

CNT 4714: Enterprise Computing

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Programming Multithreaded Applications in Java

Part 1

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Introduction to Threads in Java

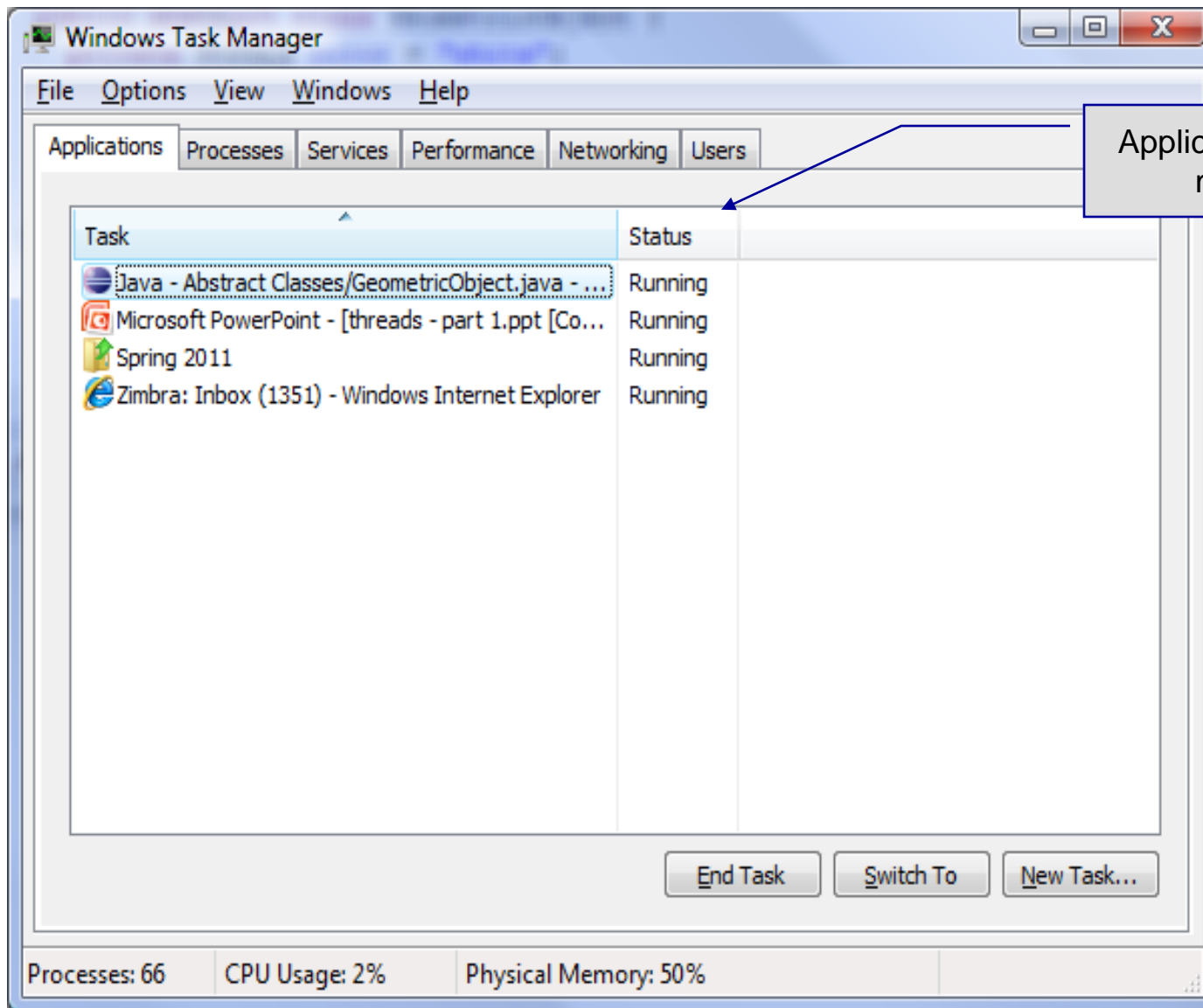
- In state-of-the-art software, a program can be composed of multiple independent flows of control.
- A flow of control is more commonly referred to as a **process** or **thread**.
- In most of the Java programs that you've written (probably) there was a single flow of control. Most console-based programs 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

File Options View Help

Applications Processes Services Performance Networking Users

Image Name	User Name	CPU	Memory (...)	Description
AdobeARM.exe	Lei Wei	00	2,840 K	Adobe Re...
ApacheMonitor.exe	Lei Wei	00	1,048 K	Apache H...
AppleMobileDeviceService.exe	SYSTEM	00	1,132 K	Apple Mo...
atchk.exe	Lei Wei	00	1,436 K	Displays s...
atchkshr.exe	SYSTEM	00	732 K	Displays s...
atiedxx.exe	SYSTEM	00	1,156 K	AMD Exte...
atiesrxx.exe	SYSTEM	00	848 K	AMD Exte...
audiodg.exe	LOCAL ...	00	9,992 K	Windows ...
csrss.exe	SYSTEM	00	1,224 K	Client Ser...
csrss.exe	SYSTEM	00	1,236 K	Client Ser...
dwm.exe	Lei Wei	00	19,060 K	Desktop ...
explorer.exe	Lei Wei	00	19,900 K	Windows ...
GoogleCrashHandler.exe	Lei Wei	00	252 K	Google In...
GoogleToolbarNotifier.exe	Lei Wei	00	1,228 K	GoogleTo...
GoogleUpdate.exe	Lei Wei	00	756 K	Google In...

Show processes from all users

End Process

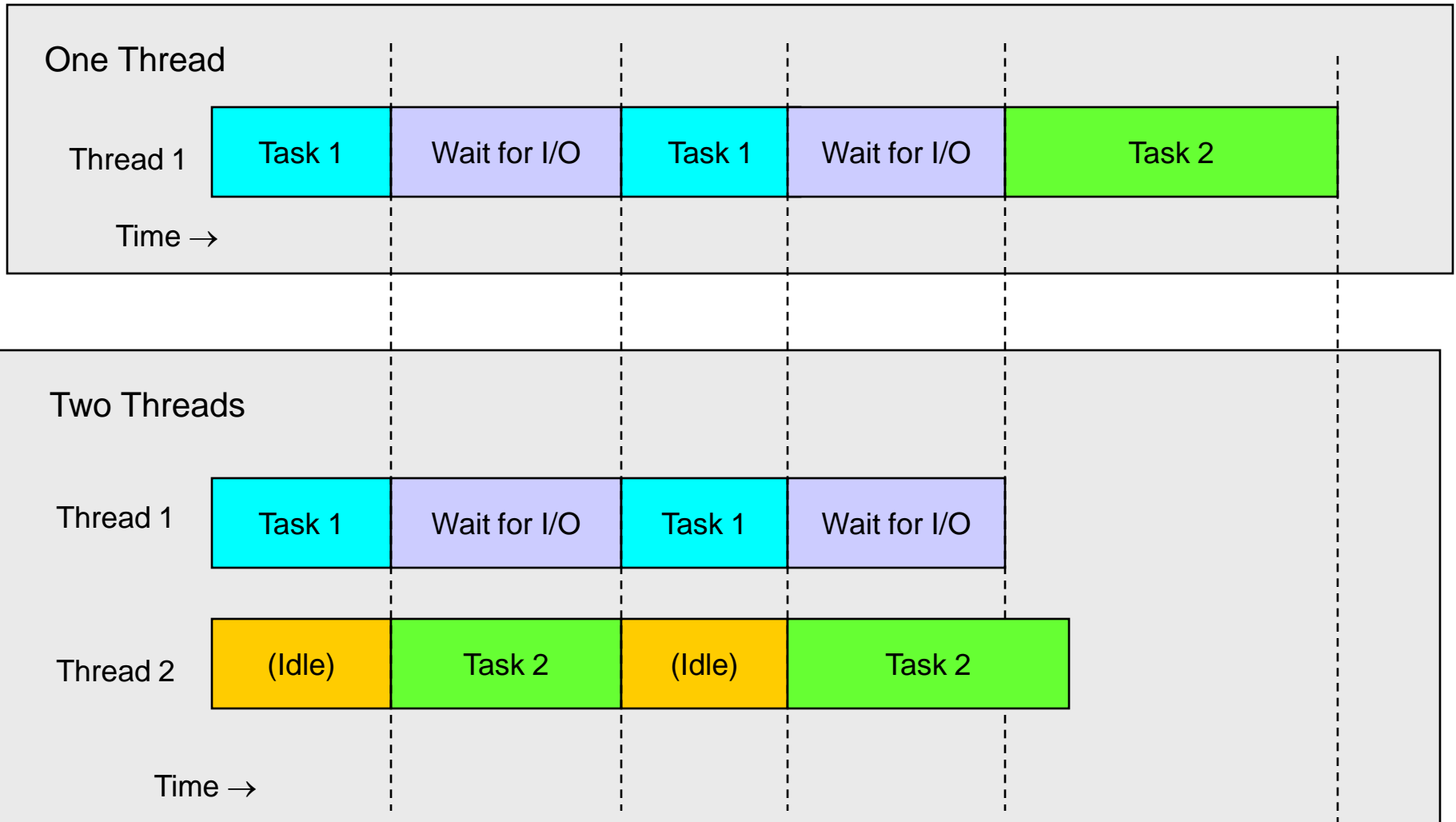
Processes: 62 CPU Usage: 0% Physical Memory: 42%

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

CPU working hard!!!



Using Threads To Improve Performance



Improving Performance With Multithreading

- As the diagram on the previous page implies, applications that perform several tasks which are not dependent on one another will benefit the most from multithreading.
- For example, in the previous diagram, Task 2 can only be overlapped with Task 1 if Task 2 doesn't depend on the results of Task 1.
- However, some overlap between the two tasks may still be possible even if Task 2 depends on the results of Task 1. In this case the two tasks must communicate so that they can coordinate their operations.



Improving Performance With Multithreading

(cont.)

- Writing multithreaded programs can be tricky and complicated, particularly when synchronization between threads is required.
- Although the human mind can perform many functions concurrently, people find it difficult to jump between parallel trains of thought.
- To see why multithreading can be difficult to program and understand, try the experiment shown on the following page.



Multithreading Experiment

In this chapter, we introduce Swing components that enable developers to build functionally rich user interfaces.

Page 1

The Swing graphical interface components were introduced with the Java Foundation Classes (JFC) as a downloadable extension to the Java 1.1 Platform, then became a standard extension with the Java 2 Platform.

Page 2

Swing provides a more complete set of GUI components than the Abstract Windowing Toolkit (AWT), including advanced features such as a pluggable look and feel, lightweight component rendering and drag-and-drop capabilities.

Page 3

The experiment: Try reading the pages above concurrently by reading a few words from the first page, then a few words from the second page, then a few words from the third page, then loop back and read a few words from the first page, and so on. Does anything make sense? Can you construct a single sentence from what you have read? Can you remember on which page a particular word appeared? Can you even remember when you get back to the first page where you left off?



Typical Multithreaded Applications

- Used to improve the performance of applications which require extensive I/O operations.
- Useful in improving the responsiveness of GUI-based applications.
- Used when two or more clients need to run server-based applications simultaneously.

Note: on a single CPU machine, threads don't actually execute simultaneously. Part of the JVM known as the thread scheduler time-slices threads which are runnable (we'll see more of this in a bit) giving the illusion of simultaneous execution.



This statement starts thread A. After starting thread A, the program continues with the next statement.

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

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

This statement starts thread B. After starting the thread, the program continues with the next statement.

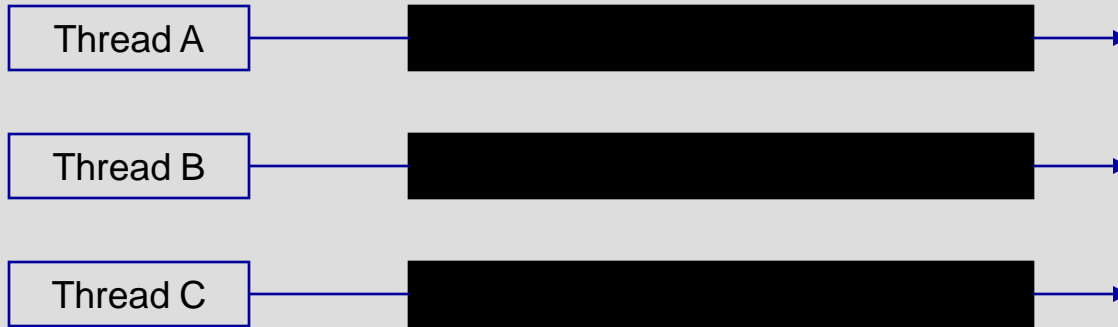
```
Thread A  
{  
  A statement 1;  
  A statement 2;  
  ...  
  A statement m;  
  ...  
  A statement n;  
}
```

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

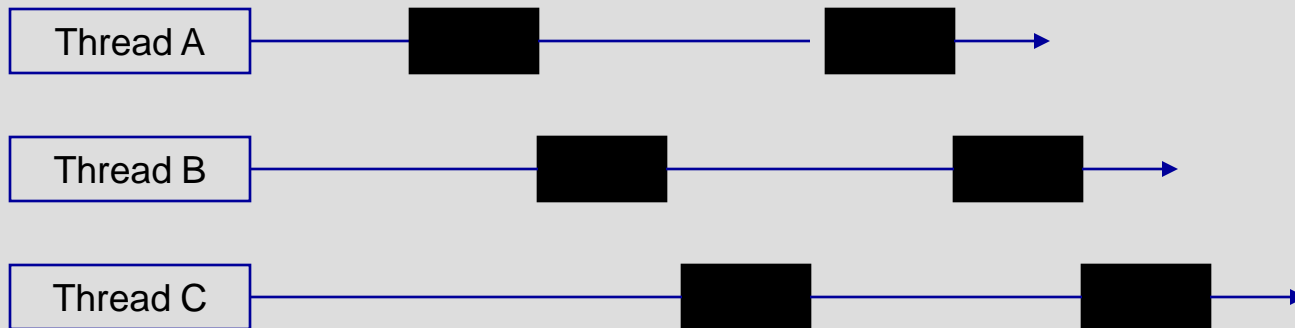
```
Thread C  
{  
  C statement 1;  
  C statement 2;  
  ...  
  C statement t;  
}
```

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





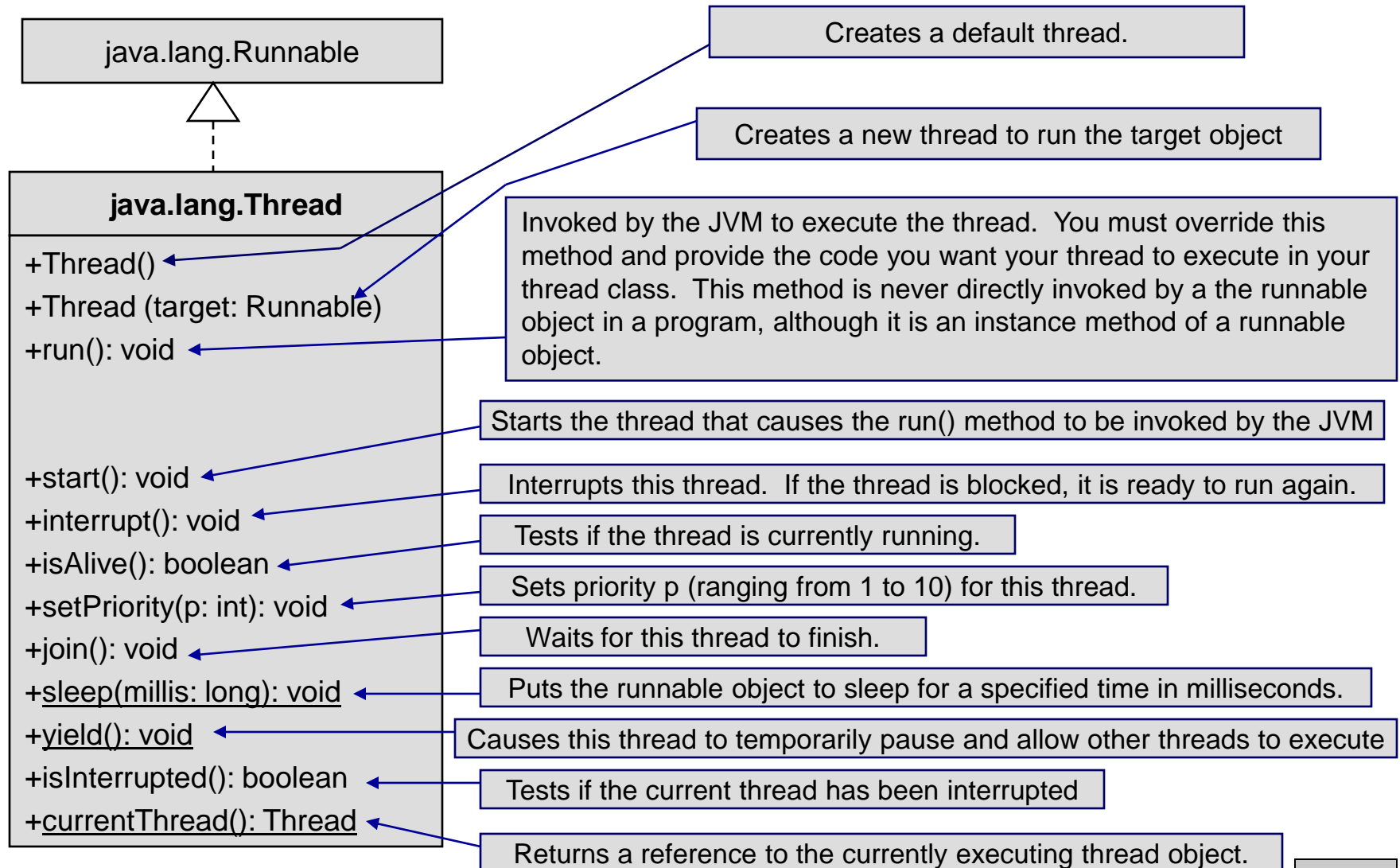
Thread Execution in a Multiprocessor Environment



Thread Execution in a Uniprocessor Environment



The Java Thread Class



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 also look at a slightly different technique 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 =
      new Thread(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.



//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();  
    }  
}
```

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

// 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
```

Extension of the Thread
class

// Construct a thread with specified character and number of times to print the character

```
public PrintChar(char c, int t) {  
    charToPrint = c;  
    times = t;  
}
```



```
// 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;
```

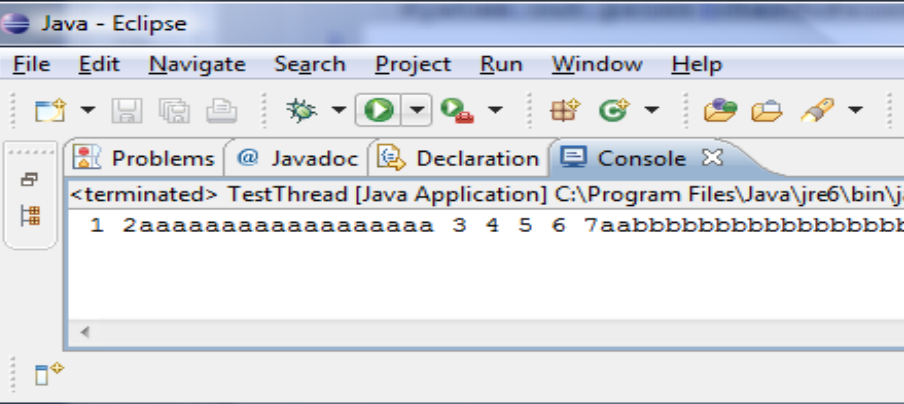
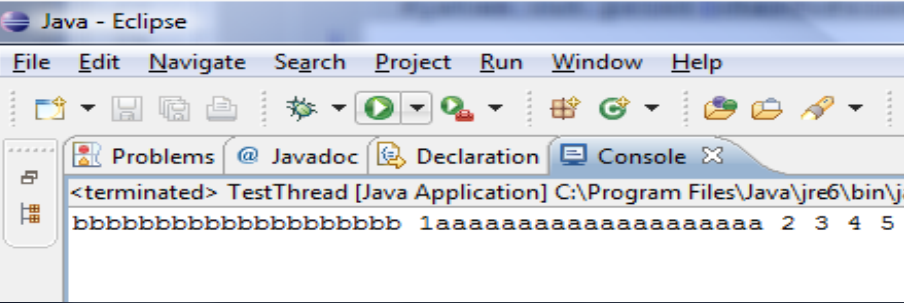
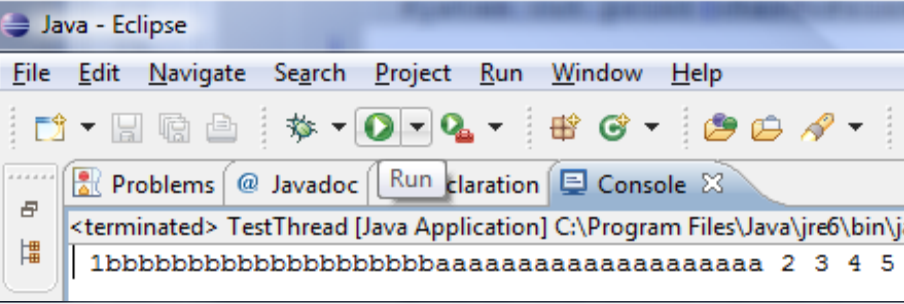
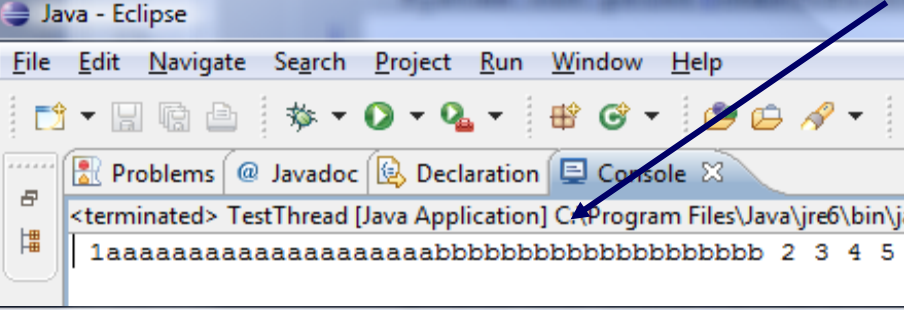
```
// Construct a thread for print 1, 2, ... i
public PrintNum(int n) {
    lastNum = n;
}
```

```
// 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



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



//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.



// 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.



Java - Threading Examples/src/TestRunnable.java - Eclipse

File Edit Source Refactor Navigate Search Project Run Window Help

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

Console X

```
<terminated> TestRunnable [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:05:44 PM)
1bbbbbbbbbbbbbbbbbbbbbaaaaaaaaaaaaaaaaaaaaaa 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
```

Java - Threading Examples/src/TestRunnable.java - Eclipse

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Run TestRunnable

Console X

```
<terminated> TestRunnable [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:06:14 PM)
aaaaaaaaaaaaaaaa 1bbbbbbbbbbbbbbbbbbbbbb 2aaaaaaaa 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
```

Java - Threading Examples/src/TestRunnable.java - Eclipse

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Console X

```
<terminated> TestRunnable [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:06:29 PM)
aaaaaaaaaaaaaaaaaaaaaaaaabbbbbbbbbbbbbbbbbbbb 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
```



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:

```
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).



```
//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);  
}
```

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

```
//display the occurrences of the character
```

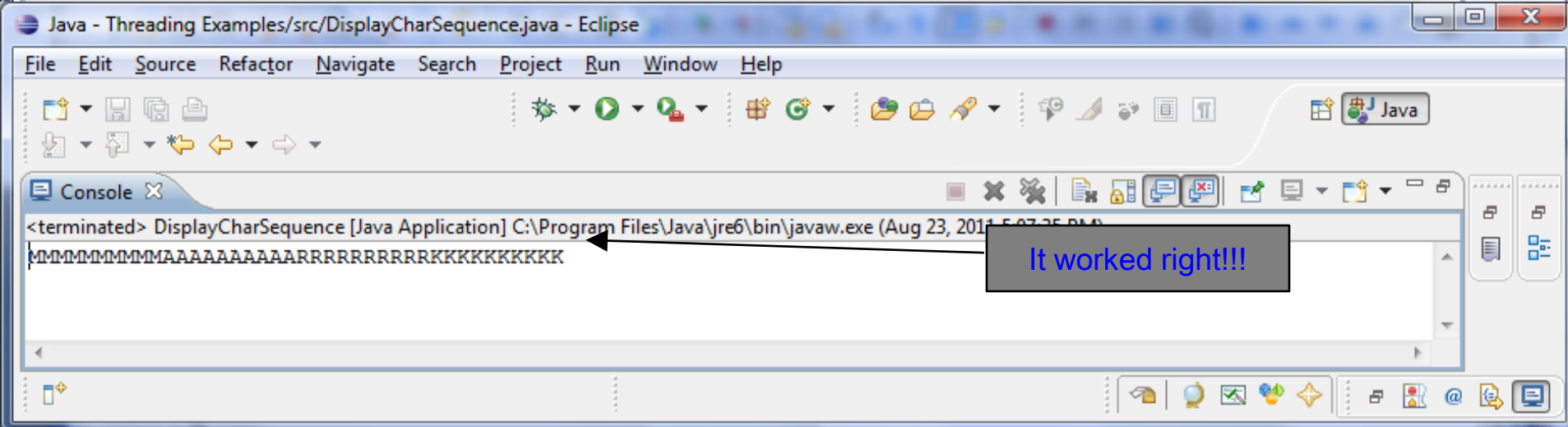
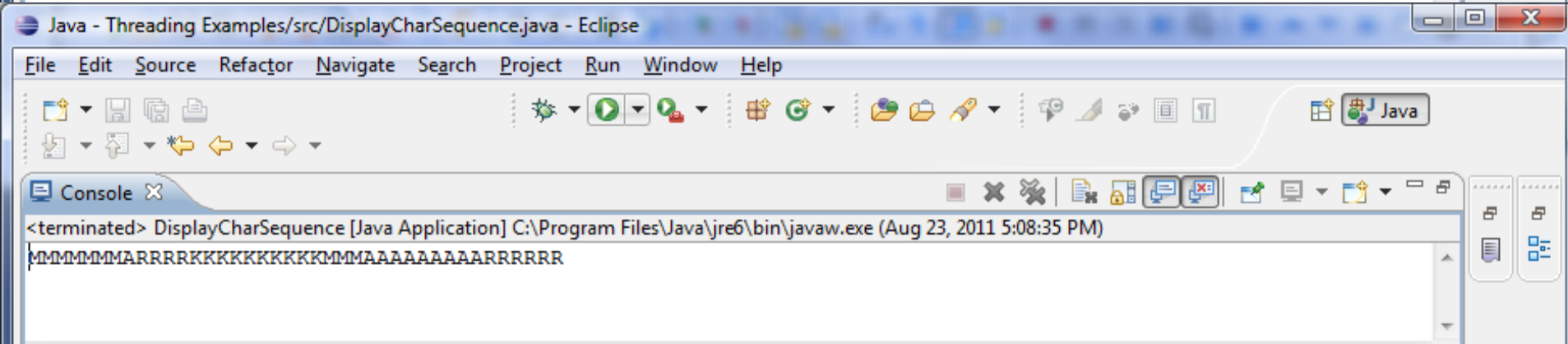
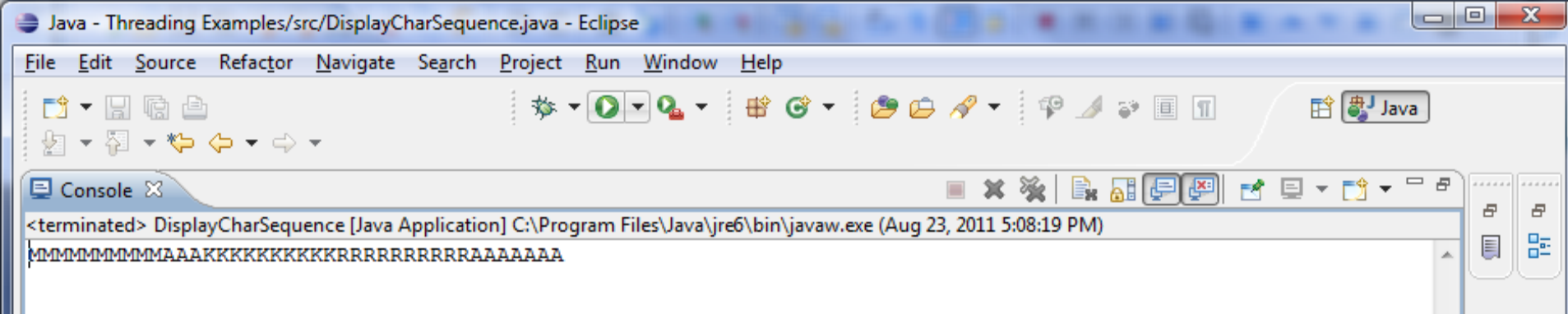
```
public void run() {  
    for (int i = 0; i < 10; ++i) {  
        System.out.print(displayChar);  
    }  
    timer.cancel();  
}
```

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.

```
//main
```

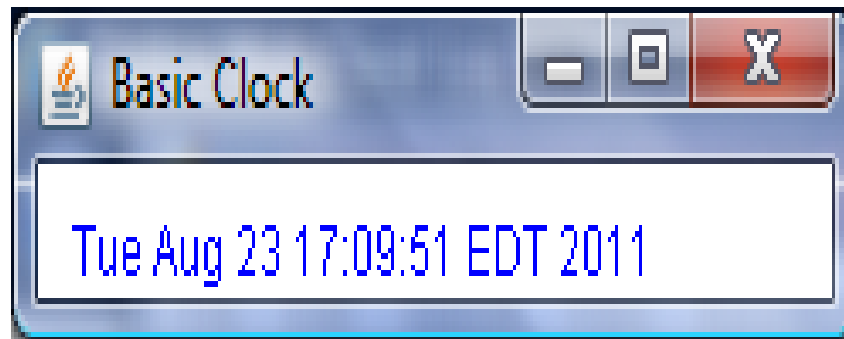
```
public static void main (String[] args) {  
    DisplayCharSequence s1 = new DisplayCharSequence('M');  
    DisplayCharSequence s2 = new DisplayCharSequence('A');  
    DisplayCharSequence s3 = new DisplayCharSequence('R');  
    DisplayCharSequence s4 = new DisplayCharSequence('K');  
}
```





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




```

//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 = "";

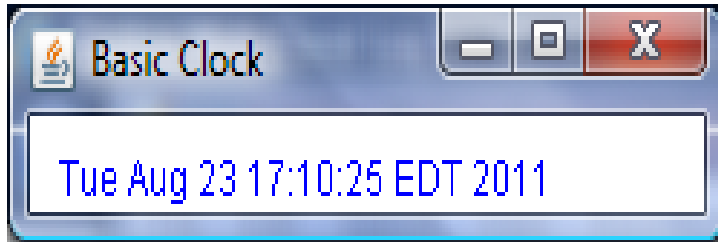
    //constructor for clock
    public BasicClock(){
        //set up GUI
        window.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        window.setSize(200,60);
        Container c = window.getContentPane();
        c.setBackground(Color.WHITE);
        window.setVisible(true);
        //update GUI 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 28 which uses a delay and a repetition factor.





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

```
//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();
}
}
```



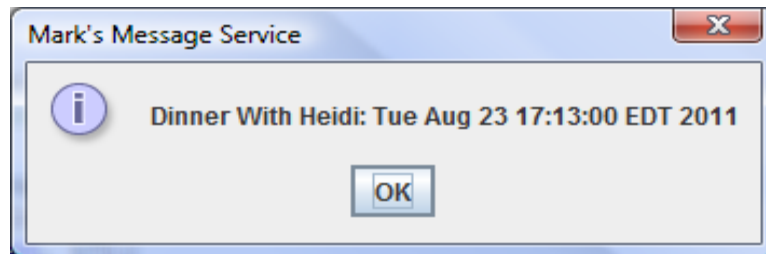
!! CAUTION !!

- 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.Timer t1 = new java.util.Timer();`
 - `javax.swing.Timer t2 = new javax.swing.Timer();`

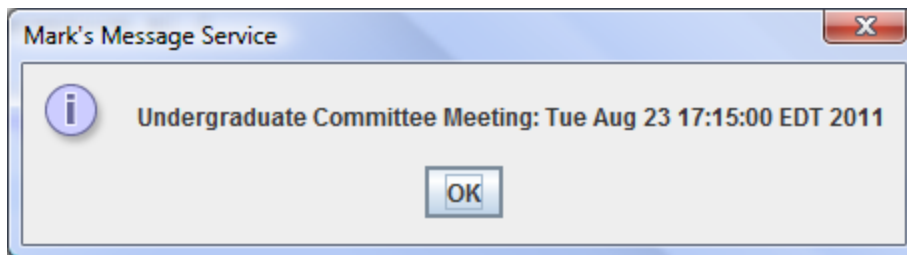


Example – Thread Execution At Specific Time

- 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



This window pops
up 2 minutes
later



```
public class DisplayAlert extends TimerTask {
    //instance variables
    private String message;
    private java.util.Timer timer;
    //constructor
    public DisplayAlert(String s, Date t){
        message = s + ": " + t;
        timer = new java.util.Timer();
        timer.schedule(this, t);
    }
    //execute thread
    public void run() {
        JOptionPane.showMessageDialog(null, message, "Mark's Message Service", JOptionPane.INFORMATION_MESSAGE);
        timer.cancel(); //kill thread
    }
    public static void main(String[] args) {
        Calendar c = Calendar.getInstance();
        c.set(Calendar.HOUR_OF_DAY, 17);
        c.set(Calendar.MINUTE, 13);
        c.set(Calendar.SECOND, 0);
        Date lunchTime = c.getTime();
        c.set(Calendar.HOUR_OF_DAY, 17);
        c.set(Calendar.MINUTE, 15);
        c.set(Calendar.SECOND, 0);
        Date meetingTime = c.getTime();
        DisplayAlert alert1 = new DisplayAlert("Dinner With Heidi", lunchTime);
        DisplayAlert alert2 = new DisplayAlert("Undergraduate Committee Meeting", meetingTime);
    }
}
```

Third version of schedule() method as shown on page 28.



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 - Threading Examples/src/ShowSleeping.java - Eclipse

File Edit Source Refactor Navigate Search Project Run Window Help

TestRunnable.java DisplayCharSequence BasicClock.java DisplayAlert.java *ShowSleeping.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.

Writable Smart Insert



Java - Threading Examples/src/ShowSleeping.java - Eclipse

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```
<terminated> ShowSleeping [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:15:57 PM)
Thread goes to sleep at: Tue Aug 23 17:15:57 EDT 2011
Thread wakes up at: Tue Aug 23 17:16:07 EDT 2011
```

Notice that the process has slept for exactly 10 seconds in each case.

Java - Threading Examples/src/ShowSleeping.java - Eclipse

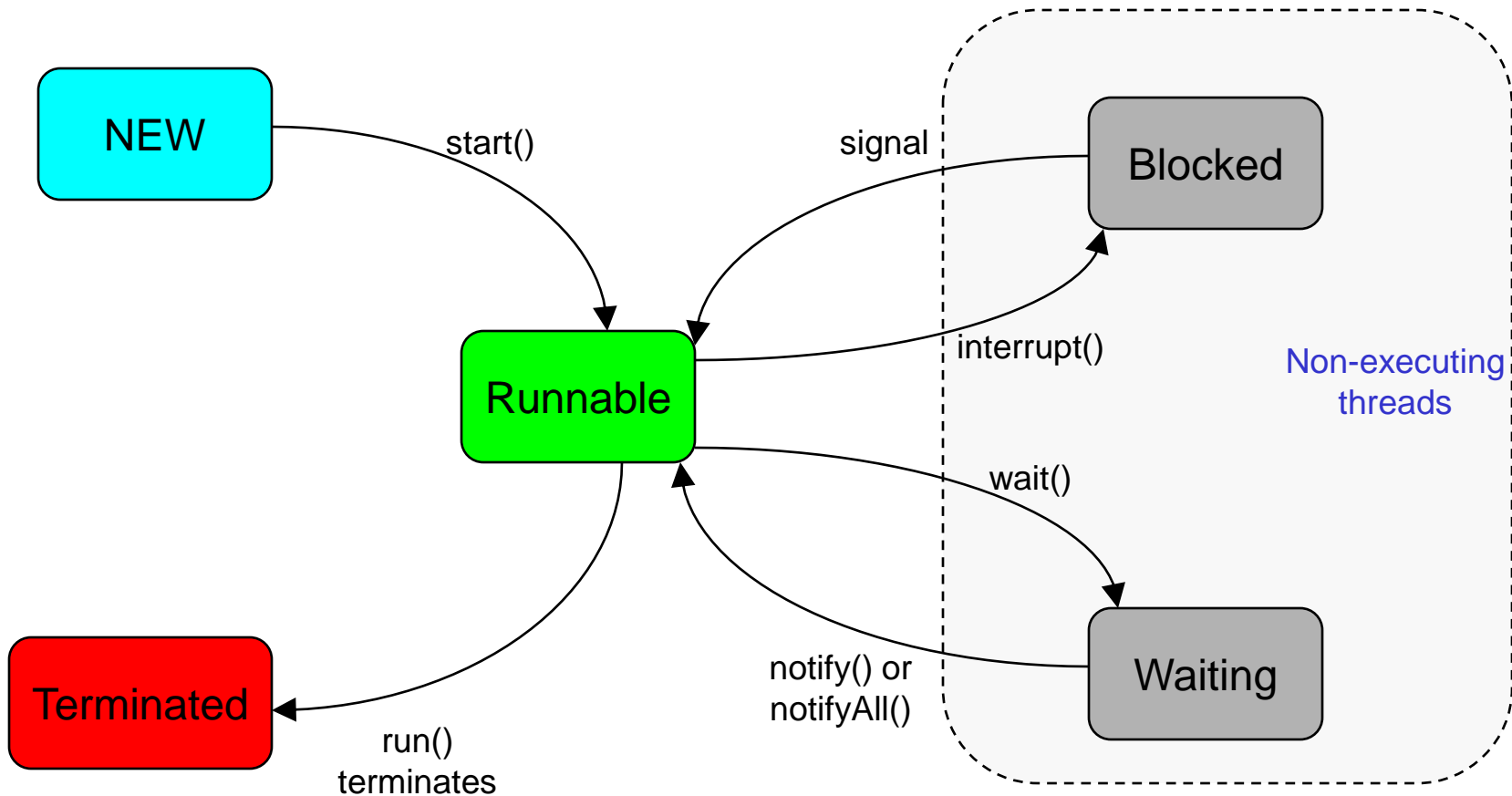
File Edit Source Refactor Navigate Search Project Run Window Help

```
<terminated> ShowSleeping [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:16:31 PM)
Thread goes to sleep at: Tue Aug 23 17:16:31 EDT 2011
Thread wakes up at: Tue Aug 23 17:16:41 EDT 2011
```

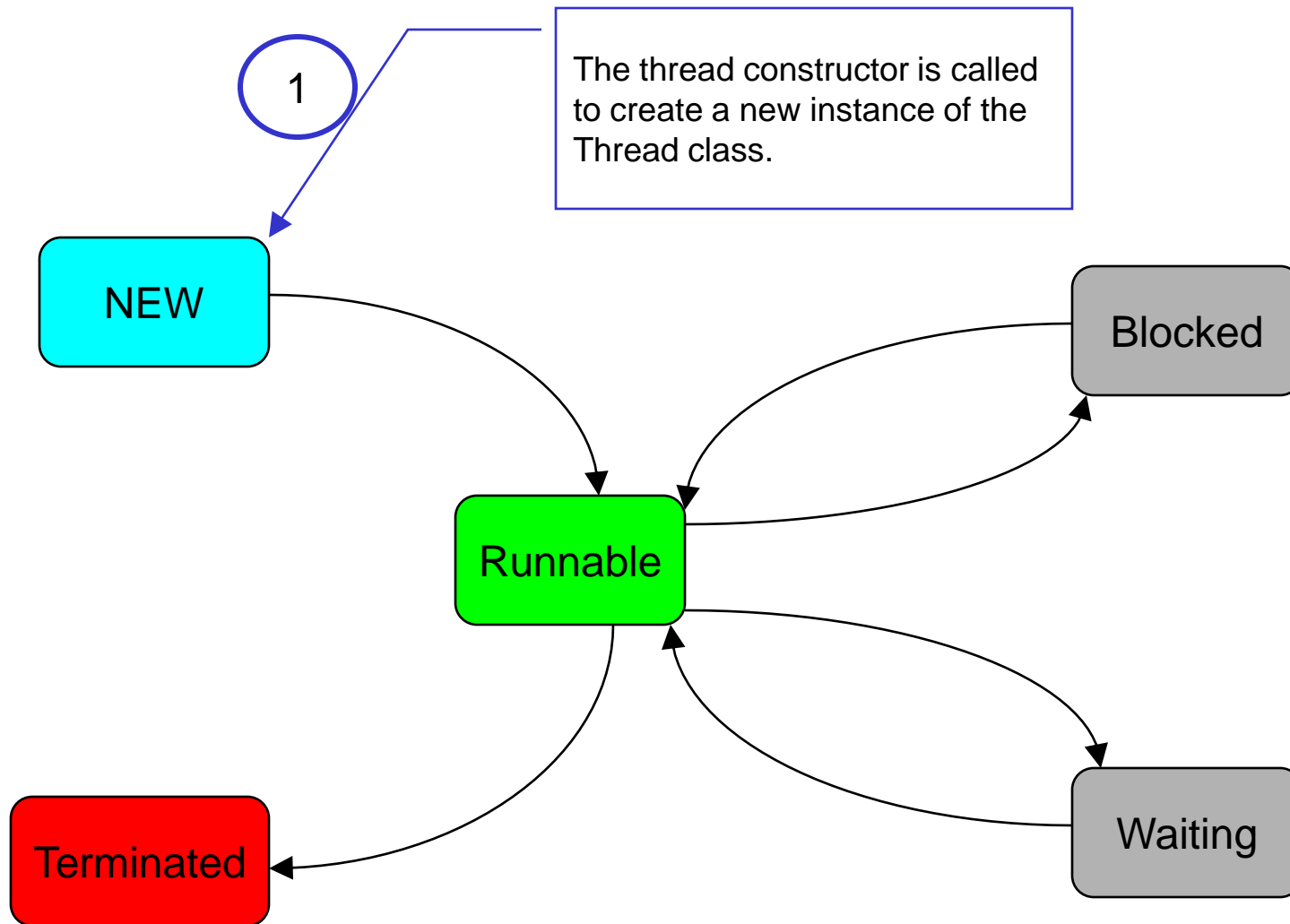


Life Cycle of a Thread

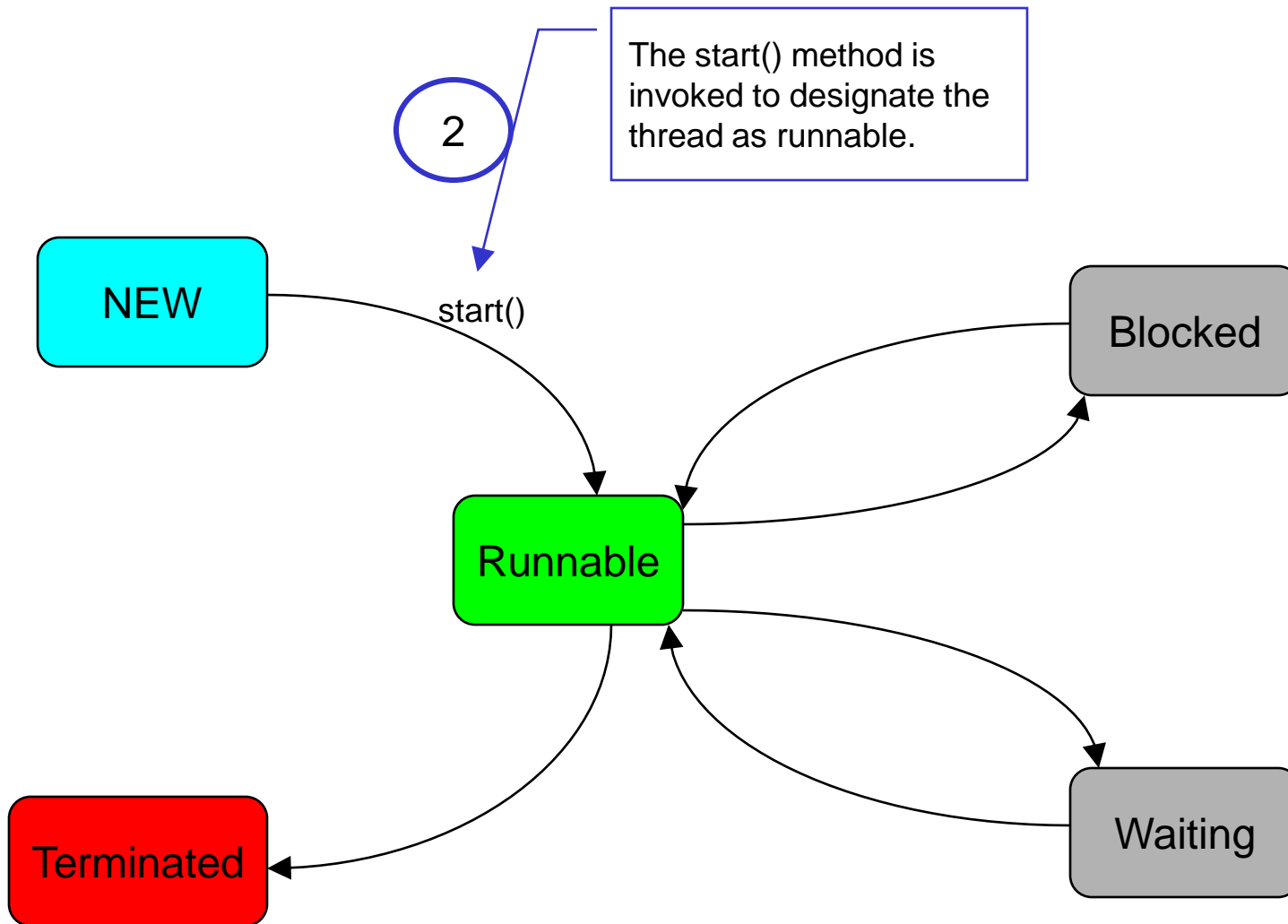
- At any given point in time, a thread is said to be in one of several **thread states** as illustrated in the diagram below.



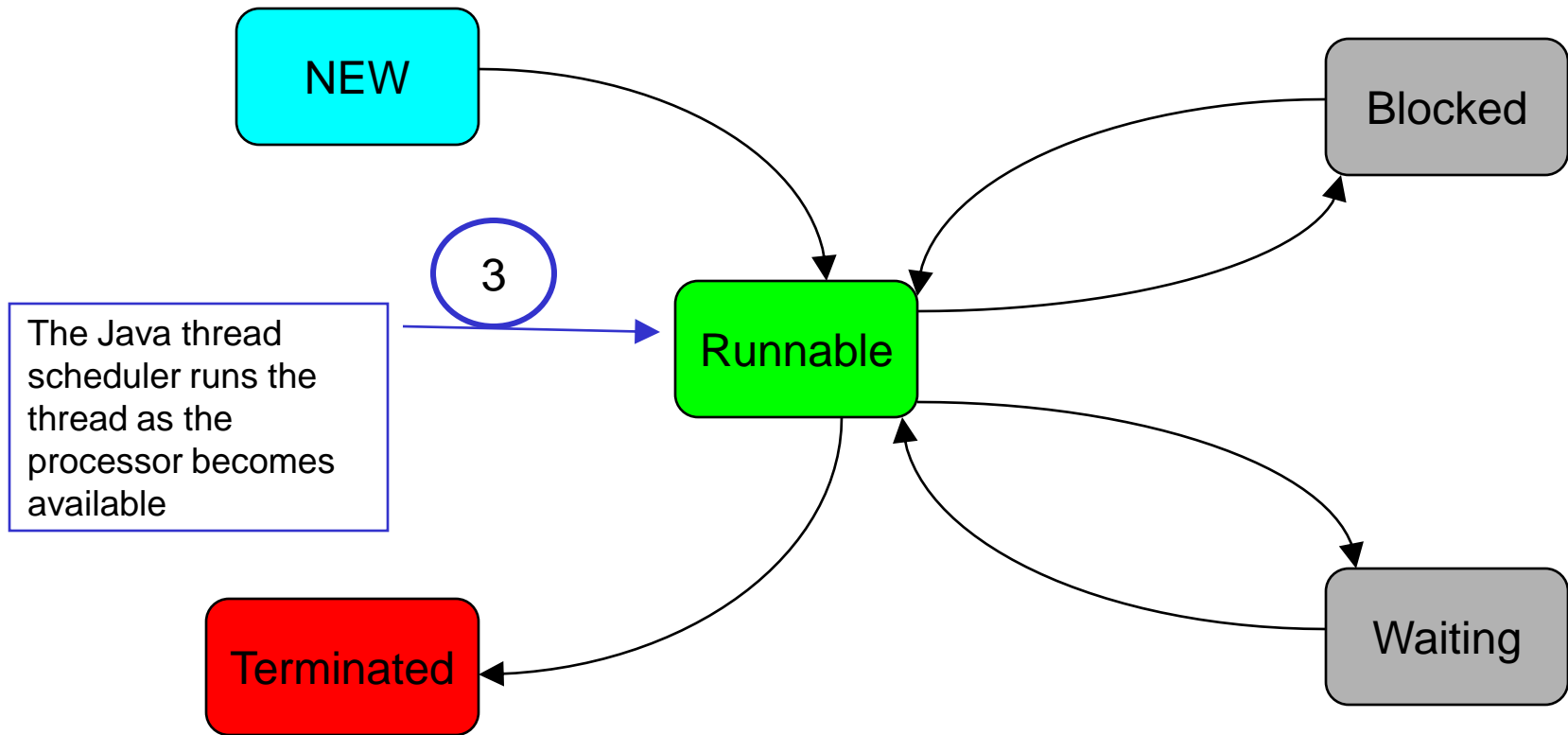
Life Cycle of a Thread (cont.)



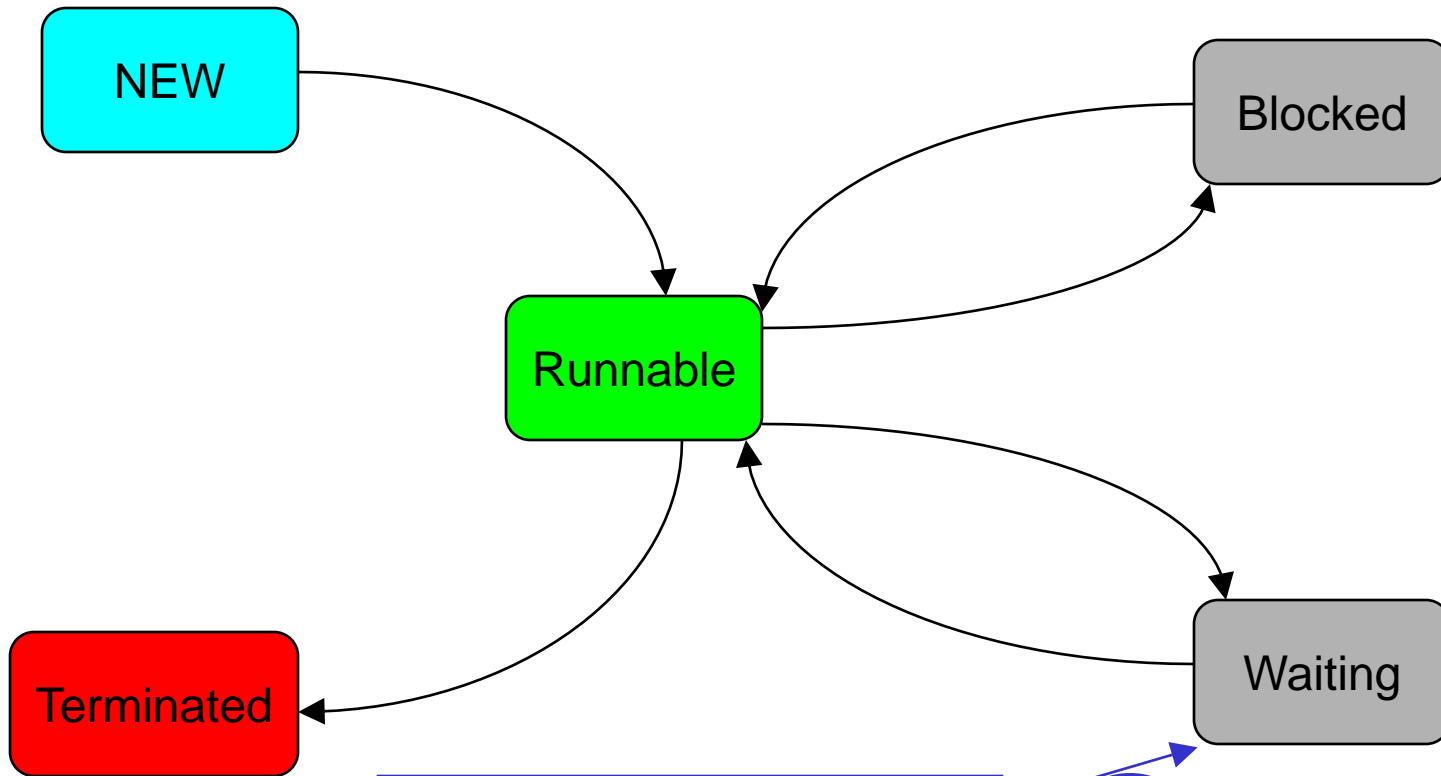
Life Cycle of a Thread (cont.)



Life Cycle of a Thread (cont.)



Life Cycle of a Thread (cont.)

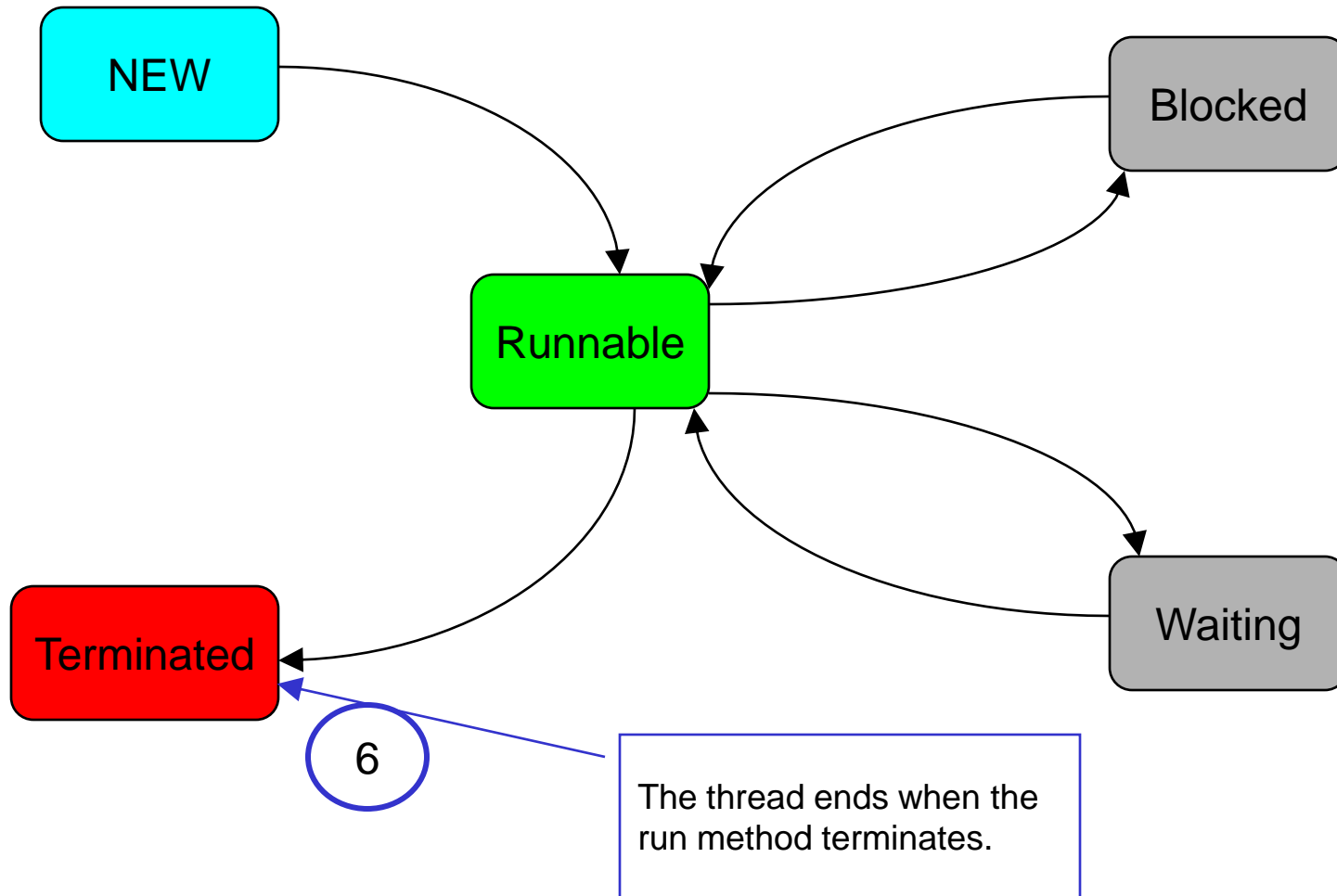


If the thread invokes the `wait()` method, it is put into the waiting state and will remain there until another thread invokes the `notify()` or `notifyAll()` method.

5

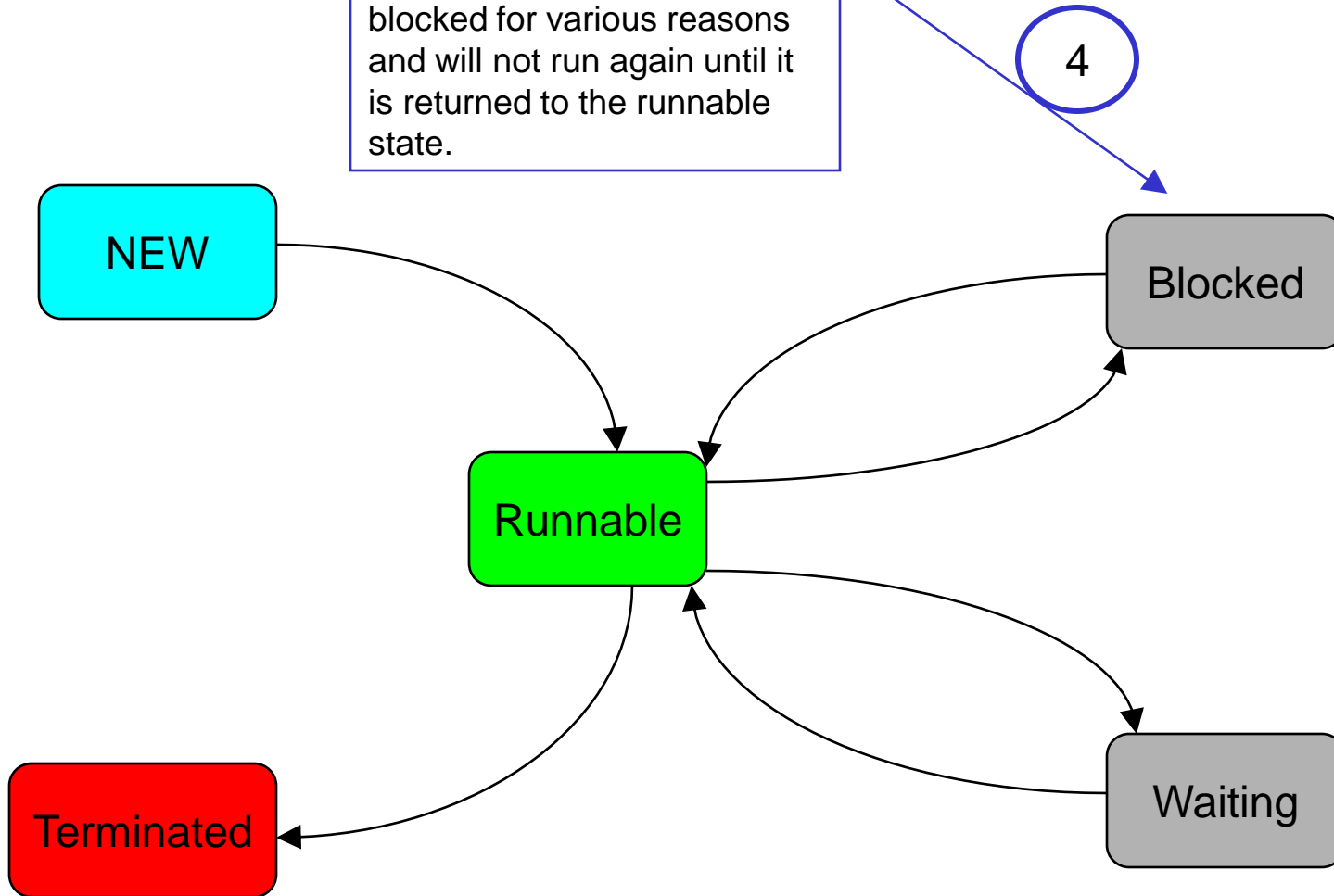


Life Cycle of a Thread (cont.)



Life Cycle of a Thread (cont.)

The thread can become blocked for various reasons and will not run again until it is returned to the runnable state.



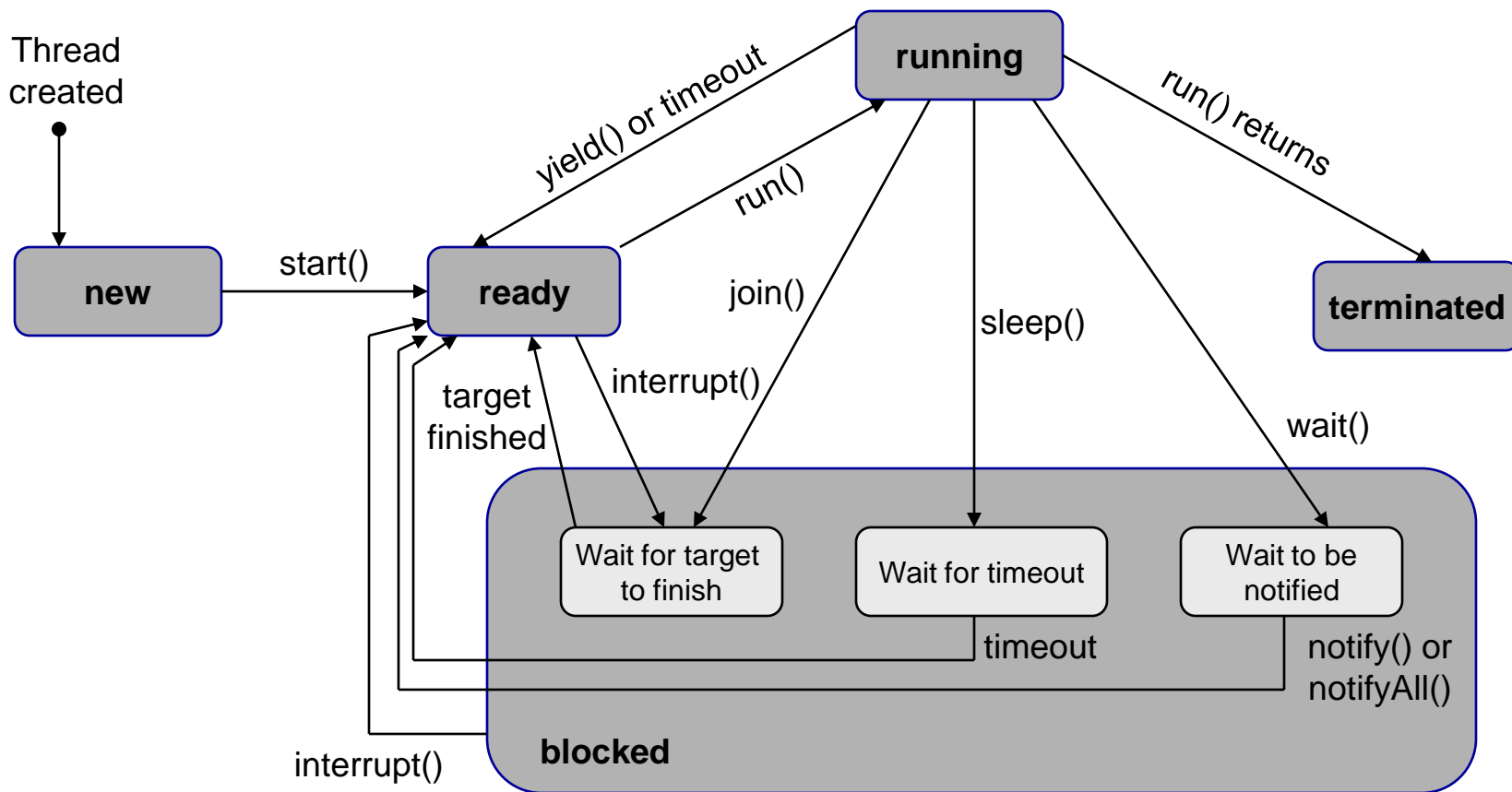
Summary of States In The Life Cycle of a Thread

State	Description
New	The thread has been created (its constructor has been invoked), but not yet started.
Runnable	The thread's start() method has been invoked and the thread is available to be run by the thread scheduler. A thread in the Runnable state may actually be running, or it may be waiting in the thread queue for an opportunity to run.
Blocked	The thread has been temporarily removed from the Runnable state so that it cannot be executed. This can happen if the thread's sleep() method is invoked, if the thread is waiting on I/O, or if the thread requests a lock on an object that is already locked. When the condition changes, the thread will be returned to the Runnable state.
Waiting	The thread has invoked its wait() method so that other threads can access an object. The thread will remain in the Waiting state until another thread invokes the notify() or notifyAll() method.
Terminated	The thread's run() method has ended.



Life Cycle of a Thread – A Slightly Different View

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



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 if 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.

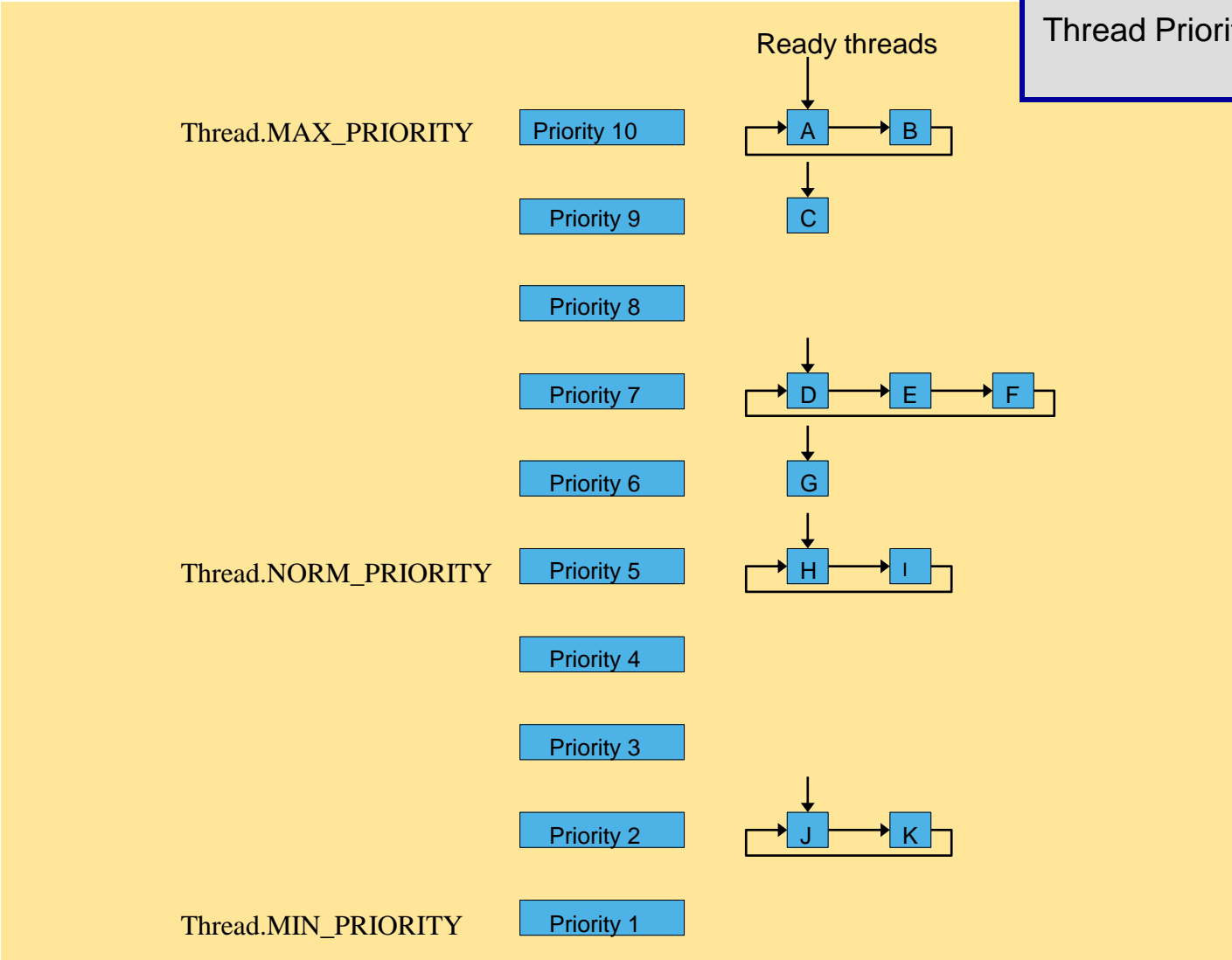


Thread Priorities

- 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



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 manages 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

```
// 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
```



Java - Threading Examples/src/RunnableTester.java - Eclipse

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Console X

```
<terminated> RunnableTester [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:18:24 PM)
Starting threads
Threads started, main ends

thread1 going to sleep for 3591 milliseconds.
thread3 going to sleep for 3127 milliseconds.
thread2 going to sleep for 2966 milliseconds.
thread2 done sleeping
thread3 done sleeping
thread1 done sleeping
```

Example Executions of RunnableTester.java

```
<terminated> RunnableTester [Java Application] C:\Program Files\Java\jre6\bin\javaw.exe (Aug 23, 2011 5:18:59 PM)
Starting threads
Threads started, main ends

thread1 going to sleep for 1105 milliseconds.
thread2 going to sleep for 60 milliseconds.
thread3 going to sleep for 4323 milliseconds.
thread2 done sleeping
thread1 done sleeping
thread3 done sleeping
```

