in java.lang
- **Put the actions to be performed in the run method of the subclass**
 - `public void run() { ... }`
- **Create an instance of your Thread subclass**
 - Or lots of instances if you want lots of threads
- **Call that instance's start method**
 - You put the code in **run**, but you call **start**!

Thread Mechanism One: Making a Thread Subclass

```
public class DriverClass extends SomeClass {  
    ...  
    public void startAThread() {  
        // Create a Thread object  
        ThreadClass thread = new ThreadClass();  
        // Start it in a separate process  
        thread.start();  
    }  
}
```

```
public class ThreadClass extends Thread {  
    public void run() {  
        // Thread behavior here  
    }  
}
```

Thread Mechanism One: Example

```
public class Counter extends Thread {
    private static int totalNum = 0;
    private int currentNum, loopLimit;

    public Counter(int loopLimit) {
        this.loopLimit = loopLimit;
        currentNum = totalNum++;
    }

    private void pause(double seconds) {
        try { Thread.sleep(Math.round(1000.0*seconds)); }
        catch (InterruptedException ie) {}
    }

    ...
}
```

Thread Mechanism One: Example (Continued)

...

```
/** When run finishes, the thread exits. */
```

```
public void run() {  
    for(int i=0; i<loopLimit; i++) {  
        System.out.println("Counter " + currentNum  
                            + ": " + i);  
        pause(Math.random()); // Sleep for up to 1 second  
    }  
}  
}
```

Thread Mechanism One: Example (Continued)

```
public class CounterTest {  
    public static void main(String[] args) {  
        Counter c1 = new Counter(5);  
        Counter c2 = new Counter(5);  
        Counter c3 = new Counter(5);  
        c1.start();  
        c2.start();  
        c3.start();  
    }  
}
```


Thread Mechanism One: Result

```
Counter 0: 0  
Counter 1: 0  
Counter 2: 0  
Counter 1: 1  
Counter 2: 1  
Counter 1: 2  
Counter 0: 1  
Counter 0: 2  
Counter 1: 3  
Counter 2: 2  
Counter 0: 3  
Counter 1: 4  
Counter 0: 4  
Counter 2: 3  
Counter 2: 4
```

Thread Mechanism Two: Implementing Runnable

- **Put the actions to be performed in the run method of your existing class**
- **Have class implement Runnable interface**
 - If your class already extends some other class (e.g., Applet), why can't it still extend Thread? Because Java does not support multiple inheritance.
- **Construct an instance of Thread passing in the existing object (i.e., the Runnable)**
 - `Thread t = new Thread(theRunnableObject);`
- **Call that Thread's start method**
 - `t.start();`

Thread Mechanism Two: Implementing Runnable (Cont.)

```
public class ThreadedClass extends AnyClass
                                implements Runnable {
    public void run() {
        // Thread behavior here
        // If you want to access thread instance
        // (e.g. to get private per-thread data), use
        // Thread.currentThread().
    }

    public void startThread() {
        Thread t = new Thread(this);
        t.start(); // Calls back to run method in this
    }
    ...
}
```

Thread Mechanism Two: Example

```
public class Counter2 implements Runnable {  
    private static int totalNum = 0;  
    private int currentNum, loopLimit;  
  
    public Counter2(int loopLimit) {  
        this.loopLimit = loopLimit;  
        currentNum = totalNum++;  
        Thread t = new Thread(this);  
        t.start();  
    }  
    ...  
}
```

Thread Mechanism Two: Example (Continued)

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

public void run() {
    for(int i=0; i<loopLimit; i++) {
        System.out.println("Counter " + currentNum
                           + ": " + i);
        pause(Math.random()); // Sleep for up to 1 second
    }
}
}
```

Thread Mechanism Two: Example (Continued)

```
public class Counter2Test {  
    public static void main(String[] args) {  
        Counter2 c1 = new Counter2(5);  
        Counter2 c2 = new Counter2(5);  
        Counter2 c3 = new Counter2(5);  
    }  
}
```

Thread Mechanism Two: Result

```
Counter 0: 0
Counter 1: 0
Counter 2: 0
Counter 1: 1
Counter 1: 2
Counter 0: 1
Counter 1: 3
Counter 2: 1
Counter 0: 2
Counter 0: 3
Counter 1: 4
Counter 2: 2
Counter 2: 3
Counter 0: 4
Counter 2: 4
```

Race Conditions: Example

```
public class BuggyCounterApplet extends Applet
                                   implements Runnable{

    private int totalNum = 0;
    private int loopLimit = 5;

    public void start() {
        Thread t;
        for(int i=0; i<3; i++) {
            t = new Thread(this);
            t.start();
        }
    }

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

...

Race Conditions: Example (Continued)

```
...
public void run() {
    int currentNum = totalNum;
    System.out.println("Setting currentNum to "
        + currentNum);
    totalNum = totalNum + 1;
    for(int i=0; i<loopLimit; i++) {
        System.out.println("Counter "
            + currentNum + ": " + i);
        pause(Math.random());
    }
}
}
```

- **What's wrong with this code?**

Race Conditions: Result

- **Usual Output**

```
Setting currentNum to 0
Counter 0: 0
Setting currentNum to 1
Counter 1: 0
Setting currentNum to 2
Counter 2: 0
Counter 2: 1
Counter 1: 1
Counter 0: 1
Counter 2: 2
Counter 0: 2
Counter 1: 2
Counter 1: 3
Counter 0: 3
Counter 2: 3
Counter 1: 4
Counter 2: 4
Counter 0: 4
```

- **Occasional Output**

```
Setting currentNum to 0
Counter 0: 0
Setting currentNum to 1
Setting currentNum to 1
Counter 0: 1
Counter 1: 0
Counter 1: 0
Counter 0: 2
Counter 0: 3
Counter 1: 1
Counter 0: 4
Counter 1: 1
Counter 1: 2
Counter 1: 3
Counter 1: 2
Counter 1: 3
Counter 1: 4
Counter 1: 4
```

Race Conditions: Solution?

- **Do things in a single step**

```
public void run() {  
    int currentNum = totalNum++;  
    System.out.println("Setting currentNum to "  
        + currentNum);  
    for(int i=0; i<loopLimit; i++) {  
        System.out.println("Counter "  
            + currentNum + ": " + i);  
        pause(Math.random());  
    }  
}
```

Arbitrating Contention for Shared Resources

- **Synchronizing a Section of Code**

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

- **Normal 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” tag

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  
    }  
}
```

Common Synchronization Bug

- What's wrong with this class?

```
public class SomeThreadedClass extends Thread {
    private static RandomClass someSharedObject;
    ...
    public synchronized void doSomeOperation() {
        accessSomeSharedObject();
    }
    ...
    public void run() {
        while (someCondition) {
            doSomeOperation(); // Accesses shared data
            doSomeOtherOperation(); // No shared data
        }
    }
}
```

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`

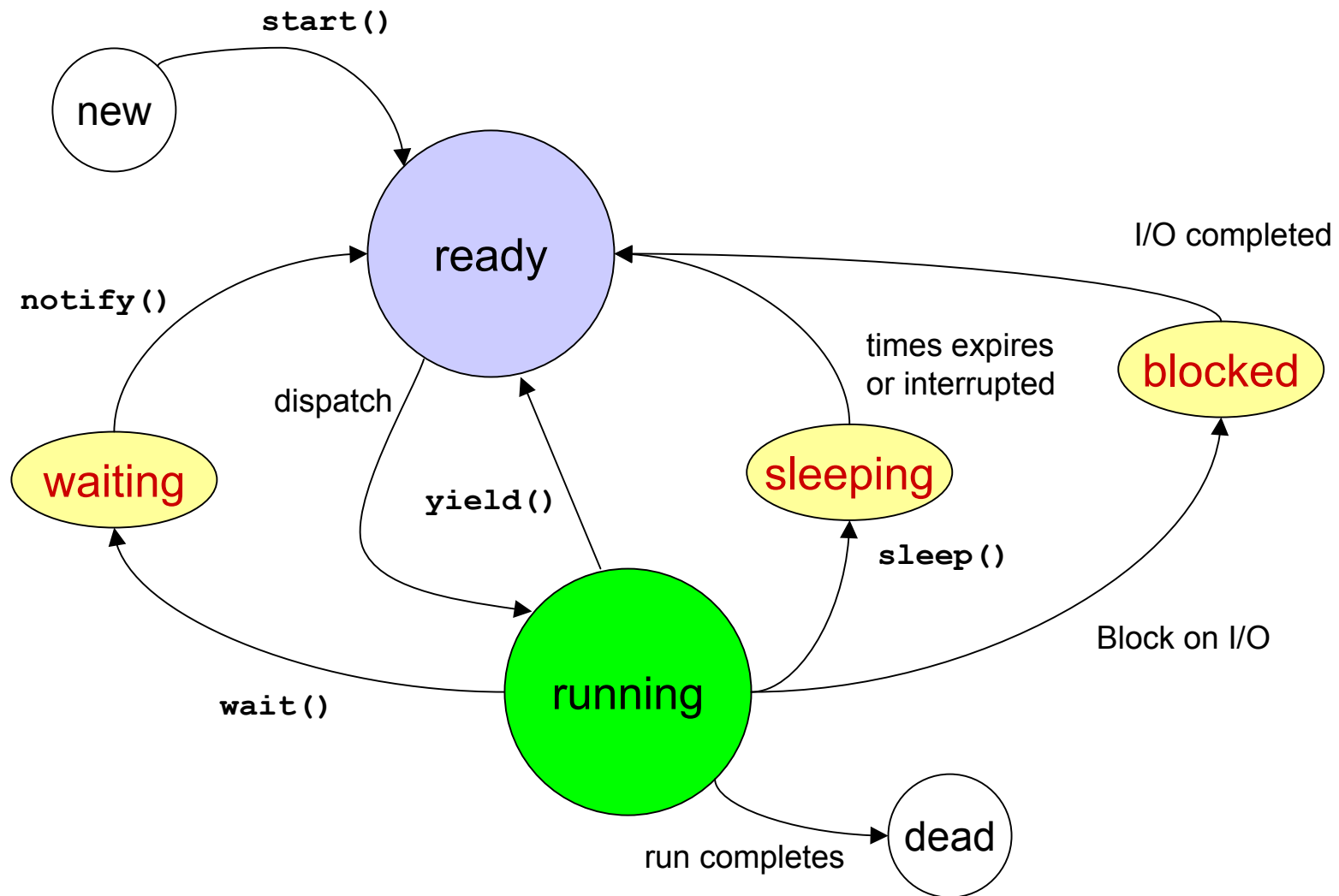
Synchronization Solution (Continued)

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

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

- Why doesn't this problem usually occur with Runnable?

Thread Lifecycle



Useful Thread Constructors

- **Thread()**
 - Default version you get when you call constructor of your custom Thread subclass.
- **Thread(Runnable target)**
 - Creates a thread, that, once started, will execute the `run` method of the target
- **Thread(ThreadGroup group, Runnable target)**
 - Creates a thread and places it in the specified thread group
 - A `ThreadGroup` is a collection of threads that can be operated on as a set
- **Thread(String name)**
 - Creates a thread with the given name
 - Useful for debugging

Thread Priorities

- **A thread's default priority is the same as the creating thread**
- **Thread API defines three thread priorities**
 - `Thread.MAX_PRIORITY` (typically 10)
 - `Thread.NORM_PRIORITY` (typically 5)
 - `Thread.MIN_PRIORITY` (typically 1)
- **Problems**
 - A Java thread **priority may map differently** to the thread priorities of the underlying OS
 - Solaris has $2^{32}-1$ priority level; Windows NT has 7 user priority levels
 - **Starvation can occur** for lower-priority threads if the higher-priority threads never terminate, sleep, or wait for I/O

Useful Thread Methods

- **currentThread**
 - Returns a reference to the **currently executing thread**
 - This is a **static** method that can be called by arbitrary methods, not just from within a Thread object
 - I.e., anyone can call Thread.currentThread
- **interrupt**
 - One of two outcomes:
 - If the thread is executing `join`, `sleep`, or `wait`, an `InterruptedException` is thrown
 - Sets a flag, from which the interrupted thread can check (`isInterrupted`)
- **interrupted**
 - Checks whether the **currently executing** thread has a request for interruption (checks flag) and clears the flag

Useful Thread Methods (Continued)

- **isInterrupted**
 - Simply checks whether the thread's interrupt flag has been set (does not modify the flag)
 - Reset the flag by calling `interrupted` from within the `run` method of the flagged thread
- **join**
 - Joins to another thread by simply waiting (sleeps) until the other thread has completed execution
- **isDaemon/setDaemon**
 - Determines or set the thread to be a daemon
 - A Java program will exit when the only active threads remaining are daemon threads

Useful Thread Methods (Continued)

- **start**
 - Initializes the thread and then calls `run`
 - If the thread was constructed by providing a `Runnable`, then `start` calls the `run` method of that `Runnable`
- **run**
 - The method in which a created thread will execute
 - Do not call `run` directly; call `start` on the thread object
 - When `run` completes the thread enters a dead state and cannot be restarted

Useful Thread Methods (Continued)

- **sleep**

- Causes the currently executing thread to do a nonbusy wait for at least the amount of time (milliseconds), unless interrupted
- As a static method, may be called for nonthreaded applications as well
 - I.e., anyone can call `Thread.sleep`
 - Note that `sleep` throws `InterruptedException`. Need `try/catch`

- **yield**

- Allows any other threads of the same or higher priority to execute (moves itself to the end of the priority queue)
- If all waiting threads have a lower priority, then the yielding thread remains on the CPU

Useful Thread Methods (Continued)

- **wait/waitForAll**
 - Releases the lock for other threads and suspends itself (placed in a wait queue associated with the lock)
 - Thread can be restarted through `notify` or `notifyAll`
 - These methods must be synchronized on the lock object of importance
- **notify/notifyAll**
 - Wakes up all threads waiting for the lock
 - A notified doesn't begin immediate execution, but is placed in the runnable thread queue

Stopping a Thread

```
public class ThreadExample implements Runnable {
    private boolean running;
    public ThreadExample()
        Thread thread = new Thread(this);
        thread.start();
    }
    public void run() {
        running = true;
        while (running) {
            ...
        }
        doCleanup();
    }

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

Signaling with wait and notify

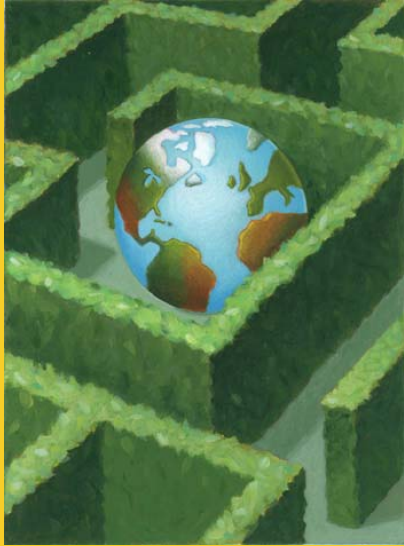
```
public class ConnectionPool implements Runnable {
    ...
    public synchronized Connection getConnection() {
        if (availableConnections.isEmpty()) {
            try {
                wait();
            } catch (InterruptedException ie) {}
            // Someone freed up a connection, so try again.
            return(getConnection());
        } else {
            // Get available connection
            ...
            return(connection)
        }
    }
}
```

Signaling with wait and notify (Continued)

```
public synchronized void free(Connection connection) {  
    busyConnections.removeElement(connection);  
    availableConnections.addElement(connection);  
    // Wake up threads that are waiting  
    // for a connection  
    notifyAll();  
}  
...  
}
```

Summary

- **Achieve multithreaded behavior by**
 - Inheriting directly from `Thread` (separate class approach)
 - Implementing the `Runnable` interface (callback approach)
- **In either case, put your code in the `run` method. Call `start` on the `Thread` object.**
- **Avoid race conditions by placing the shared resource in a synchronized block**
- **You can't restart a dead thread**
- **Stop threads by setting a flag that the thread's `run` method checks**



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Questions?