Threads in Java

(Deitel & Deitel)

<u>OOutline</u>

1- Introduction
1- Class `Thread`: An Overview of the `Thread` Methods
1- Thread States: Life Cycle of a Thread
1- Thread Priorities and Thread Scheduling
1- Thread Synchronization
1- Daemon Threads
1- `Runnable` Interface
1- Thread Groups

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Introduction

- Performing operations concurrently (in parallel)
  - We can walk, talk, breathe, see, hear, smell... all at the same time
  - Computers can do this as well - download a file, print a file, receive email, run the clock, more or less in parallel….
    - How are these tasks typically accomplished?
    - Operating systems support processes
    - What's the difference between a process and a thread?
    - Processes have their own memory space, threads share memory
    - Hence processes are "heavyweight" while threads are "lightweight"
  - Most programming languages do not allow concurrency
  - Usually limited to operating system "primitives" available to systems programmers
  - Java supports concurrency as part of language and libraries
  - What other languages support concurrency in the language?

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What and why

- Threads of execution
  - Each thread is a portion of a program that can execute concurrently with other threads (multithreading)
    - C and C++ are single-threaded
    - Gives Java powerful capabilities not found in C and C++
  - Example: downloading a video clip
    - Instead of having to download the entire clip then play it:
    - Download a portion, play that portion, download the next portion, play that portion... (streaming)
    - Ensure that it is done smoothly
  - Other example applications of multi-threading?

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Portability issues (JVM)

- Portability
  - Differences between platforms (e.g., Solaris, Windows, …)
- On Solaris (Linux?)
  - A thread runs to completion or until a higher priority thread becomes ready
  - Preemption occurs (processor is given to the higher-priority thread)
- On Win32 (Windows 9x, NT, XP)
  - Threads are timesliced
    - Thread given quantum of time to execute
    - Processor then switched to any threads of equal priority
  - Preemption occurs with higher and equal priority threads

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An Overview of the `Thread` Methods

- Thread-related methods
  - See API for more details (especially exceptions)
  - Constructors
    - **`Thread()`** **-** Creates a thread with an auto-numbered name of format **`Thread-1`**, **`Thread-2`**...
    - **`Thread( threadName )`** **-** Creates a thread with name
  - **`run`**
    - Does "work" of a thread – What does this mean?
    - Can be overridden in subclass of **`Thread`** or in **`Runnable`** object (more on interface **`Runnable`** elsewhere)
  - **`start`**
    - Launches thread, then returns to caller
    - Calls **`run`**
    - Error to call **`start`** twice for same thread

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Thread States: Life Cycle of a Thread

- Born state
  - Thread just created
  - When **`start`** called, enters ready state
- Ready state (runnable state)
  - Highest-priority ready thread enters running state
- Running state
  - System assigns processor to thread (thread begins executing)
  - When **`run`** completes or terminates, enters dead state
- Dead state
  - Thread marked to be removed by system
  - Entered when **`run`** terminates or throws uncaught exception

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Other Thread States

- Blocked state
  - Entered from running state
  - Blocked thread cannot use processor, even if available
  - Common reason for blocked state - waiting on I/O request
- Sleeping state
  - Entered when **`sleep`** method called
  - Cannot use processor
  - Enters ready state after sleep time expires
- Waiting state
  - Entered when **`wait`** called in an object thread is accessing
  - One waiting thread becomes ready when object calls **`notify`**
  - **`notifyAll`** - all waiting threads become ready

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More `Thread` Methods

- `static` void `sleep( long milliseconds )`
  - Thread sleeps (does not contend for processor) for number of milliseconds
  - Why might we want a program to invoke sleep?
  - Can give lower priority threads a chance to run
- `void interrupt()` - interrupts a thread
- `boolean isInterrupted()`
  - Determines if a thread is interrupted
- `boolean isAlive()`
  - Returns `true` if `start` called and thread not dead (`run` has not completed)
- `getPriority()` - returns this thread's priority
- `setPriority()` – sets this threads priority
- Etc.

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Thread Priorities and Scheduling

- All Java applets / applications are multithreaded
  - Threads have priority from 1 to 10
    - **`Thread.MIN_PRIORITY - 1`**
    - **`Thread.NORM_PRIORITY - 5`** (default)
    - **`Thread.MAX_PRIORITY - 10`**
    - New threads inherit priority of thread that created it
- Timeslicing
  - Each thread gets a quantum of processor time to execute
    - After time is up, processor given to next thread of equal priority (if available)
  - Without timeslicing, each thread of equal priority runs to completion

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Thread Priorities and Scheduling

- Java scheduler
  - Keeps highest-priority thread running at all times
  - If timeslicing available, ensure equal priority threads execute in round-robin fashion
  - New high priority threads could postpone execution of lower priority threads
    - Indefinite postponement (starvation)
- Priority methods
  - **`setPriority( int priorityNumber )`**
  - **`getPriority`**
  - **`yield`** - thread yields processor to threads of equal priority
    - Useful for non-timesliced systems, where threads run to completion

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Thread Scheduling Example

- Demonstrates basic threading techniques:
  - Create a class derived from **`Thread`**
  - Use **`sleep`** method
- What it does:
  - Create four threads, which sleep for random amount of time
  - After they finish sleeping, print their name
- Program has two classes:
  - **`PrintThread`**
    - Derives from **`Thread`**
    - Instance variable **`sleepTime`**
  - **`ThreadTester`**
    - Creates four **`PrintThread objects`**

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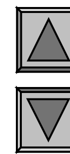

Outline

```
1  // Fig. 15.3: ThreadTester.java
2  // Show multiple threads printing at different intervals.
3
4  public class ThreadTester {
5     public static void main( String args[] )
6     {
7        PrintThread thread1, thread2, thread3, thread4;
8
9        thread1 = new PrintThread( "thread1" );
10       thread2 = new PrintThread( "thread2" );
11       thread3 = new PrintThread( "thread3" );
12       thread4 = new PrintThread( "thread4" );
13
14       System.err.println( "\nStart
15
16       thread1.start();
17       thread2.start();
18       thread3.start();
19       thread4.start();
20
21       System.err.println( "Threads started\n" );
22    }
23 }
24
25 class PrintThread extends Thread {
26    private int sleepTime;
27
28    // PrintThread constructor assigns name to thread
29    // by calling Thread constructor
```

main terminates after starting the **PrintThreads**, but the application does not end until the last thread dies.

Class ThreadTester

1. main

1.1 Initialize objects

Class PrintThread

1. extends Thread

1.1 Instance variable

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Outline

```
30     public PrintThread( String name )
31     {
32        super( name );
33
34        // sleep between 0 and 5 seconds
35        sleepTime = (int) ( Math.random() * 5000 );
36
37        System.e                            e() +
38                                            eepTime );
39     }
40
41     // execute the thread
42     public void run()
43     {
44        // put thread to sleep for a random interval
45        try {
46           System.err.println( getName() + " going to sleep" );
47           Thread.sleep( sleepTime );
48        }
49        catch ( InterruptedException exception ) {
50           System.err.println( exception.toString() );
51        }
52
53        // print thread name
54        System.err.println( getName() + " done sleeping" );
55     }
56  }
```

Call superclass constructor to assign name to thread.

`start` calls the `run` method.

`sleep` can throw an exception, so it is enclosed in a `try` block.

1.2 Constructor

1.2.1 Randomize `sleepTime`

2. `run`

2.1 `sleep`

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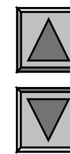

Program Output

```
Name: thread1;  sleep: 1653
Name: thread2;  sleep: 2910
Name: thread3;  sleep: 4436
Name: thread4;  sleep: 201

Starting threads
Threads started

thread1 going to sleep
thread2 going to sleep
thread3 going to sleep
thread4 going to sleep
thread4 done sleeping
thread1 done sleeping
thread2 done sleeping
thread3 done sleeping
```

```
Name: thread1;  sleep: 3876
Name: thread2;  sleep: 64
Name: thread3;  sleep: 1752
Name: thread4;  sleep: 3120

Starting threads
Threads started

thread2 going to sleep
thread4 going to sleep
thread1 going to sleep
thread3 going to sleep
thread2 done sleeping
thread3 done sleeping
thread4 done sleeping
thread1 done sleeping
```

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Thread Synchronization

- Monitors
  - Object with **`synchronized`** methods
    - Any object can be a monitor
  - Methods declared **`synchronized`**
    - **`public synchronized int myMethod( int x )`**
    - Only one thread can execute a **`synchronized method`** at a time
      - *Obtaining the lock* and *locking* an object
    - If multiple **`synchronized`** methods, only one may be active
  - Java also has **`synchronized`** blocks of code

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Thread Synchronization

- Thread may decide it cannot proceed
  - May voluntarily call **`wait`** while accessing a **`synchronized`** method
    - Removes thread from contention for monitor object and processor
    - Thread in waiting state
  - Other threads try to enter monitor object
    - Suppose condition first thread needs has now been met
    - Can call **`notify`** to tell a single waiting thread to enter ready state
    - **`notifyAll`** - tells all waiting threads to enter ready state

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Daemon Threads

- Daemon threads
  - Threads that run for benefit of other threads
    - E.g., garbage collector
  - Run in background
    - Use processor time that would otherwise go to waste
  - Unlike normal threads, do not prevent a program from terminating - when only daemon threads remain, program exits
  - Must designate a thread as daemon before **`start`** called:

    `void setDaemon( true );`
  - Method **`boolean isDaemon()`**
    - Returns **`true`** if thread is a daemon thread

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`Runnable` Interface

- Java does not support multiple inheritance
  - Instead, use interfaces
  - Until now, we inherited from class **`Thread`**, overrode **`run`**
- Multithreading for an already derived class
  - Implement interface **`Runnable`** (**`java.lang`**)
    - New class objects "are" **`Runnable`** objects
  - Override **`run`** method
    - Controls thread, just as deriving from **`Thread`** class
    - In fact, class **`Thread`** implements interface **`Runnable`**
  - Create new threads using **`Thread`** constructors
    - **`Thread( runnableObject )`**
    - **`Thread( runnableObject, threadName )`**

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Synchonized blocks

- Synchronized blocks of code

```
synchronized( monitorObject ){
    ...
}
```

  - **`monitorObject`**- Object to be locked while thread executes block of code – Why?
- Suspending threads
  - In earlier versions of Java, there were methods to stop/suspend/resume threads
    - Why have these methods been deprecated?
    - Dangerous, can lead to deadlock
  - Instead, use **`wait`** and **`notify`**
    - **`wait`** causes current thread to release ownership of a monitor until another thread invokes the **`notify`** or **`notifyAll`** method
    - Why is this technique safer?

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`Runnable` Interface example

- Upcoming example program
  - Create a GUI and three threads, each constantly displaying a random letter
  - Have suspend buttons, which will suspend a thread
    - Actually calls **`wait`**
    - When suspend unclicked, calls **`notify`**
    - Use an array of **`boolean`**s to keep track of which threads are suspended

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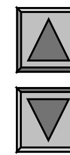


```
1  // Fig. 15.7: RandomCharacters.java
2  // Demonstrating the Runnable interface
3  import java.awt.*;
4  import java.awt.event.*;
5  import javax.swing.*;
6
7  public class RandomCharacters extends JApplet
8                               implements Runnable,
9                                          ActionListener {
10    private String alphabet = "ABCDEFGHIJK
11    private JLabel outputs[];
12    private JCheckBox checkboxes[];
13    private final static int SIZE = 3;
14
15    private Thread threads[];
16    private boolean suspended[];
17
18    public void init()
19    {
20       outputs = new JLabel[ SIZE ];
21       checkboxes = new JCheckBox[ SIZE ];
22
23       threads = new Thread[ SIZE ];
24       suspended = new boolean[ SIZE ];
25
26       Container c = getContentPane();
27       c.setLayout( new GridLayout( SIZE, 2, 5, 5 ) );
28
```

Use a **`boolean`** array to keep track of which threads are "suspended". We will actually use **`wait`** and **`notify`** to suspend the threads.

Class `RandomCharacters`

1. `implements Runnable`

bles

1.2 `init`

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```
29      for ( int i = 0; i < SIZE; i++ ) {
30         outputs[ i ] = new JLabel();
31         outputs[ i ].setBackground( Color.green );
32         outputs[ i ].setOpaque( true );
33         c.add( outputs[ i ] );
34
35         checkboxes[ i ] = new JCheckBox( "Suspended" );
36         checkboxes[ i ].addActionListener( this );
37         c.add( checkboxes[ i ] );
38      }
39   }
40
41   public void start()
42   {
43      // create threads and start every time start is called
44      for ( int i = 0; i < threads.length; i++ ) {
45         threads[ i ] =
46            new Thread( this, "Thread " +
47         threads[ i ].start();
48      }
49   }
50
51   public void run()
52   {
53      Thread currentThread = Thread.currentThread();
54      int index = getIndex( currentThread );
55      char displayChar;
56
57      while ( threads[ index ] == currentThread ) {
58         // sleep from 0 to 1 second
59         try {
60            Thread.sleep( (int) ( Math.random() * 1000 ) );
```

Use the **`Thread`** constructor to create new threads. **`Runnable`** object is **`this`** applet.

Loop will execute indefinitely because **`threads[index] == currentThread`**. The **`stop`** method in the applet sets all threads to ... to end.

`start` calls **`run`** method for thread.

Outline

2. `start`

2.1 Initialize objects

2.2 `start`

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Outline

```
62             synchronized( this ) {
63                while ( suspended[ index ] &&
64                        threads[ index ] == currentThread )
65                   wait();
66             }
67          }
68          catch ( InterruptedException e
69             System.err.println( "sleep i
70          }
71 
72          displayChar = alphabet.charAt(
73                           (int) ( Math.random() * 26 ) );
74 
75          outputs[ index ].setText( currentThread.getName() +
76             ": " + displayChar );
77       }
78 
79       System.err.println(
80          currentThread.getName() + " terminating" );
81    }
82 
83    private int getIndex( Thread current )
84    {
85       for ( int i = 0; i < threads.length; i++ )
86          if ( current == threads[ i ] )
87             return i;
88 
89       return -1;
90    }
91 
```

Synchronized block tests suspended array to see if a thread should be "suspended". If so, calls **wait**.

3.1 synchronized block

random

4. getIndex

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Outline

```
92    public synchronized void stop()
93    {
94       // stop threads every time stop is called
95       // as the user browses another Web page
96       for ( int i = 0; i < threads.length; i++ )
97          threads[ i ] = null;
98
99       notifyAll();
100   }
101
102   public synchronized void actionPerformed( ActionEvent e )
103   {
104      for ( int i = 0; i < checkboxes.length; i++ ) {
105         if ( e.getSource() == checkboxes[ i ] ) {
106            suspended[ i ] = !suspended[ i ];
107
108            outputs[ i ].setBackground(
109               !suspended[ i ] ? Color.green : Color.red );
110
111            if ( !suspended[ i ] )
112               notify();
113
114            return;
115         }
116      }
117   }
118}
```

5. **stop**

...andler

Sets all threads to **null**, which causes loop in **run** to end, and **run** terminates.

Loop and find which box was checked, and suspend appropriate thread. The **run** method checks for suspended threads.

If suspend is off, then notify the appropriate thread.

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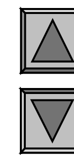
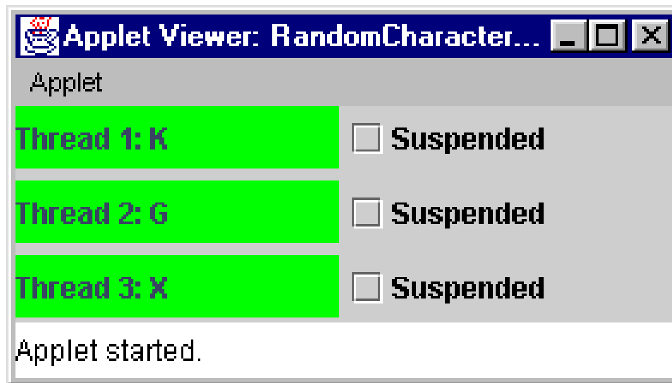
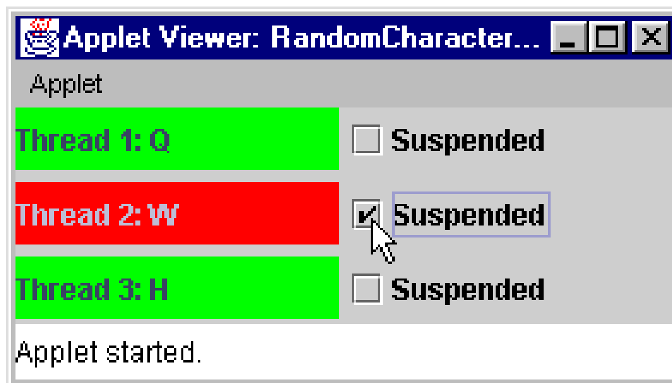


Program Output





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Client/Server example: class QuizServer constructor

```
import java.net.*; //Network sockets (communication endpoints)
public class QuizServer extends Frame {
     TextArea display;  //GUI display for QuizServer
     static ServerSocket server;  //Serves QuizClients
     public QuizServer() {
        //… Frame stuff …
        try //Create a ServerSocket
        { server = new ServerSocket( 5000, 100 );  }
        catch (IOException e)
        { System.out.println("Can't create ServerSocket");
    e.printStackTrace();
         }
    }
}
```

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Client/Server example: class QuizServer `main()`

```
public static void main( String args[] )
{ //Check command-line parameter (should be quiz #)
    if (args.length < 1 || args.length > 1)
    { System.out.println("Usage: QuizServer <number>");
      System.exit(1);
    } //OK, get quiz number from command-line
    QuizNumber = new Integer(args[0].trim()).intValue() - 1; //Convert to index
   //Set up a Frame for the QuizServer
    QuizServer qs = new QuizServer();
   //Wait for connections from students running the Quiz program
    QuizClient client;                          //a QuizClient
    Vector clients = new Vector(25);            //keep track of a Vector of clients
    while (true) {                              //server goes into infinite loop
      try
      { client =  new QuizClient( server.accept(),  qs);     //create a QuizClient
        client.start();                         //What is start()?
        clients.addElement(client);
      }
      catch (IOException e)
      { System.out.println("QuizServer couldn't accept QuizClient connection");  }
} //main()
```

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Client/server example: class QuizClient

```
class QuizClient extends Thread {
//How else could I have gotten thread functionality?
//class QuizClient implements Runnable  {

    Socket connection; //From java.net.*
    DataOutputStream output; //Data to socket
    DataInputStream input; //Data from socket
    QuizServer quizServer; //Talk to my quizServer
```

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Client/server example: QuizClient constructor

```
public QuizClient( Socket s, QuizServer server )
{ //Get input and output streams.
    connection = s;
    quizServer = server;
    quizServer.display.append( "Connection received from: " +
                connection.getInetAddress().getHostName() );
    try
    {               input = new DataInputStream( connection.getInputStream()
);
        output = new DataOutputStream( connection.getOutputStream() );
    }
   catch ( IOException e )
   { System.out.println("QuizClient can’t open streams thru connection");
     e.printStackTrace();
   }
}
```

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Client/server example: QuizClient `run()`

```
public void run() //excerpts
{  String name=new String();
    quizServer.display.append("userIndex="+userIndex);

    //Logic for updating student's score …

    //Update UMscores file—Why synchronized?
    synchronized (quizServer.studentScores)
   { quizServer.studentScores.writeFile(); }

   quizServer.display.append("Updated UMscores for " + name);
   connection.close(); //Close this socket connection
}
```

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Thread Groups

- Thread groups
  - Why might it be useful to organize threads into groups?
  - May want to **`interrupt`** all threads in a group
  - Thread group can be parent to a child thread group
- Class **`ThreadGroup`**
  - Constructors

    `ThreadGroup( threadGroupName )`

    `ThreadGroup( parentThreadGroup, name )`

    - Creates child **`ThreadGroup`** named **`name`**

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Associating **`Threads`** with **`ThreadGroup`**s

- Use constructors
  - **`Thread( threadGroup, threadName )`**
  - **`Thread( threadGroup, runnableObject )`**
    - Invokes **`run`** method of **`runnableObject`** when thread executes
  - **`Thread( threadGroup, runnableObject, threadName )`**
    - As above, but **`Thread`** named **`threadName`**

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ThreadGroup methods

- **`ThreadGroup`** Methods
  - See API for more details
  - **`activeCount`**
    - Number of active threads in a group and all child groups
  - **`enumerate`**
    - Two versions copy active threads into an array of references
    - Two versions copy active threads in a child group into an array of references
  - **`getMaxPriority`**
    - Returns maximum priority of a **`ThreadGroup`**
    - **`setMaxPriority`**
  - **`getName, getParent`**

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