COP 4610L: Applications in the Enterprise Spring 2005

Programming Multithreaded Applications in Java Part 1

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Introduction to Threads in Java

- In state-of-the art software, a program can be composed of multiple independent flows of control.

- A flow of control is more commonly referred to as a process or thread.

- In most of the Java programs that you've written (probably) there was a single flow of control. Most console-based programs begin with the first statement of the method `main()` and work forward to the last statement of the method `main()`. Flow of control is often temporarily passed to other methods through invocations, but the control returned to `main()` after their completion.

- Programs with a single control flow are known as sequential processes.

Introduction to Threads in Java (cont.)

- Java supports the creation of programs with concurrent flows of control. These independent flows of control are called threads.

- Threads run within a program and make use of that program's resources in their execution. For this reason threads are also called lightweight processes (LWP).

- The ability to run more than one process simultaneously is an important characteristic of modern OS such as Linux/Unix and Windows.

    – The following two pages show screen shots of a set of applications running on my office PC as well as the set of OS and applications processes required to run those applications.
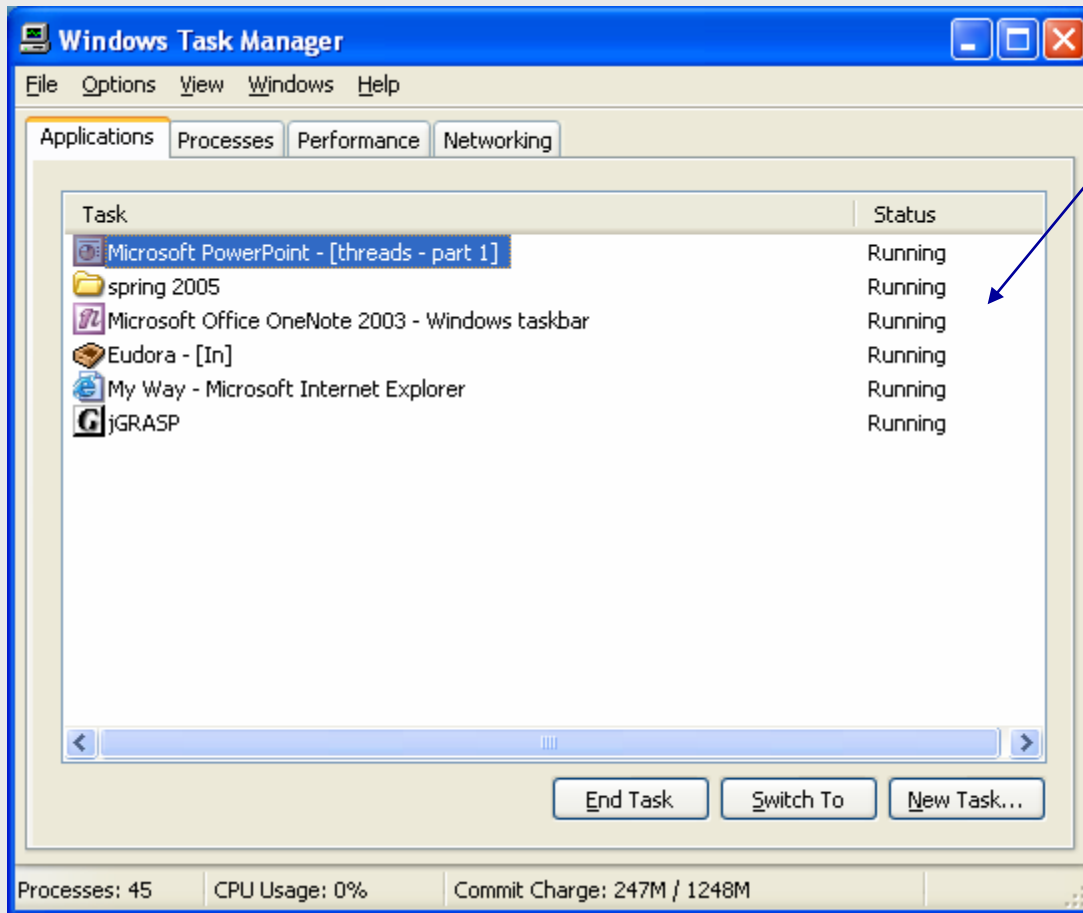
Applications running on my office PC

Windows Task Manager — Processes tab

| Image Name	PID	User Name	CPU	Mem Usage	USER Objects
jGRASPjava.exe	3768	markl	00	4,144 K	26
Eudora.exe	3444	markl	00	4,904 K	493
wisptis.exe	3376	markl	00	3,756 K	87
TASKBAR.exe	3260	markl	00	2,872 K	22
POWERPNT.EXE	2868	markl	00	14,096 K	132
IEXPLORE.EXE	2764	markl	00	6,284 K	128
jgrasp.exe	2664	markl	00	2,624 K	16
wuauclt.exe	2472	markl	00	5,228 K	8
ccApp.exe	1992	markl	00	7,832 K	4
SPOOLSV.EXE	1836	SYSTEM	00	5,824 K	0
TASKMGR.EXE	1724	markl	00	1,972 K	116
qttask.exe	1696	markl	00	2,092 K	2
ccEvtMgr.exe	1684	SYSTEM	00	2,212 K	0
winampa.exe	1628	markl	00	1,980 K	2
ccSetMgr.exe	1600	SYSTEM	00	3,948 K	0
SVCHOST.EXE	1516	LOCAL SERVICE	00	4,132 K	0
mm_tray.exe	1500	markl	00	3,836 K	9
SVCHOST.EXE	1484	NETWORK SERVICE	00	2,116 K	0
mmtask.exe	1428	markl	00	2,988 K	1

☑ Show processes from all users   End Process

Processes: 45   CPU Usage: 0%   Commit Charge: 252M / 1248M

Some of the processes running the applications running on my office PC

CPU working hard!!!
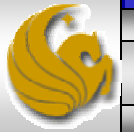
This statement starts thread A. After starting thread A, the program continues with the next statement.

A multithreaded program ends when all of its individual flows of control (threads) end.

```
Multithreaded Program
{
    statement 1;
    statement 2;
    …
    statement x;
    …
    statement y;
    …
    statement z;
}
```

This statement starts thread B. After starting the thread, the program continues with the next statement.
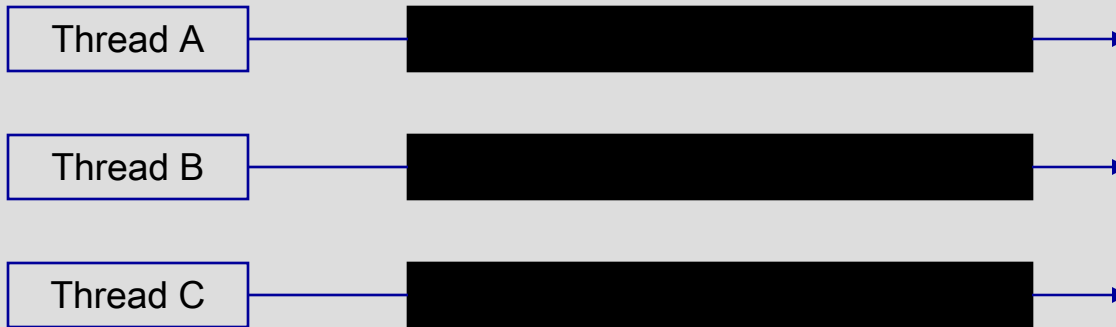
```
Thread A
{
    A statement 1;
    A statement 2;
    …
    A statement m;
    …
    A statement n;
}
```

```
Thread B
{
    B statement 1;
    B statement 2;
    …
    statement r;
}
```

```
Thread C
{
    C statement 1;
    C statement 2;
    …
    C statement t;
}
```

This statement in thread A starts thread C. Thread A continues with next statement.

Thread A

Thread B

Thread C

Thread Execution in a Multiprocessor Environment

Thread A
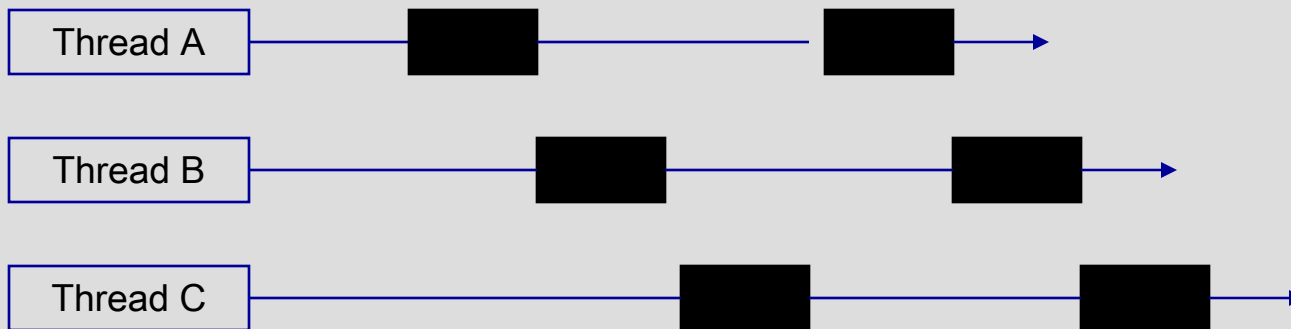
Thread B

Thread C

Thread Execution in a Uniprocessor Environment

The Java `Thread` Class

java.lang.Runnable

```
                java.lang.Thread

+Thread()
+Thread (target: Runnable)
+run(): void



+start(): void
+interrupt(): void
+isAlive(): boolean
+setPriority(p: int): void
+join(): void
+sleep(millis: long): void
+yield(): void
+isInterrupted(): boolean
+currentThread(): Thread
```

Creates a default thread.

Creates a new thread to run the target object

Invoked by the JVM to execute the thread. You must override this method and provide the code you want your thread to execute in your thread class. This method is never directly invoked by a the runnable object in a program, although it is an instance method of a runnable object.

Starts the thread that causes the run() method to be invoked by the JVM

Interrupts this thread. If the thread is blocked, it is ready to run again.

Tests if the thread is currently running.

Sets priority p (ranging from 1 to 10) for this thread.

Waits for this thread to finish.

Puts the runnable object to sleep for a specified time in milliseconds.

Causes this thread to temporarily pause and allow other threads to execute

Tests if the current thread has been interrupted

Returns a reference to the currently executing thread object.

Java Classes and Threads

- Java has several classes that support the creation and scheduling of threads.

- The two basic ways of creating threads in Java are:

  – 1) extending the `Thread` class

  – or 2) implementing the `Runnable` interface.

    (Both are found in package `java.lang`. `Thread` actually implements `Runnable`.)

- We'll look at a slightly different for creating and scheduling threads later using the `java.util.Timer` and `java.util.TimerTask` classes.

Java Classes and Threads (cont.)

- The following two simple examples, illustrate the differences in creating threads using these two different techniques.

- The example is simple, three threads are created, one that prints the character 'A' twenty times, one that prints the character 'B' twenty times, and a third thread that prints the integer numbers from 1 to 20.

- The first program is an example of extending the thread class. The second program is an example of using the `Runnable` interface. This latter technique is the more common and preferred technique. While we will see more examples of this technique later, this simple example will illustrate the difference in the two techniques.

```
//Custom Thread Class
Public class CustomThread extends Thread
{ …
    public CustomThread(…)
    {
       …
    }
    //Override the run method in Thread
    //Tell system how to run custom thread
    public void run( )
    {
       …
    }
    …
} //end CustomThread Class
```

```
//Client Class to utilize CustomThread
Public class Client
{ …
    public void someMethod( )
    {
       …
       //create a thread
       CustomThread thread1 =
               new CustomThread(…);
       //start a thread
       thread1.start( );
       …

       //create another thread
       CustomThread thread2 =
               new CustomThread(…);
       //start another thread
       thread2.start( );
       …
    }
…
} //end Client Class
```

Template for defining a thread class by extending the `Thread` class. Threads thread1 and thread2 are runnable objects created from the CustomThread class. The start method informs the system that the thread is ready to run.

```
//Custom Thread Class
Public class CustomThread implements Runnable
{ …
    public CustomThread(…)
    {
        …
    }
    //Implement the run method in Runnable
    //Tell system how to run custom thread
    public void run( )
    {
        …
    }
    …
} //end CustomThread Class
```

```
//Client Class to utilize CustomThread
Public class Client
{ …
    public void someMethod( )
    {
        …
        //create an instance of CustomThread
        CustomThread custhread =
                new CustomThread(…);
        …
        //create a thread
        Thread thread =
                newThread(custhread);
        …
        //start a thread
        thread.start( );
        …
    }
…
} //end Client Class
```

Template for defining a thread class by implementing the `Runnable` interface. To start a new thread with the `Runnable` interface, you must first create an instance of the class that implements the `Runnable` interface (in this case `custhread`), then use the `Thread` class constructor to construct a thread.

```java
//Class to generate threads by extending the Thread class
public class TestThread {
  // Main method
  public static void main(String[] args) {
    // Create threads
    PrintChar printA = new PrintChar('a', 20);
    PrintChar printB = new PrintChar('b', 20);
    PrintNum  print20 = new PrintNum(20);

    // Start threads
    print20.start();
    printA.start();
    printB.start();
  }
}


// The thread class for printing a specified character a specified number of times
class PrintChar extends Thread {
  private char charToPrint;  // The character to print
  private int times;  // The times to repeat

  // Construct a thread with specified character and number of times to print the character
  public PrintChar(char c, int t) {
    charToPrint = c;
    times = t;
  }
```

Start thread execution after a 0 msec delay (i.e., immediately)

Extension of the Thread class

```java
// Override the run() method to tell the system what the thread will do
  public void run() {
    for (int i = 0; i < times; i++)
      System.out.print(charToPrint);
  }
}

// The thread class for printing number from 1 to n for a given n
class PrintNum extends Thread {
  private int lastNum;

  // Construct a thread for print 1, 2, ... i
  public PrintNum(int n) {
    lastNum = n;
  }

  // Tell the thread how to run
  public void run() {
    for (int i = 1; i <= lastNum; i++)
      System.out.print(" " + i);
  }
} //end class TestThread
```

Overriding the `run` method
in the Thread class

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servertool.exe
StockQuote.java
StockReader.java
SurveyServlet.class
SurveyServlet.java
TabbedPaneWebBrowser$ExitAction.class
TabbedPaneWebBrowser$NewTabAction.cla:
TabbedPaneWebBrowser.class
TabbedPaneWebBrowser.java
TestThread.class
TestThread.java
TextAreaDemo.class
TextAreaDemo.java

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TestThread.java C:\Program Files\Java\jdk1.5.0\bin - jGRASP CSD (Java)

File   Edit   View   Templates   Compiler   Run   Workbench   Help

```java
//Class to generate threads by extending the Thread class
public class TestThread {
   // Main method
   public static void main(String[] args) {
      // Create threads
      PrintChar printA = new PrintChar('a', 20);
      PrintChar printB = new PrintChar('b', 20);
      PrintNum  print20 = new PrintNum(20);

      // Start threads
      print20.start();
      printA.start();
```

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currentW...   TestThre...

Sample executions of class
TestThread. Notice that the output
from the three threads is interleaved.
Also notice that the output sequence
is not repeatable.

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End

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Help

```
L    ----jGRASP: operation complete.

     ----jGRASP exec: java TestThread

  1ba 2ba 3ba 4ba 5ba 6ba 7ba 8ba 9ba 10ba 11ba 12ba 13ba 14ba 15ba 16ba 17ba 18ba 19ba 20ba
     ----jGRASP: operation complete.

     ----jGRASP exec: java TestThread

 a 1ba 2ba 3ba 4ba 5ba 6ba 7ba 8ba 9ba 10ba 11ba 12ba 13ba 14ba 15ba 16ba 17ba 18ba 19ba 20b
     ----jGRASP: operation complete.

     ----jGRASP exec: java TestThread

  1ab 2ab 3ab 4ab 5ab 6ab 7ab 8ab 9ab 10ab 11ab 12ab 13ab 14ab 15ab 16ab 17ab 18ab 19ab 20ab
     ----jGRASP: operation complete.
L
```

```java
//Class to generate threads by implementing the Runnable interface
public class TestRunnable {
 // Create threads
 Thread printA = new Thread(new PrintChar('a', 20));
 Thread printB = new Thread(new PrintChar('b', 20));
 Thread print20 = new Thread(new PrintNum(20));

 public static void main(String[] args) {
   new TestRunnable();
 }

 public TestRunnable() {
   // Start threads
   print20.start();
   printA.start();
   printB.start();
 }

 // The thread class for printing a specified character in specified times
 class PrintChar implements Runnable {
   private char charToPrint;  // The character to print
   private int times;  // The times to repeat

   // Construct a thread with specified character and number of times to print the character
   public PrintChar(char c, int t) {
     charToPrint = c;
     times = t;
   }
```

Main method simple creates a new Runnable object and terminates.

Runnable object starts thread execution.

Implements the Runnable interface.

```java
// Override the run() method to tell the system what the thread will do
  public void run() {
    for (int i = 0; i < times; i++)
      System.out.print(charToPrint);
  }
 }

 // The thread class for printing number from 1 to n for a given n
 class PrintNum implements Runnable {
   private int lastNum;

   // Construct a thread for print 1, 2, ... i
   public PrintNum(int n) {
     lastNum = n;
   }

   // Tell the thread how to run
   public void run() {
     for (int i = 1; i <= lastNum; i++)
       System.out.print(" " + i);
   }
 }
} //end class TestRunnable
```

Override the run method for both types of threads.

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servertool.exe
StockQuote.java
StockReader.java
SurveyServlet.class
SurveyServlet.java
TabbedPaneWebBrowser$ExitAction.class
TabbedPaneWebBrowser$NewTabAction.cla
TabbedPaneWebBrowser.class
TabbedPaneWebBrowser.java
TestRunnable$PrintChar.class
TestRunnable$PrintNum.class
TestRunnable.class
TestRunnable.java

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mpile Messages | jGRASP Messages | Run I/O

TestRunnable.java C:\Program Files\Java\jdk1.5.0\bin - jGRASP CSD (Java)

File   Edit   View   Templates   Compiler   Run   Workbench   Help

```
//Class to illustrate threads created via Runnable interface
public class TestRunnable {
  // Create threads
  Thread printA = new Thread(new PrintChar('a', 20));
  Thread printB = new Thread(new PrintChar('b', 20));
  Thread print20 = new Thread(new PrintNum(20));

  public static void main(String[] args) {
    new TestRunnable();
  }

  public TestRunnable() {
```

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currentW... | TestThre... | TestRunn...

Sample executions of class TestRunnable. Notice that the output from the three threads is interleaved. Also notice that the output sequence is not repeatable.

```
L   ----jGRASP: operation complete.

  ----jGRASP exec: java TestRunnable

  1ba 2ba 3ba 4ba 5ba 6ba 7ba 8ba 9ba 10ba 11ba 12ba 13ba 14ba 15ba 16ba 17ba 18ba 19ba 20ba
  ----jGRASP: operation complete.

  ----jGRASP exec: java TestRunnable

  1ab 2ab 3ab 4ab 5ab 6ab 7ab 8ab 9ab 10ab 11ab 12ab 13ab 14ab 15ab 16ab 17ab 18ab 19ab 20ab
  ----jGRASP: operation complete.

  ----jGRASP exec: java TestRunnable

  a 1ba 2ba 3ba 4ba 5ba 6ba 7ba 8ba 9ba 10ba 11ba 12ba 13ba 14ba 15ba 16ba 17ba 18ba 19ba 20b
  ----jGRASP: operation complete.
L
```

End

Clear

Help

Some Modifications to the Example

- To illustrate some of the methods in the `Thread` class, you might want to try a few modifications to the `TestRunnable` class in the previous example. Notice how the modifications change the order of the numbers and characters in the output.

- Use the `yield()` method to temporarily release time for other threads to execute. Modify the code in the `run` method in `PrintNum` class to the following:

```
public void run() {
    for (int i = 1; i <= lastNum; i++) {
      System.out.print(" " + i);
       Thread.yield();
     }
```

  - Now every time a number is printed, the print20 thread yields, so each number will be followed by some characters.

Some Modifications to the Example (cont.)

- The `sleep(long millis)` method puts the thread to sleep for the specified time in milliseconds. Modify the code in the `run` method in `PrintNum` class to the following:

```
public void run() {
    for (int i = 1; i <= lastNum; i++) {
        System.out.print(" " + i);
        try {
                if (i >= 10) Thread.sleep(2);
        }
        catch (InterruptedException ex) { }
    }
}
```

- Now every time a number greater than 10 is printed, the print20 thread is put to sleep for 2 milliseconds, so all the characters will complete printing before the last integer is printed.

Some Modifications to the Example (cont.)

- You can use the `join()` method to force one thread to wait for another thread to finish. Modify the code in the `run` method in `PrintNum` class to the following:

```java
public void run() {
    for (int i = 1; i <= lastNum; i++) {
      System.out.print(" " + i);
      try {
            if (i == 10) printA.join();
      }
      catch (InterruptedException ex) { }
    }
}
```

  – Now the numbers greater than 10 are printed only after thread printA is finished.

Other Java Classes and Threads

- We noted earlier that Java has several different classes that support the creation and scheduling of threads. Classes `java.util.Timer` and `java.util.TimerTask` are generally the easiest to use. They allow a thread to be created and run either at a time relative to the current time or at some specific time.

- We'll look at these classes briefly and give a couple of examples.

Java Classes and Threads (cont.)

- Class `Timer` overloads the `schedule()` method three times for creating threads after either some specified delay or at some specific time.

  - `public void schedule(TimerTask task, long m);`

    - Runs `task.run()` after waiting `m` milliseconds.

  - `public void schedule(TimerTask task, long m, long n);`

    - Runs `task.run()` after waiting `m` milliseconds, then repeats it every `n` milliseconds.

  - `Public void schedule(TimerTask task, Date t);`

    - Runs `task.run()` at the time indicated by date `t`.

- By extending the abstract class `TimerTask` and specifying a definition for its abstract method `run()`, an application-specific thread can be created.

Example – Thread Execution After a Delay

- The code listing on the following page gives a very simple example of executing a thread after a delay (using the first schedule() method from the previous page).

- The thread in this example, simply prints a character 10 times and then ends.

- Look at the code and follow the flow, then execute it on your machine (code appears on the course webpage).

```java
//displays characters in separate threads
import java.util.*;
public class DisplayCharSequence extends TimerTask {
    private char displayChar;
    Timer timer;

    //constructor for character displayer
    public DisplayCharSequence(char c){
        displayChar = c;
        timer = new Timer();
        timer.schedule(this, 0);
    }

    //display the occurrences of the character
    public void run() {
        for (int i = 0; i < 10; ++i) {
            System.out.print(displayChar);
        }
        timer.cancel();
    }

    //main
    public static void main (String[] args) {
        DisplayCharSequence s1 = new DisplayCharSequence('M');
        DisplayCharSequence s2 = new DisplayCharSequence('A');
        DisplayCharSequence s3 = new DisplayCharSequence('R');
        DisplayCharSequence s4 = new DisplayCharSequence('K');
    }
}
```

Start thread execution after a 0 msec delay (i.e., immediately)

A subclass implementation of TimerTask's abstract method run() has typically two parts – first part is application specific (what the thread is supposed to do) and the second part ends the thread.

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currentWeather.java
denver.wth
DisplayCharSequence.class
DisplayCharSequence.java
DisplayQueryResults$1.class
DisplayQueryResults$2.class
DisplayQueryResults$3.class
DisplayQueryResults$4.class
DisplayQueryResults$5.class
DisplayQueryResults.class
DisplayQueryResults.java
DisplayQueryResults2$1.class

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DisplayCharSequence.java C:\Program Files\Java\jdk1.5.0\bin - jGRASP CSD (Java)

File   Edit   View   Templates   Compiler   Run   Workbench   Help

```java
// Example of creating threads by extending TimerTask class
// Displays characters in separate threads
import java.util.*;
public class DisplayCharSequence extends TimerTask {
    private char displayChar;
    Timer timer;

    //constructor for character displayer
    public DisplayCharSequence(char c){
        displayChar = c;
        timer = new Timer();
        timer.schedule(this, 0);
```

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currentW...   DisplayCh...

mpile Messages   jGRASP Messages   Run I/O

End

Clear

Help

```
L  ----jGRASP: operation complete.

  ----jGRASP exec: java DisplayCharSequence

MMMMMMMMMRRRRRARAKRAKRAKRAKRAKAKAKAKAKK
 ----jGRASP: operation complete.

  ----jGRASP exec: java DisplayCharSequence

MMMMMMMMMRMAAAARARAKRAKRAKRAKRAKRKRKRKKK
 ----jGRASP: operation complete.

  ----jGRASP exec: java DisplayCharSequence

MMMMMMMMMRMMARKARKARKARKARKARKARKARKARKAK
 ----jGRASP: operation complete.
L
```

Example – Repeated Thread Execution

- This next example demonstrates how to schedule a thread to run multiple times. Basically, the thread updates a GUI-based clock every second.

Sample GUI
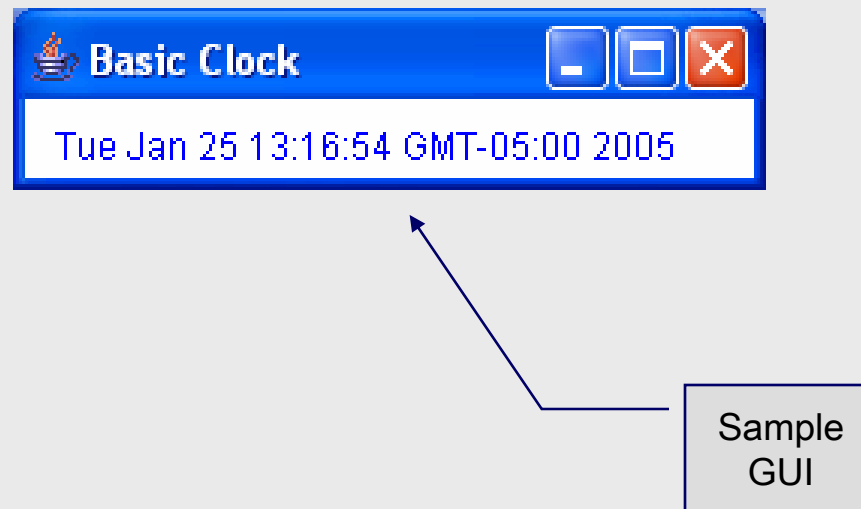
```java
//displays current time – threaded execution
import java.util.*;
import javax.swing.JFrame;
import java.text.*;
import java.awt.*;

public class BasicClock extends TimerTask {
    final static long MILLISECONDS_PER_SECOND = 1000;
    private JFrame window = new JFrame("Basic Clock");
    private Timer timer = new Timer();
    private String clockFace = "";

    //constructor for clock
    public BasicClock(){
        //set up GUI
        window.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        window.setSize(200,60);
        Container c = window.getContentPane();
        c.setBackground(Color.WHITE);
        window.setVisible(true);
        //update GUI every second beginning immediately
        timer.schedule(this,0,1*MILLISECONDS_PER_SECOND);
    }
```

Two tasks: (1) configure the GUI and (2) schedule the thread to update the GUI-clock every second.

This form of the overloaded schedule() method is the second one shown on page 8 which uses a delay and a repetition factor.

Basic Clock

Tue Jan 25 13:18:06 GMT-05:00 2005

Date() returns current time to the millisecond. toString() method returns a textual representation of the date in the form: *w c d h:m:s z y*
Where: w: 3 char-rep of day of week
        c: 3 char-rep of month
        d: 2 digit-rep of day of month
        h: 2 digit-rep of hour
        m: 2 digit-rep of minute within hr
        s: 2 digit-rep of second within min
        z: 3 char-rep of time zone
        y: 4 char-rep of year

```java
    //display updated clock
    public void run(){
        Date time = new Date();
        Graphics g = window.getContentPane().getGraphics();
        g.setColor(Color.WHITE);
        g.drawString(clockFace, 10, 20);
        clockFace = time.toString();
        g.setColor(Color.BLUE);
        g.drawString(clockFace,10, 20);
}

    //main
    public static void main (String[] args) {
        BasicClock clock = new BasicClock();
    }
}
```
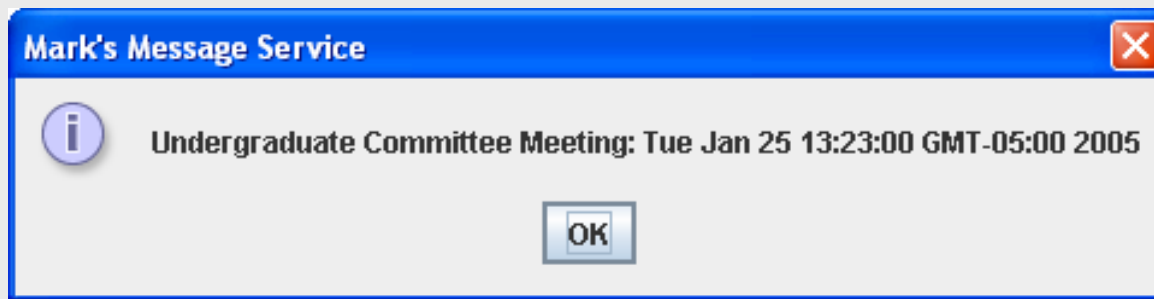
!! CAUTION !!

- Java provides two different standard classes named `Timer`. The class we've used in the past two examples is part of the `util` API. There is also a `Timer` class that is part of the `swing` API.

- In our previous example, we needed to make sure that we didn't inadvertently bring both `Timer` classes into our program which would have created an ambiguity about which `Timer` class was being used.

- Although you cannot import both `Timer` classes into a single Java source file, you can use both `Timer` classes in the same Java source file. An `import` statement exists to allow a syntactic shorthand when using Java resources; i.e., an `import` statement is not required to make use of Java resources. Using fully qualified class names will remove the ambiguity.

  - java.util.Time t1 = new java.util.Timer();

  - javax.swing.Timer t2 = new javax swing.Timer();

Example – Thread Execution At Specific Time

- This next example demonstrates how to schedule a thread to run at a specific time. This example will create a couple of threads to remind you of impending appointments. Basically, the thread pops-up a window to remind you of the appointment.

Sample
DisplayAlert
Window

```
//Displays an alert at a specific time - threaded execution
    import javax.swing.JOptionPane;
    import java.awt.*;
    import java.util.*;

    public class DisplayAlert extends TimerTask {
         //instance variables
       private String message;
         private Timer timer;

         //constructor
         public DisplayAlert(String s, Date t){
            message = s + ": " + t;
                timer = new Timer();
                timer.schedule(this, t);
         }

         //execute thread
         public void run() {
            JOptionPane.showMessageDialog(null, message, "Mark's Message
   Service", JOPtionPane.INFORMATION_MESSAGE);  //application specific task
                timer.cancel();  //kill thread
         }
```

Third version of schedule() method as shown on page 8.

```java
public static void main(String[] args) {
    Calendar c = Calendar.getInstance();
        c.set(Calendar.HOUR_OF_DAY, 13);
        c.set(Calendar.MINUTE, 23);
        c.set(Calendar.SECOND, 0);

        Date meetingTime = c.getTime();

        c.set(Calendar.HOUR_OF_DAY, 10);
        c.set(Calendar.MINUTE, 25);
        c.set(Calendar.SECOND, 0);

        Date classTime = c.getTime();

        DisplayAlert alert1 = new DisplayAlert("Undergraduate
                Committee Meeting", meetingTime);
        DisplayAlert alert2 = new DisplayAlert("COP 4610L Class
                Time", classTime);
    }
}
```

Create two messages
to be displayed at
different times.

Sleeping

- In the three examples so far, all the threads performed some action. Threads are also used to pause a program for some period of time.

- Standard class `java.lang.Thread` has a class method `sleep()` for pausing the flow of control.

  ```
  public static void sleep (long n) throws InterruptedException
  ```

- For example, the following code segment will twice get and display the current time, but the time acquisitions are separated by 10 seconds by putting the process to sleep.

```java
//Illustrates putting a process to sleep
   import java.util.*;

   public class ShowSleeping {

       public static void main(String[] args) {
          Date t1 = new Date();
               System.out.println("Thread goes to sleep at: " +
   t1);

               try {
                   Thread.sleep(10000);
               }
               catch (InterruptedException e) {
               }
               Date t2 = new Date();
               System.out.println("Thread wakes up at: " + t2);
       }
   }
```

Put the process to sleep for 10 seconds.

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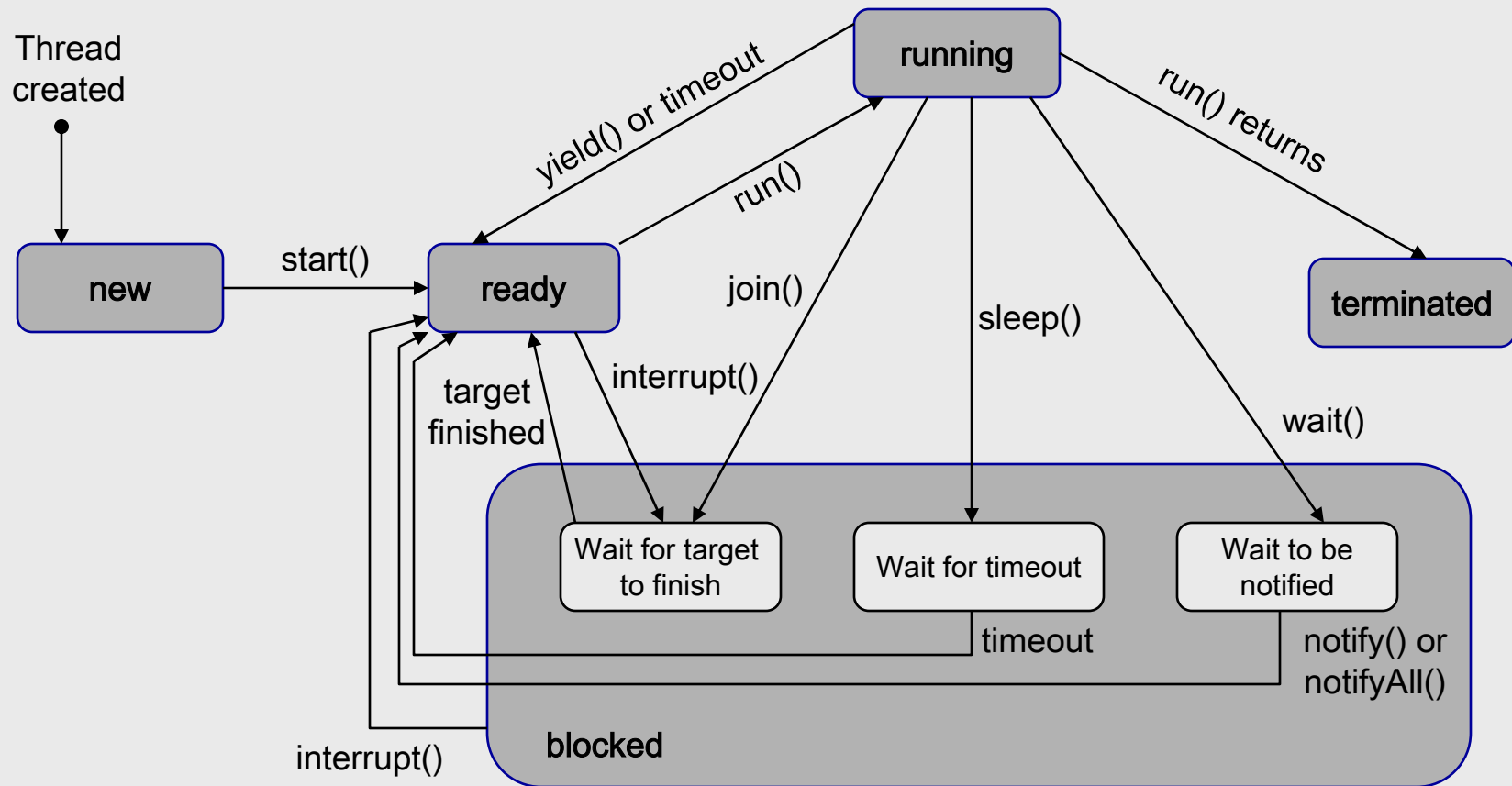
End

Clear

Help

```
    ----jGRASP exec: java ShowSleeping

 Thread goes to sleep at: Tue Jan 25 13:32:23 GMT-05:00 2005
 Thread wakes up at: Tue Jan 25 13:32:33 GMT-05:00 2005

  ----jGRASP: operation complete.

    ----jGRASP exec: java ShowSleeping

 Thread goes to sleep at: Tue Jan 25 13:32:50 GMT-05:00 2005
 Thread wakes up at: Tue Jan 25 13:33:00 GMT-05:00 2005

  ----jGRASP: operation complete.
```

Notice that the process has slept for exactly 10 seconds in both cases.

Life Cycle of a Thread

- At any given point in time, a thread is said to be in one of several thread states as illustrated in the diagram below.

Thread created

new → start() → ready

yield() or timeout

running

run()

run() returns

terminated

join()

interrupt()

target finished

sleep()

wait()

Wait for target to finish

Wait for timeout

Wait to be notified

timeout

notify() or notifyAll()

interrupt()

blocked

Life Cycle of a Thread (cont.)

- A new thread begins its life cycles in the new state. It remains in this state until the program starts the thread, which places the thread in the ready state (also commonly referred to as the runnable state). A thread in this state is considered to be executing its task, although at any given moment it may not be actually executing.

- When a ready thread begins execution, it enters the running state. A running thread may return to the ready state if its CPU time slice expires or its `yield()` method is invoked.

- A thread can enter the blocked state (i.e., it becomes inactive) for several reasons. It may have invoked the `join()`, `sleep()`, or `wait()` method, or some other thread may have invoked these methods. It may be waiting for an I/O operation to complete.

- A blocked thread can be reactivated when the action which inactivated it is reversed. For example, if a thread has been put to sleep and the sleep time has expired, the thread is reactivated and enters the ready state.

Life Cycle of a Thread (cont.)

- A thread is terminated if it completes the execution of its `run()` method.

- The `isAlive()` method is used to query the state of a thread. This method returns true it a thread is in the ready, blocked, or running state; it returns false if a thread is new and has not started or if it is finished.

- The `interrupt()` method interrupts a thread in the following way: If a thread is currently in the ready or running state, its interrupted flag is set; if a thread is currently blocked, it is awakened and enters the ready state, and a java.lang.InterruptedException is thrown.

- Threads typically sleep when they momentarily do not have work to perform. Example, a word processor may contain a thread that periodically writes a copy of the current document to disk for recovery purposes.

Life Cycle of a Thread (cont.)

- A runnable thread enters the terminated state when it completes its task or otherwise terminates (perhaps due to an error condition).

- At the OS level, Java's runnable state actually encompasses two separate states. The OS hides these two states from the JVM, which sees only the runnable state.

  - When a thread first transitions to the runnable state from the new state, the thread is in the ready state. A ready thread enters the running state (i.e., begins execution) when the OS assigns the thread to a processor (this is called dispatching the thread). In most OS, each thread is given a small amount of processor time – called a quantum or time slice – with which to perform its task. When the thread's quantum expires, the thread returns to the ready state and the OS assigns another thread to the processor. Transitions between these states are handled solely by the OS.
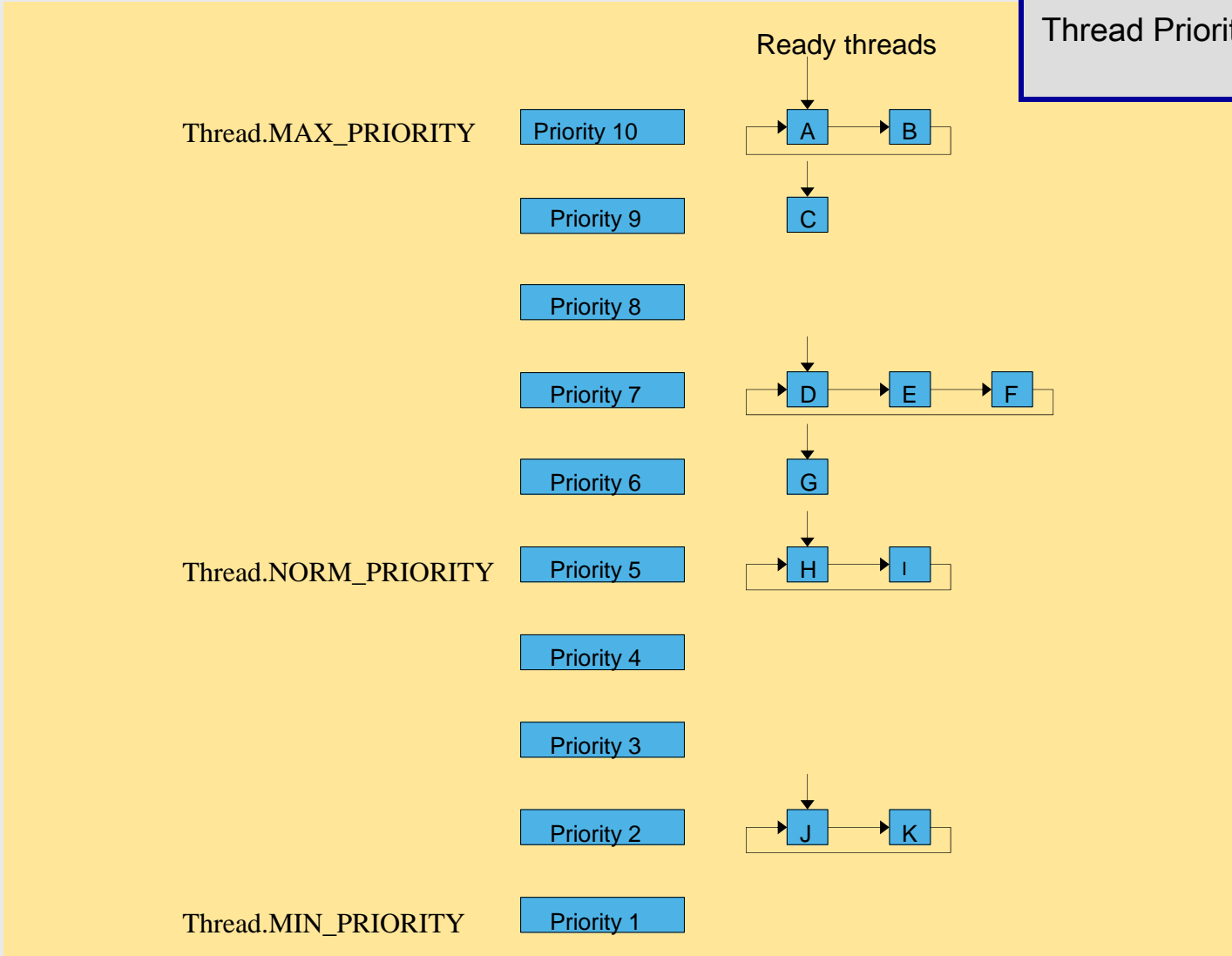
Thread Priorities

- Every Java thread has a priority that helps the OS determine the order in which threads are scheduled.

- Java priorities are in the range between MIN_PRIORITY (a constant of 1) and MAX_PRIORITY (a constant of 10).

- Threads with a higher priority are more important to a program and should be allocated processor time before lower-priority threads. However, thread priorities cannot guarantee the order in which threads execute.

- By default, every thread is given priority NORM_PRIORITY (a constant of 5). Each new thread inherits the priority of the thread that created it.

Thread Priority Scheduling

Ready threads

Thread.MAX_PRIORITY   Priority 10   A → B

Priority 9   C

Priority 8

Priority 7   D → E → F

Priority 6   G

Thread.NORM_PRIORITY   Priority 5   H → I

Priority 4

Priority 3

Priority 2   J → K

Thread.MIN_PRIORITY   Priority 1

Creating and Executing Threads

- In J2SE 5.0, the preferred means of creating a multithreaded application is to implement the `Runnable` interface (package `java.lang`) (see earlier examples also) and use built-in methods and classes to create `Threads` that execute the `Runnables`.

- The `Runnable` interface declares a single method named `run`, `Runnables` are executed by an object of a class that implements the `Executor` interface (package `java.util.concurrent`). This interface declares a single method named `execute`.

- An `Executor` object typically creates and managed a group of threads called a thread pool. These threads execute the `Runnable` objects passed to the `execute` method.

Creating and Executing Threads (cont.)

- The `Executor` assigns each `Runnable` to one of the available threads in the thread pool. If there are no available threads in the thread pool, the `Executor` creates a new thread or waits for a thread to become available and assigns that thread the `Runnable` that was passed to method `execute`.

- Depending on the Executor type, there may be a limit to the number of threads that can be created. Interface ExecutorService (package `java.util.concurrent`) is a subinterface of Executor that declares a number of other methods for managing the life cycle of the Executor. An object that implements this ExecutorService interface can be created using static methods declared in class Executors (package `java.util.concurrent`). The next examples illustrates these.

Multithreading Example – Sleeping/Waking Threads

```
// PrintTask class sleeps for a random time from 0 to 5 seconds
import java.util.Random;

public class PrintTask implements Runnable
{
    private int sleepTime; // random sleep time for thread
    private String threadName; // name of thread
    private static Random generator = new Random();

    // assign name to thread
    public PrintTask( String name )
    {
        threadName = name; // set name of thread

        // pick random sleep time between 0 and 5 seconds
        sleepTime = generator.nextInt( 5000 );
    } // end PrintTask constructor
```

Multithreading Example – Sleeping/Waking Threads

```
// method run is the code to be executed by new thread
   public void run()
   {
      try // put thread to sleep for sleepTime amount of time
   {
   System.out.printf( "%s going to sleep for %d milliseconds.\n",
            threadName, sleepTime );

         Thread.sleep( sleepTime ); // put thread to sleep
   } // end try
    // if thread interrupted while sleeping, print stack trace
    catch ( InterruptedException exception )
    {
      exception.printStackTrace();
    } // end catch
      // print thread name
      System.out.printf( "%s done sleeping\n", threadName );
   } // end method run
} // end class PrintTask
```

Multithreading Example – Create Threads and Execute

```java
// Multiple threads printing at different intervals.
import java.util.concurrent.Executors;
import java.util.concurrent.ExecutorService;
public class RunnableTester
{
   public static void main( String[] args )  {
      // create and name each runnable
      PrintTask task1 = new PrintTask( "thread1" );
      PrintTask task2 = new PrintTask( "thread2" );
      PrintTask task3 = new PrintTask( "thread3" );

      System.out.println( "Starting threads" );

      // create ExecutorService to manage threads
      ExecutorService threadExecutor = Executors.newCachedThreadPool();
      // start threads and place in runnable state
      threadExecutor.execute( task1 ); // start task1
      threadExecutor.execute( task2 ); // start task2
      threadExecutor.execute( task3 ); // start task3

      threadExecutor.shutdown(); // shutdown worker threads

      System.out.println( "Threads started, main ends\n" );
   } // end main
} // end class RunnableTester
```

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End

Clear

Help

```
    ----jGRASP exec: java RunnableTester

Starting threads
thread1 going to sleep for 628 milliseconds.
thread3 going to sleep for 3699 milliseconds.
thread2 going to sleep for 2854 milliseconds.
Threads started, main ends

thread1 done sleeping
thread2 done sleeping
thread3 done sleeping

  ----jGRASP: operation complete.

    ----jGRASP exec: java RunnableTester

Starting threads
thread1 going to sleep for 1845 milliseconds.
thread3 going to sleep for 1799 milliseconds.
thread2 going to sleep for 1975 milliseconds.
Threads started, main ends

thread3 done sleeping
thread1 done sleeping
thread2 done sleeping

  ----jGRASP: operation complete.

    ----jGRASP exec: java RunnableTester

Starting threads
thread1 going to sleep for 4471 milliseconds.
thread2 going to sleep for 2777 milliseconds.
Threads started, main ends

thread3 going to sleep for 37 milliseconds.
thread3 done sleeping
thread2 done sleeping
thread1 done sleeping

  ----jGRASP: operation complete.
```

Example Executions of
RunnableTester.java