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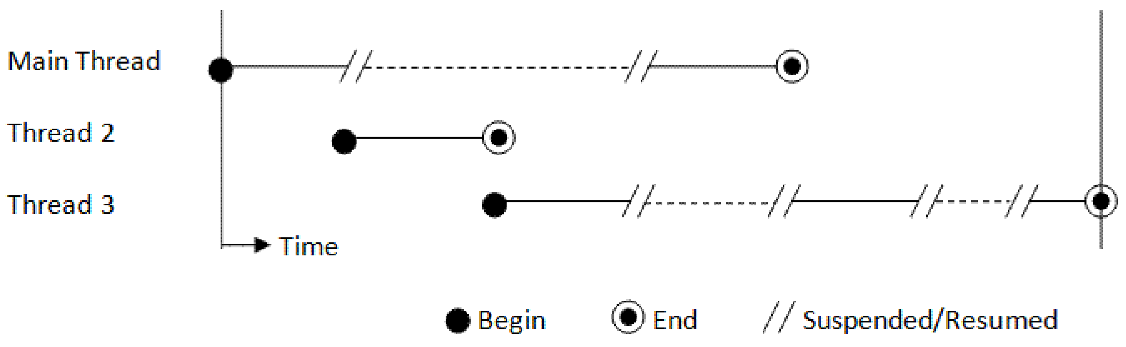
Java Programming Tutorial

Multithreading & Concurrent Programming

1. Introduction

Java supports *single-thread* as well as *multi-thread* operations. A single-thread program has a single entry point (the `main()` method) and a single exit point. A multi-thread program has an initial entry point (the `main()` method), followed by many entry and exit points, which are run concurrently with the `main()`. The term "*concurrency*" refers to doing multiple tasks at the same time.

Java has built-in support for *concurrent programming* by running multiple threads concurrently within a single program. A *thread*, also called a *lightweight process*, is a single sequential flow of programming operations, with a definite beginning and an end. During the lifetime of the thread, there is only a single point of execution. A thread by itself is not a program because it cannot run on its own. Instead, it runs within a program. The following figure shows a program with 3 threads running under a single CPU:



1.1 Multitasking (or Multi-processing)

Modern operating systems (such as Windows and UNIX) are *multitasking* system. A multitasking system can perform many tasks concurrently by sharing the computing resources, such as CPU(s), main memory, and I/O channels. In a single-CPU machine, only one task can be executed at one time – through time-slicing of the CPU. In a multi-CPU machine, a few tasks can be executed simultaneously, either distributed among or time-slicing the CPUs.

Multitasking is necessary in today's operating systems for better performance by making full use and optimize the usage of the computing resources. There are generally two kinds of multitasking operating systems:

1. *Co-operative multitasking systems*: Each task must *voluntarily* yield control to other tasks. This has the drawback that a run-away or uncooperative task may hang the entire system.
2. *Pre-emptive multitasking systems*: Tasks are given time-slices of the CPU(s) and will be forced to yield control to other tasks once their allocation is used up.

1.2 Multithreading (within a Process)

In UNIX, we *fork* a new process. In Windows, we start a program. A process or program has its own address space and control blocks. It is called *heavyweight* because it consumes a lot of system resources. Within a process or program, we can run multiple threads concurrently to improve the performance.

Threads, unlike heavyweight process, are lightweight and run inside a single process – they share the same address space, the resources allocated and the environment of that process. It is lightweight because it runs within the context of a heavyweight process and takes advantage of the resources allocated for that program and the program's environment. A thread must carve out its own resources within the running process. For example, a thread has its own stack, registers and program counter. The code running within the thread works only within that context, hence, a thread (of a sequential flow of operations) is also called an execution context.

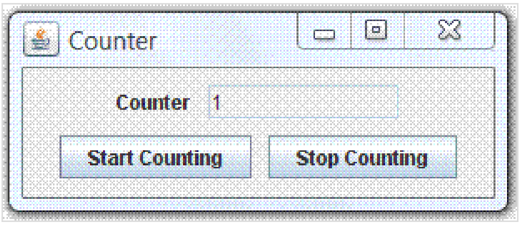
Multithreading within a program improves the performance of the program by optimizing the usage of system resources. For example, while one thread is blocked (e.g., waiting for completion of an I/O operation), another thread can use the CPU time to perform computations, resulted in better performance and overall throughput.

Multithreading is also necessary to provide better interactivity with the users. For example, in a word processor, while one thread is printing or saving the file, another thread can be used to continue typing. In GUI applications, multithreading is essential in providing a *responsive* user interface.

For this article, I shall assume that you understand Swing programming, as Swing applications rely on multithreading (to perform their specific function, repaint and process the events) and best to illustrate multithreading.

A typical Java program runs in a single process, and is not interested in multile processes. However, within the process, it often uses multiple threads to to run multiple tasks concurrently. A standalone Java application starts with a single thread (called *main thread*) associated with the main() method. This *main thread* can then start new user threads.

2. The Infamous "Unresponsive User Interface"



The infamous *Unresponsive User Interface (UI) problem* is best illustrated by the following Swing program with a counting-loop.

The GUI program has two buttons. Pushing the "Start Counting" button starts the counting. Pushing the "Stop Counting" button is *supposed* to stop (pause) the counting. The two button-handlers communicate via a `boolean` flag called `stop`. The stop-button handler sets the `stop` flag; while the start-button handler checks if `stop` flag has been set before continuing the next count.

You should write the program under Eclipse/NetBeans so that we could trace the threads.

2.1 Example 1: Unresponsive UI

```java
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/** Illustrate Unresponsive UI problem caused by "busy" Event-Dispatching Thread */
public class UnresponsiveUI extends JFrame {
   private boolean stop = false;  // start or stop the counter
   private JTextField tfCount;
   private int count = 1;

   /** Constructor to setup the GUI components */
   public UnresponsiveUI() {
      Container cp = this.getContentPane();
      cp.setLayout(new FlowLayout(FlowLayout.CENTER, 10, 10));
      cp.add(new JLabel("Counter"));
      tfCount = new JTextField(count + "", 10);
      tfCount.setEditable(false);
      cp.add(tfCount);

      JButton btnStart = new JButton("Start Counting");
      cp.add(btnStart);
      btnStart.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            stop = false;
            for (int i = 0; i < 100000; ++i) {
               if (stop) break;  // check if STOP button has been pushed,
                                 //  which changes the stop flag to true
               tfCount.setText(count + "");
               ++count;
            }
         }
      });
      JButton btnStop = new JButton("Stop Counting");
      cp.add(btnStop);
      btnStop.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            stop = true;  // set the stop flag
         }
      });

      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      setTitle("Counter");
      setSize(300, 120);
      setVisible(true);
   }

   /** The entry main method */
   public static void main(String[] args) {
      // Run GUI codes in Event-Dispatching thread for thread safety
      SwingUtilities.invokeLater(new Runnable() {
         public void run() {
            new UnresponsiveUI();  // Let the constructor do the job
         }
      });
   }
}
```

However, once the START button is pushed, the UI is *frozen* – the counter value is not updated on the display (i.e., the display is not *refreshed*), and the user interface is not responding to the clicking of the STOP button, or any other user interaction.

Tracing the threads (Advanced)

From the program trace (via Eclipse/NetBeans), we observe:

1. The `main()` method is started in the "main" thread.
2. The JRE's windowing subsystem, via `SwingUtilities.invokeLater()`, starts 3 threads: "AWT-Windows" (daemon thread), "AWT-Shutdown" and "AWT-EventQueue-0". The "AWT-EventQueue-0" is known as the *Event-Dispatching Thread* (*EDT*), which is the one and only thread responsible for handling all the events (such as clicking of buttons) and refreshing the display to ensure thread safety in GUI operations and manipulating GUI components. The constructor `UnresponsiveUI()` is scheduled to run on the Event-Dispatching thread (via `invokeLater()`), after all the existing events have been processed. The "main" thread exits after the `main()` method completes. A new thread called "DestroyJavaVM" is created.
3. When you click the START button, the `actionPerformed()` is run on the EDT. The EDT is now fully-occupied with the compute-intensive counting-loop. In other words, while the counting is taking place, the EDT is *busy* and unable to process any event (e.g., clicking the STOP button or the window-close button) and refresh the display - until the counting completes and EDT becomes available. As the result, the display freezes until the counting-loop completes.

It is recommended to run the GUI construction codes on the EDT via the `invokeLater()`. This is because many of the GUI components are not guaranteed to be thread-safe. Channelling all accesses to GUI components in a single thread ensure thread safety. Suppose that we run the constructor directly on the `main()` method (under the "main" thread), as follow:

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

The trace shows that:

1. The `main()` method starts in the "main" thread.
2. A new thread "AWT-Windows" (Daemon thread) is started when we step-into the constructor "`new UnresponsiveUI()`" (because of the "`extends JFrame`").
3. After executing "`setVisible(true)`", another two threads are created - "AWT-Shutdown" and "AWT-EventQueue-0" (i.e., the EDT).
4. The "main" thread exits after the `main()` method completes. A new thread called "DestroyJavaVM" is created.
5. At this point, there are 4 threads running - "AWT-Windows", "AWT-Shutdown" and "AWT-EventQueue-0 (EDT)" and "DestroyJavaVM".
6. Clicking the START button invokes the `actionPerformed()` in the EDT.

In the earlier case, the EDT is started via the `invokeLater()`; while in the later case, the EDT starts after `setVisible()`.

2.2 Example 2: Still Unresponsive UI with Thread

Instead of using the *event-dispatching thread* to do the compute-intensive counting, let's create a new thread to do the counting, instead of using the EDT, as follows:

```
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/** Illustrate the Unresponsive UI problem caused by "starved" event-dispatching thread */
```

```java
public class UnresponsiveUIwThread extends JFrame {
   private boolean stop = false;
   private JTextField tfCount;
   private int count = 1;

   /** Constructor to setup the GUI components */
   public UnresponsiveUIwThread() {
      Container cp = getContentPane();
      cp.setLayout(new FlowLayout(FlowLayout.CENTER, 10, 10));
      cp.add(new JLabel("Counter"));
      tfCount = new JTextField(count + "", 10);
      tfCount.setEditable(false);
      cp.add(tfCount);

      JButton btnStart = new JButton("Start Counting");
      cp.add(btnStart);
      btnStart.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            stop = false;
            // Create our own Thread to do the counting
            Thread t = new Thread() {
               @Override
               public void run() {  // override the run() to specify the running behavior
                  for (int i = 0; i < 100000; ++i) {
                     if (stop) break;
                     tfCount.setText(count + "");
                     ++count;
                  }
               }
            };
            t.start();  // call back run()
         }
      });

      JButton btnStop = new JButton("Stop Counting");
      cp.add(btnStop);
      btnStop.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            stop = true;
         }
      });

      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      setTitle("Counter");
      setSize(300, 120);
      setVisible(true);
   }

   /** The entry main method */
   public static void main(String[] args) {
      // Run GUI codes in Event-Dispatching thread for thread safety
      javax.swing.SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new UnresponsiveUIwThread();  // Let the constructor do the job
         }
      });
   }
}
```

A new thread is created by sub-classing the `Thread` class, with an anonymous inner class. We override the `run()` method to specify the running behavior of the thread, which performs the compute-intensive counting. An instance is created. Invoking the `start()` method of the instance causes the `run()` to execute on its own thread. (The details on creating new thread will be explained later.)

The responsiveness improves slightly. But the proper counter value is still not shown, and there is a delay in response to the "STOP" button. (You may not see the difference running with a dual-core processor.)

This is because the counting thread does not voluntarily yield control to the EDT. The "starved" EDT is unable to update the display and response to the "STOP" button. Nonetheless, the JVM may force the counting thread to yield control according to the scheduling algorithm, which results in delay on updating the display (TODO: not sure about this).

Tracing the Threads (Advanced)

When the "START" button is clicked, a new thread called "Thread-*n*" (n is a running number) is created to run the compute-intensive counting-loop. However, this thread is not programmed to yield control to other threads, in particular, the event-dispatching thread.

This program is, however, slightly better than the previous program. The display is updated, and the clicking of "STOP" button has its effect after some delays.

2.3 Example 3: Responsive UI with Thread

Let's modify the program by making a call to the counting-thread's `sleep()` method, which requests the counting-thread to yield control to the event-dispatching thread to update the display and response to the "STOP" button. The counting program now works as desired. The `sleep()` method also provides the necessary delay needed.

```
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/** Resolve the unresponsive UI problem by running the compute-intensive task
    in this own thread, which yields control to the EDT regularly */
public class UnresponsiveUIwThreadSleep extends JFrame {
   private boolean stop = false;
   private JTextField tfCount;
   private int count = 1;

   /** Constructor to setup the GUI components */
   public UnresponsiveUIwThreadSleep() {
      Container cp = getContentPane();
      cp.setLayout(new FlowLayout(FlowLayout.CENTER, 10, 10));
      cp.add(new JLabel("Counter"));
      tfCount = new JTextField(count + "", 10);
      tfCount.setEditable(false);
      cp.add(tfCount);

      JButton btnStart = new JButton("Start Counting");
      cp.add(btnStart);
      btnStart.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            stop = false;
            // Create a new Thread to do the counting
            Thread t = new Thread() {
               @Override
               public void run() {  // override the run() for the running behaviors
                  for (int i = 0; i < 100000; ++i) {
                     if (stop) break;
                     tfCount.setText(count + "");
                     ++count;
                     // Suspend this thread via sleep() and yield control to other threads.
                     // Also provide the necessary delay.
                     try {
                        sleep(10);  // milliseconds
                     } catch (InterruptedException ex) {}
                  }
               }
            };
            t.start();  // call back run()
         }
      });

      JButton btnStop = new JButton("Stop Counting");
      cp.add(btnStop);
      btnStop.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent evt) {
            stop = true;
         }
      });

      setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      setTitle("Counter");
      setSize(300, 120);
      setVisible(true);
   }

   /** The entry main method */
   public static void main(String[] args) {
      // Run GUI codes in Event-Dispatching thread for thread safety
      javax.swing.SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            new UnresponsiveUIwThreadSleep();  // Let the constructor do the job
         }
      });
   }
}
```

The `sleep()` method suspends the current thread and put it into the *waiting state* for the specified number of milliseconds. Another thread can begin execution (in a single CPU environment). (The `sleep()` can be interrupted by invoking the `interrupt()` method of this thread, which triggers an `InterruptedException` - this is unusual!)

In this case, the thread created to do the counting ("Thread-n") yields control *voluntarily* to other threads after every count (via the "`sleep(10)`"). This allows the event-dispatching thread to refresh the display as well as processing the "STOP" button after *each* count.

2.4 Example 4: `SwingWorker`

JDK 1.6 provides a new `javax.swing.SwingWorker` class, which can be used to run compute-intensive tasks in background threads, and passes the final result or intermediate results back to methods that run on the event-dispatching thread. We shall discuss `SwingWorker` in the later section.

3. Creating a new Thread

There are two ways to create a new thread:

1. Extend a subclass from the superclass `Thread` and override the `run()` method to specify the running behavior of the thread. Create an instance and invoke the `start()` method, which will call-back the `run()` on a new thread. For example:

```
Thread t = new Thread() {   // Create an instance of an anonymous inner class that extends Thread
   @Override
   public void run() {      // Override run() to specify the running behaviors
      for (int i = 0; i < 100000; ++i) {
         if (stop) break;
         tfCount.setText(count + "");
         ++count;
         // Suspend itself and yield control to other threads for the specified milliseconds
         // Also provide the necessary delay
         try {
            sleep(10); // milliseconds
         } catch (InterruptedException ex) {}
      }
   }
};
t.start();  // Start the thread. Call back run() in a new thread
```

2. Create a class that implements the `Runnable` interface and provide the implementation to the `abstract` method `run()` to specify the running behavior of the thread. Construct a new `Thread` instance using the constructor with a `Runnable` object and invoke the `start()` method, which will call back `run()` on a new thread.

```
// Create an anonymous instance of an anonymous inner class that implements Runnable
// and use the instance as the argument of Thread's constructor.
Thread t = new Thread(new Runnable() {
   // Provide implementation to abstract method run() to specify the running behavior
   @Override
   public void run() {
      for (int i = 0; i < 100000; ++i) {
         if (stop) break;
         tfCount.setText(count + "");
         ++count;
         // Suspend itself and yield control to other threads
         // Also provide the necessary delay
         try {
            Thread.sleep(10);  // milliseconds
         } catch (InterruptedException ex) {}
      }
   }
});
t.start();  // call back run() in new thread
```

The second method is needed as Java does not support *multiple inheritance*. If a class already extends from a certain superclass, it cannot extend from `Thread`, and have to implement the `Runnable` interface. The second method is also used to provide compatibility with JDK 1.1. It should be noted that the `Thread` class itself implements the `Runnable` interface.

The `run()` method specifies the running behavior of the thread and gives the thread something to do. You do not invoke the `run()` method directly from your program. Instead, you create a `Thread` instance and invoke the `start()` method. The `start()` method, in turn, will *call back* the `run()` on a new thread.

3.1 Interface `Runnable`

The interface `java.lang.Runnable` declares one `abstract` method `run()`, which is used to specify the running behavior of the thread:

```
public void run();
```

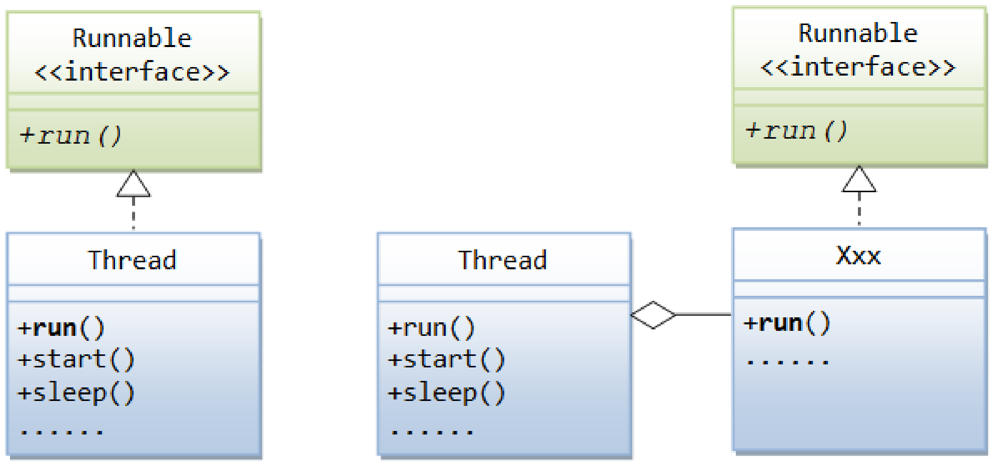
3.2 Class `Thread`

The class `java.lang.Thread` has the following constructors:

```
public Thread();
public Thread(String threadName);
public Thread(Runnable target);
public Thread(Runnable target, String threadName);
```

The first two constructors are used for creating a thread by sub-classing the `Thread` class. The next two constructors are used for creating a thread with an instance of class that implements `Runnable` interface.

The class `Thread` implements `Runnable` interface, as shown in the class diagram.



As mentioned, the method `run()` specifies the running behavior of the thread. You do not invoke the `run()` method explicitly. Instead, you call the `start()` method of the class `Thread`. If a thread is constructed by extending the `Thread` class, the method `start()` will call back the overridden `run()` method in the extended class. On the other hand, if a thread is constructed by providing a `Runnable` object to the `Thread`'s constructor, the `start()` method will call back the `run()` method of the `Runnable` object (and not the `Thread`'s version).

3.3 Creating a new Thread by sub-classing `Thread` and overriding `run()`

To create and run a new thread by extending `Thread` class:

1. Define a subclass (named or anonymous) that extends from the superclass `Thread`.
2. In the subclass, override the `run()` method to specify the thread's operations, (and provide other implementations such as constructors, variables and methods).
3. A client class creates an instance of this new class. This instance is called a `Runnable` object (because `Thread` class itself implements `Runnable` interface).
4. The client class invokes the `start()` method of the `Runnable` object. The result is two thread running concurrently – the current thread continue after invoking the `start()`, and a new thread that executes `run()` method of the `Runnable` object.

For example,

```
class MyThread extends Thread {
   // override the run() method
   @Override
   public void run() {
      // Thread's running behavior
   }
   // constructors, other variables and methods
   ......
}
```

```
public class Client {
   public static void main(String[] args) {
      ......
      // Start a new thread
      MyThread t1 = new MyThread();
      t1.start();  // Called back run()
      ......
      // Start another thread
      new MyThread().start();
      ......
   }
}
```

Often, an inner class (named or anonymous) is used instead of a ordinary subclass. This is done for readability and for providing access to the private variables and methods of the outer class. For example,

```
public class Client {
   ......
   public Client() {
      Thread t = new Thread() { // Create an anonymous inner class extends Thread
         @Override
         public void run() {
            // Thread's running behavior
            // Can access the private variables and methods of the outer class
         }
      };
      t.start();
      ...
      // You can also used a named inner class defined below
      new MyThread().start();
   }

   // Define a named inner class extends Thread
   class MyThread extends Thread {
      public void run() {
         // Thread's running behavior
         // Can access the private variables and methods of the outer class
      }
   }
}
```

Example

```
public class MyThread extends Thread {
   private String name;

   public MyThread(String name) {   // constructor
      this.name = name;
   }

   // Override the run() method to specify the thread's running behavior
   @Override
   public void run() {
      for (int i = 1; i <= 5; ++i) {
         System.out.println(name + ": " + i);
         yield();
      }
   }
}
```

A class called `MyThread` is created by extending `Thread` class and overriding the `run()` method. A constructor is defined to takes a `String` as the name of the thread. The `run()` method prints 1 to 5, but invokes `yield()` to yield control to other threads voluntarily after printing each number.

```
public class TestMyThread {
   public static void main(String[] args) {
      Thread[] threads = {
         new MyThread("Thread 1"),
         new MyThread("Thread 2"),
         new MyThread("Thread 3")
      };
      for (Thread t : threads) {
         t.start();
      }
   }
}
```

The test class allocates and starts three threads. The output is as follows:

```
Thread 1: 1
Thread 3: 1
Thread 1: 2
Thread 2: 1
Thread 1: 3
Thread 3: 2
Thread 2: 2
Thread 3: 3
Thread 1: 4
Thread 1: 5
Thread 3: 4
Thread 3: 5
Thread 2: 3
Thread 2: 4
Thread 2: 5
```

Take note that the output is indeterminate (different run is likely to produce different output), as we do not have complete control on how the threads would be executed.

3.4 Creating a new Thread by implementing the `Runnable` Interface

To create and run a new thread by implementing `Runnable` interface:

1. Define a class that implements the `Runnable` interface.
2. In the class, provide implementation to the `abstract` method `run()` to specify the thread's operations, (and provide other implementations such as constructors, variables and methods).
3. A client class creates an instance of this new class. The instance is called a `Runnable` object.
4. The client class then constructs a new `Thread` object with the `Runnable` object as argument to the constructor, and invokes the `start()` method. The `start()` called back the `run()` in the `Runnable` object (instead of the `Thread` class).

```
class MyRunnable extends SomeClass implements Runnable {
   // provide implementation to abstract method run()
   @Override
   public void run() {
      // Thread's running behavior
   }
   ......
   // constructors, other variables and methods
}
```

```
public class Client {
   ......
   Thread t = new Thread(new MyRunnable());
   t.start();
   ...
}
```

Again, an inner class (named or anonymous) is often used for readability and to provide access to the private variables and methods of the outer class.

```
Thread t = new Thread(new Runnable() { // Create an anonymous inner class that implements Runnable interface
   public void run() {
      // Thread's running behavior
      // Can access the private variables and methods of the outer class
   }
});
t.start();
```

3.5 Methods in the `Thread` Class

The methods available in Thread class include:

- public void start(): Begin a new thread. JRE calls back the `run()` method of this class. The current thread continues.
- public void run(): to specify the execution flow of the new thread. When `run()` completes, the thread terminates.
- public static sleep(long millis) throws InterruptedException
  public static sleep(long millis, int nanos) throws InterruptedException
  public void interrupt()
  Suspend the current thread and yield control to other threads for the given milliseconds (plus nanoseconds). Method `sleep()` is thread-safe as it does not release its monitors. You can awaken a sleep thread before the specified timing via a call to the `interrupt()` method. The awaken thread will throw an `InterruptedException` and execute its `InterruptedException` handler before resuming its operation. This is a `static` method (which does not require an instance) and commonly used to pause the current thread (via `Thread.sleep()`) so that the other threads can have a chance to execute. It also provides the necessary delay in many applications. For example:

```
try {
   // Suspend the current thread and give other threads a chance to run
   // Also provide the necessary delay
   Thread.sleep(100);   // milliseconds
} catch (InterruptedException ex) {}
```

- public static void yield(): hint to the scheduler that the current thread is willing to yield its current use of a processor to allow other threads to run. The scheduler is, however, free to ignore this hint. Rarely-used.
- public boolean isAlive(): Return `false` if the thread is new or dead. Returns `true` if the thread is "runnable" or "not runnable".
- public void setPriority(int p): Set the priority-level of the thread, which is implementation dependent.

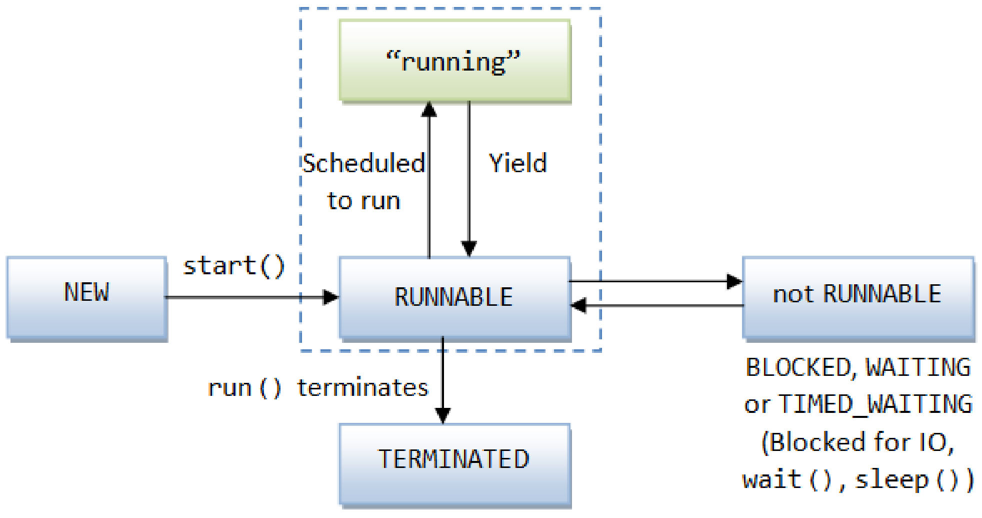
The `stop()`, `suspend()`, and `resume()` methods have been deprecated in JDK 1.4, because they are not thread-safe, due to the release of monitors. See JDK API documentation for more discussion.

3.6 Daemon threads

There are two kinds of threads, *daemon threads* and *user threads*. A daemon thread can be set via the `setDaemon(boolean on)` method. A deamon thread is an infrastructure thread, e.g., the garbage collector thread and the GUI's event dispatcher thread. The JVM exits when the only threads running are all daemon threads. In other words, the JVM considers its job done, when there is no more user threads and all the remaining threads are its infrastructure threads.

[@PENDING more]

3.7 The Life Cycle of a Thread



The thread is in the "new" state, once it is constructed. In this state, it is merely an object in the heap, without any system resources allocated for execution. From the "new" state, the only thing you can do is to invoke the `start()` method, which puts the thread into the "runnable" state. Calling any method besides the `start()` will trigger an `IllegalThreadStateException`.

The `start()` method allocates the system resources necessary to execute the thread, schedules the thread to be run, and calls back the `run()` once it is scheduled. This put the thread into the "runnable" state. However, most computers have a single CPU and *time-slice* the CPU to support multithreading. Hence, in the "runnable" state, the thread may be running or waiting for its turn of the CPU time.

A thread cannot be started twice, which triggers a runtime `IllegalThreadStateException`.

The thread enters the "not-runnable" state when one of these events occurs:

1. The `sleep()` method is called to suspend the thread for a specified amount of time to yield control to the other threads. You can also invoke the `yield()` to hint to the scheduler that the current thread is willing to yield its current use of a processor. The scheduler is, however, free to ignore this hint.
2. The `wait()` method is called to wait for a specific condition to be satisfied.
3. The thread is *blocked* and waiting for an I/O operation to be completed.

For the "non-runnable" state, the thread becomes "runnable" again:

1. If the thread was put to sleep, the specified sleep-time expired or the sleep was interrupted via a call to the `interrupt()` method.
2. If the thread was put to wait via `wait()`, its `notify()` or `notifyAll()` method was invoked to inform the waiting thread that the specified condition had been fulfilled and the wait was over.
3. If the thread was blocked for an I/O operation, the I/O operation has been completed.

A thread is in a "terminated" state, only when the `run()` method terminates naturally and exits.

The method `isAlive()` can be used to test whether the thread is alive. The `isAlive()` returns `false` if the thread is "new" or "terminated". It returns `true` if the thread is "runnable" or "not-runnable".

JDK 1.5 introduces a new `getState()` method. This method returns an (nested) `enum` of type `Thread.State`, which takes a constant of `{NEW, BLOCKED, RUNNABLE, TERMINATED, WAITING}`.

- `NEW`: the thread has not yet started.
- `RUNNABLE`:
- `WAITING`:
- `BLOCKED`: the thread is blocked waiting for a monitor lock.
- `TIMED_WAITING`: the thread is waiting with a specified waiting time.
- `TERMINATED`:

4. Thread Scheduling and Priority

JVM implements a fixed priority thread-scheduling scheme. Each thread is assigned a priority number (between the `Thread.MIN_PRIORITY` and `Thread.MAX_PRIORITY`). The higher the number, the higher is the priority for the thread. When a new thread is created, it inherits the priority number from the thread that created it. You can used the method `setPriority()` to change the priority number of a thread as follows:

```
public void setPriority(int priority);
```

The `int priority` is JVM dependent. It may take a value between 1 (lowest priority) to 10.

JVM chooses the highest-priority thread for execution. If there is more than one thread with the same highest-priority, JVM schedules them in a round-robin manner.

JVM also implements a pre-emptive scheduling scheme. In a pre-emptive environment, if at any time a higher priority thread becomes "runnable", the current lower priority thread will yield control to the higher priority thread immediately.

If there are more than one equal-priority runnable threads, one thread may run until the completion without yielding control to other equal-priority threads. This is known as *starvation*. Therefore, it is a good practice to yield control to other equal-priority thread via the `sleep()` or `yield()` method. However, you can never yield control to a lower-priority thread.

In some operating systems such as Windows, each of the running thread is given a specific amount of CPU time. It is known as time slicing to prevent a thread from starving the other equal-priority threads. However, do not rely on time slicing, as it is implementation dependent.

Hence, a running thread will continue running until:

- A higher priority thread becomes "runnable".
- The running thread yields control voluntarily by calling methods such as `sleep()`, `yield()`, and `wait()`.
- The running thread terminates, i.e., its `run()` method exits.
- On system that implements time slicing, the running thread consumes its CPU time quota.

An important point to note is the thread scheduling and priority is JVM dependent. This is natural as JVM is a virtual machine and requires the native operating system resources to support multithreading. Most JVM does not guarantee that the highest-priority thread is being run at all times. It may choose to dispatch a lower-priority thread for some reasons such as to prevent starvation. Therefore, you should not rely on the priority in your algorithm.

5. Monitor Lock & Synchronization

A `monitor` is an object that can be used to block and revive thread. It is supported in the `java.lang.Object` root class, via these mechanisms:

1. A lock for each object.
2. The keyword `synchronized` for accessing object's lock.
3. The `wait()`, `notify()` and `notifyAll()` methods in `java.lang.Object` for controlling threads.

Each Java object has a lock. At any time, the lock is controlled by, at most, a single thread. You could mark a method or a block of the codes with keyword `sychronized`. A thread that wants to execute an object's synchronized code must first attempt to acquire its lock. If the lock is under the control of another thread, then the attempting thread goes into the *Seeking Lock* state and becomes ready only when the lock becomes available. When a thread that owns a lock completes the synchronized code, it gives up the lock.

5.1 Keyword "sychronized"

For example,

```
public synchronized void methodA() { ...... }  // synchronized a mehtod based on this object

public void methodB() {
   synchronized(this) {      // synchronized a block of codes based on this object
      ......
   }

   synchronized(anObject) {  // synchronized a block of codes based on another object
      ......
   }
   ......
}
```

Synchronization can be controlled at method level or block level. Variables cannot be synchronized. You need to synchronized the ALL the methods that access the variables.

```
private static int counter = 0;

public static synchronized void increment() {
   ++counter;
}

public static synchronized void decrement() {
   --counter;
}
```

You can also `synchronized` on `static` methods. In this case, the *class lock* (instead of the instance lock) needs to be acquired in order to execute the method.

Example

```
public class SynchronizedCounter {
   private static int count = 0;

   public synchronized static void increment() {
      ++count;
      System.out.println("Count is " + count + " @ " + System.nanoTime());
   }

   public synchronized static void decrement() {
      --count;
      System.out.println("Count is " + count + " @ " + System.nanoTime());
   }
}
```

```
public class TestSynchronizedCounter {
   public static void main(String[] args) {
      Thread threadIncrement = new Thread() {
         @Override
         public void run() {
            for (int i = 0; i < 10; ++i) {
               SynchronizedCounter.increment();
               try {
                  sleep(1);
               } catch (InterruptedException e) {}
            }
         }
      };

      Thread threadDecrement = new Thread() {
         @Override
         public void run() {
            for (int i = 0; i < 10; ++i) {
               SynchronizedCounter.decrement();
               try {
                  sleep(1);
               } catch (InterruptedException e) {}
            }
         }
      };

      threadIncrement.start();
      threadDecrement.start();
   }
}
```

```
Count is -1 @ 71585106672577
Count is 0 @ 71585107040916
Count is -1 @ 71585107580661
Count is 0 @ 71585107720865
Count is 1 @ 71585108577488
Count is 0 @ 71585108715261
Count is 1 @ 71585109590928
Count is 0 @ 71585111400613
Count is 1 @ 71585111640095
Count is 0 @ 71585112581002
Count is 1 @ 71585112748760
Count is 2 @ 71585113580259
Count is 1 @ 71585113729378
Count is 2 @ 71585114579922
Count is 1 @ 71585114712832
Count is 2 @ 71585115578775
Count is 1 @ 71585115722626
Count is 2 @ 71585116578843
Count is 1 @ 71585116719452
Count is 0 @ 71585117583368
```

It is important to note that while the object is locked, `synchronized` methods and codes are blocked. However, non-`synchronized` methods can proceed without acquiring the lock. Hence, it is necessary to synchronize all the methods involved the shared resources. For example, if `synchronized` access to a variable is desired, all the methods to that variable should be `synchronized`. Otherwise, a non-`synchronized` method can proceed without first obtaining the lock, which may corrupt the state of the variable.

5.2 `wait()`, `notify()` & `notifyAll()` for Inter-Thread Synchronization

These methods are defined in the `java.lang.Object` class (instead of `java.land.Thread` class). These methods can only be called in the *synchronous* codes.

The `wait()` and `notify()` methods provide a way for a shared object to pause a thread when it becomes unavailable to that thread and to allow the thread to continue when appropriate.

Example: Consumer and Producer

In this example, a producer produces a message (via `putMessage()` method) that is to be consumed by the consumer (via `getMessage()` method), before it can produce the next message. In a so-called producer-consumer pattern, one thread can suspend itself using `wait()` (and release the lock) until such time when another thread awaken it using `notify()` or `notifyAll()`.

```
// Testing wait() and notify()
public class MessageBox {
   private String message;
   private boolean hasMessage;

   // producer
   public synchronized void putMessage(String message) {
```

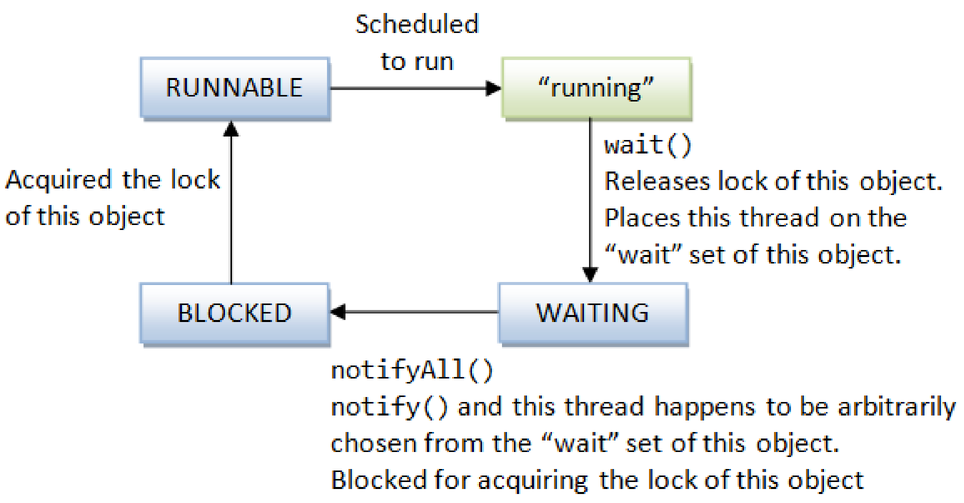
```java
      while (hasMessage) {
         // no room for new message
         try {
            wait();  // release the lock of this object
         } catch (InterruptedException e) { }
      }
      // acquire the lock and continue
      hasMessage = true;
      this.message = message + " Put @ " + System.nanoTime();
      notify();
   }

   // consumer
   public synchronized String getMessage() {
      while (!hasMessage) {
         // no new message
         try {
            wait();  // release the lock of this object
         } catch (InterruptedException e) { }
      }
      // acquire the lock and continue
      hasMessage = false;
      notify();
      return message + " Get @ " + System.nanoTime();
   }
}
```

```java
public class TestMessageBox {
   public static void main(String[] args) {
      final MessageBox box = new MessageBox();

      Thread producerThread = new Thread() {
         @Override
         public void run() {
            System.out.println("Producer thread started...");
            for (int i = 1; i <= 6; ++i) {
               box.putMessage("message " + i);
               System.out.println("Put message " + i);
            }
         }
      };

      Thread consumerThread1 = new Thread() {
         @Override
         public void run() {
            System.out.println("Consumer thread 1 started...");
            for (int i = 1; i <= 3; ++i) {
               System.out.println("Consumer thread 1 Get " + box.getMessage());
            }
         }
      };

      Thread consumerThread2 = new Thread() {
         @Override
         public void run() {
            System.out.println("Consumer thread 2 started...");
            for (int i = 1; i <= 3; ++i) {
               System.out.println("Consumer thread 2 Get " + box.getMessage());
            }
         }
      };

      consumerThread1.start();
      consumerThread2.start();
      producerThread.start();
   }
}
```

```
Consumer thread 1 started...
Producer thread started...
Consumer thread 2 started...
Consumer thread 1 Get message 1 Put @ 70191223637589 Get @ 70191223680947
Put message 1
Put message 2
Consumer thread 2 Get message 2 Put @ 70191224046855 Get @ 70191224064279
Consumer thread 1 Get message 3 Put @ 70191224164772 Get @ 70191224193543
Put message 3
Put message 4
Consumer thread 2 Get message 4 Put @ 70191224647382 Get @ 70191224664401
Put message 5
Consumer thread 2 Get message 5 Put @ 70191224939136 Get @ 70191224965070
Consumer thread 1 Get message 6 Put @ 70191225071236 Get @ 70191225101222
Put message 6
```

The output messages (on `System.out`) may appear out-of-order. But closer inspection on the put/get timestamp confirms the correct sequence of operations.

The `synchronized` producer method `putMessage()` acquires the lock of this object, check if the previous message has been cleared. Otherwise, it calls `wait()`, releases the lock of this object, goes into `WAITING` state and places this thread on this object's "wait" set. On the other hand, the `synchronized` consumer's method `getMessage()` acquires the lock of this object and checks for new message. If there is a new message, it clears the message and issues `notify()`, which arbitrarily picks a thread on this object's "wait" set (which happens to be the producer thread in this case) and place it on `BLOCKED` state. The consumer thread, in turn, goes into the `WAITING` state and placed itself in the "wait" set of this object (after the `wait()` method). The producer thread then acquires the thread and continue its operations.



Scheduled to run
RUNNABLE
"running"
wait()
Releases lock of this object.
Places this thread on the "wait" set of this object.
Acquired the lock of this object
BLOCKED
WAITING
notifyAll()
notify() and this thread happens to be arbitrarily chosen from the "wait" set of this object.
Blocked for acquiring the lock of this object

The difference between `notify()` and `notifyAll()` is `notify()` arbitrarily picks a thread from this object's waiting pool and places it on the Seeking-lock state; while `notifyAll()` awakens all the threads in this object's waiting pool. The awaken threads then compete for execution in the normal manner.

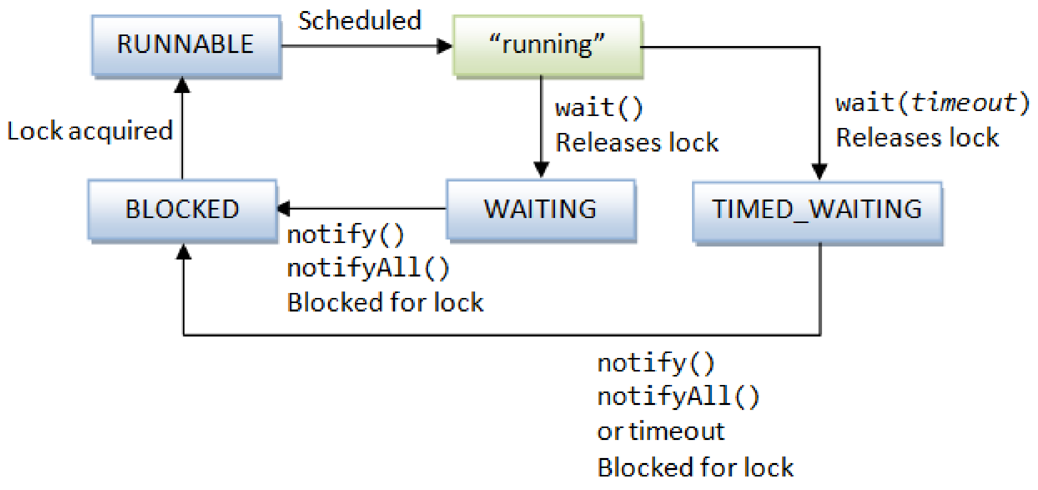
It is interesting to point out that multithreading is built into the Java language right at the root class `java.lang.Object`. The synchronization lock is kept in the `Object`. Methods `wait()`, `notify()`, `notifyAll()` used for coordinating threads are right in the class `Object`.

`wait()` with timeout

There are variations of `wait()` which takes in a timeout value:

```
public final void wait() throws InterruptedException
public final void wait(long timeout) throws InterruptedException
public final void wait(long timeout, int nanos) throws InterruptedException
```

The thread will ALSO go to `BLOCKED` state after the timeout expired.



5.3 Starvation & Deadlock

Starvation is the state where one (or more) thread is deprived of a chance to access an object. The problem can be resolved by setting the correct priorities to all the threads.

Deadlock refers to the situation where a thread is waiting for a condition, but somewhere else in the program prevented the condition from being fulfilled, thus, prevented the thread from executing. A classical example, known as "deadly embrace" is as follow: thread 1 is holding the lock to object A and thread 2 is holding the lock to object B. Thread 1 is waiting to acquire the lock to object B and thread 2 is waiting to acquire the lock to object A. Both threads are in deadlock and cannot proceed. If both threads seek the lock in the same order, the situation will not arise. But it is complex to program this arrangement. Alternatively, you could synchronize on another object, instead of object A and B; or synchronize only a portion of a method instead of the entire method. Deadlock can be complicated which may involves many threads and objects and can be hard to detect.

6. Multithreading issues in Swing Applications

References:

1. Swing Tutorial's "Concurrency in Swing".
2. John O'Conner, "Improve Application Performance With SwingWorker in Java SE 6" @ http://java.sun.com/developer/technicalArticles/javase/swingworker/.

A Swing application runs on multiple threads. Specifically, It has three types of threads:

1. An initial thread, or the Main thread, which runs the `main()` method, starts the building of GUI, and exits.
2. An Event-Dispatching Thread (EDT)
3. Some Background Worker threads for compute-intensive task and IO.

All the event-handling, painting and screen refreshing codes runs in a single thread, called the *event-dispatching thread*. This is to ensure that one event handler finishes execution before the next handler starts, and that painting is not interrupted by events. If the event-dispatching thread is starved by another compute-intensive task, the user interface "freezes", and the program becomes unresponsive to user interaction. "Ideally, any task that requires more than 30 to 100 milliseconds should not run on the EDT. Otherwise, users will sense a pause between their input and the UI response."

Furthermore, all codes accessing the GUI components should be run on the event-dispatching thread as many of these components are not guaranteed to be thread-safe. Accessing them from the same thread avoids the multithreading issues.

In summary,

1. Time-consuming and blocking-IO tasks should not be run on the event-dispatching thread, so as not to starve the event-dispatching thread to response to events triggered through user's interaction and repainting the screen.
2. Swing components should be accessed on the event-dispatching thread only for thread safety.

6.1 `javax.Swing.SwingUtilities.invokeLater()` and `invokeAndWait()`

The `invokeLater(Runnable)` and `invokeAndWait(Runnable)` methods schedule the `Runnable` task in the event-dispatching thread.

To avoid threading issues between the main thread (which runs the `main()` method) and the event-dispatching thread, it is recommended that you use `javax.swing.SwingUtilities.invokeLater(Runnable)` to create the GUI components on the event-dispatching thread, instead of using the main thread. Recall that Swing components are not guaranteed to be thread-safe and their access shall be confined to a single thread, the EDT. For example,

```
/** The entry main() method */
public static void main(String args[]) {
   // Run the GUI codes on the event-dispatching thread for thread-safety
   SwingUtilities.invokeLater(new Runnable() {
      @Override
      public void run() {
         JFrame frame = new JFrame("My Swing Application");
         frame.setContentPane(new MyMainPanel());
         frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
         frame.pack();
         frame.setLocationRelativeTo(null); // center on screen
         frame.setVisible(true);            // show it
      }
   });
}
```

The static method SwingUtilities.invokelater() takes a Runnable object (implemented as an anonymous inner class) as its argument, and schedules the task (specified in the run() method) on the event-dispatching thread. You can call invokeLater() from any thread to request the event-dispatching thread to run certain codes, as specified in the run() method of the Runnable argument. The invokeLater() returns immediately, without waiting for the event-dispatching thread to execute the code.

If needed, you can use invokeAndWait(), which waits until the event-dispatching thread has executed the specified codes, and returns. For applet, it is recommended to run the GUI construction codes (in init()) via invokeAndWait(). This is to avoid problems caused by init() exits before the completion of GUI construction. For example,

```
public class SwingTemplateJApplet extends JApplet {
   /** init() to setup the GUI components */
   @Override
   public void init() {
      // Run GUI codes in the Event-Dispatching thread for thread safety
      try {
         // Use invokeAndWait() to ensure that init() exits after GUI construction
         SwingUtilities.invokeAndWait(new Runnable() {
            @Override
            public void run() {
               // Set the content-pane of JApplet to an instance of main JPanel
               setContentPane(new SwingTemplateJPanel());
            }
         });
      } catch (Exception ex) {
         ex.printStackTrace();
      }
   }
}
```

You can also java.awt.EventQueue.invokeLater() in place of the javax.swing.SwingUtilities.invokeLater(). The javax.swing.SwingUtilities.invokeLater() is just a cover for java.awt.EventQueue.invokeLater().

The traces in the earlier examples show that if SwingUtilities.invokeLater() is not used, the event-dispatching thread is started after the setVisible() method. On the other hand, the invokerLater() starts the event-dispatching thread.

6.2 javax.swing.Timer (JDK 1.2)

If you need to update a component after a certain time delay or at a regular time interval, use a timer class, such as javax.swing.Timer (JDK 1.2) or java.util.Timer (JDK 1.3).

For javax.swing.Timer, read "animation using javax.swing.Timer".

[TODO] java.util.Timer (JDK 1.3)

6.3 javax.swing.SwingWorker<T,V> (JDK 1.6)

As mentioned, in a Swing application:

1. Compute-intensive task should not be run on the event-dispatching thread (EDT), so as not to starve the EDT from processing events and repaints.
2. Swing components shall be accessed in the EDT only for thread safety.

The javax.swing.SwingWorkder<T,V> class helps to manage the interaction between the only EDT and several background worker threads. It can be used to schedule a compute-intensive task in a background thread and return the final result or intermediate results in the EDT.

The signature of the SwingWorker class is as follow:

```
public abstract class SwingWorker<T,V> implements RunnableFuture
```

SwingWorker<T,V> is an abstract class with two type parameters: where T specifies the *final* result type of the doInBackground() and get() methods, and V specifies the type of the *intermediate* results of the publish() and process() methods.

The RunnableFuture interface is the combination of two interfaces: Runnable and Future. The interface Runnable declares an abstract method run(); while Future declares get(), cancel(), isDone(), and isCancelled().

Scheduling a Backgroud Task

```
protected abstract T doInBackground() throws Exception
   // Do this task in a background thread
```

```
protected void done()
   // Executes on the Event-Dispatching thread after the doInBackground() method finishes.
public final T get() throws InterruptedException, ExecutionException
   // Waits for doInBackground() to complete and gets the result.
   // Calling get() on the Event-Dispatching thread blocks all events, including repaints,
   //  until the SwingWorker completes.
public final void execute()
   // Schedules this SwingWorker for execution on one of the worker thread.
public final boolean cancel(boolean mayInterruptIfRunning)
   // Attempts to cancel execution of this task.
public final boolean isDone()
   // Returns true if this task has completed (normally or exception)
public final boolean isCancelled()
   // Returns true if this task was cancelled before it completed normally
```

To schedule a task in a worker thread, extend a subclass of `SwingWorker<T,V>` (typically an inner class) and override:

1. the `doInBackground()` to specify the task behavior, which will be scheduled in one of the worker thread and returns a result of type `T`.
2. the `done()` methods, which will be run in the EDT after `doInBackground()` completes. In `done()`, use the `get()` method to retrieve the result of `doInBackground()` (of the type `T`).

Example

This example includes a compute-intensive task into the counter application. The compute-intensive task is scheduled to run in one of the worker thread, and hence will not starve the event-dispatching thread to run the counter and repaints.

```
import java.awt.*;
import java.awt.event.*;
import java.util.concurrent.ExecutionException;
import javax.swing.*;

/** Test SwingWorker on the counter application with a compute-intensive task */
@SuppressWarnings("serial")
public class SwingWorkerCounter extends JPanel {
   // For counter
   private JTextField tfCount;
   private int count = 0;
   // For SwingWorker
   JButton btnStartWorker;   // to start the worker
   private JLabel lblWorker; // for displaying the result

   /** Constructor to setup the GUI components */
   public SwingWorkerCounter () {
      setLayout(new FlowLayout());

      add(new JLabel("Counter"));
      tfCount = new JTextField("0", 10);
      tfCount.setEditable(false);
      add(tfCount);

      JButton btnCount = new JButton("Count");
      add(btnCount);
      btnCount.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            ++count;
            tfCount.setText(count + "");
         }
      });

      /** Create a SwingWorker instance to run a compute-intensive task
          Final result is String, no intermediate result (Void) */
      final SwingWorker<String, Void> worker = new SwingWorker<String, Void>() {
         /** Schedule a compute-intensive task in a background thread */
         @Override
         protected String doInBackground() throws Exception {
            // Sum from 1 to a large n
            long sum = 0;
            for (int number = 1; number < 1000000000; ++number) {
               sum += number;
            }
            return sum + "";
         }

```

```java
         /** Run in event-dispatching thread after doInBackground() completes */
         @Override
         protected void done() {
            try {
               // Use get() to get the result of doInBackground()
               String result = get();
               // Display the result in the label (run in EDT)
               lblWorker.setText("Result is " + result);
            } catch (InterruptedException e) {
               e.printStackTrace();
            } catch (ExecutionException e) {
               e.printStackTrace();
            }
         }
      };

      btnStartWorker = new JButton("Start Worker");
      add(btnStartWorker);
      btnStartWorker.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            worker.execute();                 // start the worker thread
            lblWorker.setText("  Running...");
            btnStartWorker.setEnabled(false); // Each instance of SwingWorker run once
         }
      });
      lblWorker = new JLabel("  Not started...");
      add(lblWorker);

   }

   /** The entry main() method */
   public static void main(String[] args) {
      // Run the GUI construction in the Event-Dispatching thread for thread-safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            JFrame frame = new JFrame("SwingWorker Test");
            frame.setContentPane(new SwingWorkerCounter());
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setSize(300, 150);
            frame.setVisible(true);
         }
      });
   }
}
```

A instance of `SwingWorker` is designed to run only once. You cannot restart the instance. You need to create a new instance for run the task again.

More Example: "`TumbleItem`" demo of the Swing Tutorial.

Publishing and Processing Intermediate Results

Other than processing the final result in `done()`, you can `publish()` and `process()` intermediate results as the need arises.

```
@SafeVarargs
protected final void publish(V... chunks)
   // Sends data chunks to the process(java.util.List<V>) method.
   // This method shall be called inside the doInBackground() to deliver intermediate results
   //  for processing on the Event-Dispatching thread inside the process() method.
protected void process(List<V> chunks)
   // Receives data chunks from publish() asynchronously on the Event-Dispatching thread.
```

In `doInBackground()`, use `publish(V...)` to publish one or more intermediate result(s) of type `V`. Override the `process(List<V>)` method to process the results published so far in a `List<V>`. The `process()` method runs in the event-dispatching thread.

Example

```java
import java.awt.*;
import java.awt.event.*;
import java.util.concurrent.ExecutionException;
import javax.swing.*;

/** Test SwingWorker on the counter application with a compute-intensive task */
```

```java
@SuppressWarnings("serial")
public class SwingWorkerCounterIntermediateResult extends JPanel {
   // For counter
   private JTextField tfCount;
   private int count = 0;
   // For SwingWorker
   JButton btnStartWorker;   // to start the worker
   private JLabel lblWorker; // for displaying the result

   /** Constructor to setup the GUI components */
   public SwingWorkerCounterIntermediateResult () {
      setLayout(new FlowLayout());

      add(new JLabel("Counter"));
      tfCount = new JTextField("0", 10);
      tfCount.setEditable(false);
      add(tfCount);

      JButton btnCount = new JButton("Count");
      add(btnCount);
      btnCount.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            ++count;
            tfCount.setText(count + "");
         }
      });

      /** Create a SwingWorker instance to run a compute-intensive task */
      final SwingWorker<String, String> worker = new SwingWorker<String, String>() {

         /** Schedule a compute-intensive task in a background thread */
         @Override
         protected String doInBackground() throws Exception {
            long sum = 0;
            for (int number = 0; number < 10000000; ++number) {
               sum += number;
               publish(sum + ""); // Send "every" intermediate result to process()
                                  // You might not publish every intermediate result
            }
            return sum + "";
         }

         /** Run in event-dispatching thread after doInBackground() completes */
         @Override
         protected void done() {
            try {
               // Use get() to get the result of doInBackground()
               String finalResult = get();
               // Display the result in the label (run in EDT)
               lblWorker.setText("Final Result is " + finalResult);
            } catch (InterruptedException e) {
               e.printStackTrace();
            } catch (ExecutionException e) {
               e.printStackTrace();
            }
         }

         /** Run in event-dispatching thread to process intermediate results
              send from publish(). */
         @Override
         protected void process(java.util.List<String> chunks) {
            // Get the latest result from the list
            String latestResult = chunks.get(chunks.size() - 1);
            lblWorker.setText("Result is " + latestResult);
         }
      };

      btnStartWorker = new JButton("Start Worker");
      add(btnStartWorker);
      btnStartWorker.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            worker.execute();  // start the worker thread
            lblWorker.setText("  Running...");
            btnStartWorker.setEnabled(false);  // SwingWorker can only run once
         }
      });
      lblWorker = new JLabel("  Not started...");
      add(lblWorker);

   }

   /** The entry main() method */
   public static void main(String[] args) {
      // Run the GUI construction in the Event-Dispatching thread for thread-safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
            JFrame frame = new JFrame("SwingWorker Test");
            frame.setContentPane(new SwingWorkerCounterIntermediateResult());
            frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
            frame.setSize(300, 150);
            frame.setVisible(true);
         }
      });
   }
}
```

More Example: "`IconDemoApp`" demo of Swing Tutorial.

Property Change Event

The `doInBackground()` fires `PropertyChangeEvent` to all its `PropertyChangeListeners` about bound properties changes. There are two bound properties: "`state`" and "`progress`". "`state`" is defined in the nested `enum SwingWorker.StateValue`, with value of `PENDING` (`SwingWorker` instance created), `START` (`doInBackground` started) and `DONE` (`doInBackground` completed). "`progress`" is an `int`, in the range of 0 to 100. You can change the `progress` value via `setProgress()` method inside the `doInBackground()` to fire a `PropertyChangeEvent` to all its `PropertyChangeListeners`.

Example

In this example, inside the `doInBackground()`, we invoke `setProgess()` to change the `progress` bound-property value (between 0 to 100), which in turn fires a `PropertyChangeEvent`. A `PropertyChangeListener` is defined and registered with this `SwingWorker`, which shows the `progress` value on a progress bar. The event-handler runs in the EDT.

```
import java.awt.*;
import java.awt.event.*;
import java.beans.PropertyChangeEvent;
import java.beans.PropertyChangeListener;
import java.util.concurrent.ExecutionException;
import javax.swing.*;

/** Test SwingWorker on the counter application with a compute-intensive task */
@SuppressWarnings("serial")
public class SwingWorkerCounterProgress extends JPanel {
   // For counter
   private JTextField tfCount;
   private int count = 0;
   // For SwingWorker
   JButton btnStartWorker;   // to start the worker
   private JLabel lblWorker; // for displaying the result
   JProgressBar pbWorker;    // progress bar for the worker task

   /** Constructor to setup the GUI components */
   public SwingWorkerCounterProgress () {
      setLayout(new FlowLayout());

      add(new JLabel("Counter"));
      tfCount = new JTextField("0", 10);
      tfCount.setEditable(false);
      add(tfCount);

      JButton btnCount = new JButton("Count");
      add(btnCount);
      btnCount.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            ++count;
            tfCount.setText(count + "");
         }
```

```java
      });

      /** Create a SwingWorker instance to run a compute-intensive task */
      final SwingWorker<String, String> worker = new SwingWorker<String, String>() {

         /** Schedule a compute-intensive task in a background thread */
         @Override
         protected String doInBackground() throws Exception {
            long sum = 0;
            int maxNumber = 10000000;
            for (int number = 0; number < maxNumber; ++number) {
               sum += number;
               publish(sum + ""); // send intermediate result to process()
               // Fire PropertyChangeEvent for the bound-property "progress"
               setProgress(100 * (number + 1) / maxNumber);
            }
            return sum + "";
         }

         /** Run in event-dispatching thread after doInBackground() completes */
         @Override
         protected void done() {
            try {
               // Use get() to get the result of doInBackground()
               String finalResult = get();
               // Display the result in the label (run in EDT)
               lblWorker.setText("Final Result is " + finalResult);
            } catch (InterruptedException e) {
               e.printStackTrace();
            } catch (ExecutionException e) {
               e.printStackTrace();
            }
         }

         /** Run in event-dispatching thread to process intermediate results
              send from publish(). */
         @Override
         protected void process(java.util.List<String> chunks) {
            // Get the latest result from the list
            String latestResult = chunks.get(chunks.size() - 1);
            lblWorker.setText("Result is " + latestResult);
         }
      };

      /** Event handler for the PropertyChangeEvent of property "progress" */
      worker.addPropertyChangeListener(new PropertyChangeListener() {
         @Override
         public void propertyChange(PropertyChangeEvent evt) {
            if (evt.getPropertyName().equals("progress")) {  // check the property name
               pbWorker.setValue((Integer)evt.getNewValue());  // update progress bar
            }
         }
      });

      btnStartWorker = new JButton("Start Worker");
      add(btnStartWorker);
      btnStartWorker.addActionListener(new ActionListener() {
         @Override
         public void actionPerformed(ActionEvent e) {
            worker.execute();  // start the worker thread
            lblWorker.setText("  Running...");
            btnStartWorker.setEnabled(false);  // SwingWorker can only run once
         }
      });
      lblWorker = new JLabel("  Not started...");
      add(lblWorker);
      pbWorker = new JProgressBar();
      add(pbWorker);
   }

   /** The entry main() method */
   public static void main(String[] args) {
      // Run the GUI construction in the Event-Dispatching thread for thread-safety
      SwingUtilities.invokeLater(new Runnable() {
         @Override
         public void run() {
                JFrame frame = new JFrame("SwingWorker Test");
                frame.setContentPane(new SwingWorkerCounterProgress());
                frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
                frame.setSize(300, 150);
                frame.setVisible(true);
            }
        });
    }
}
```

6.4 Summary

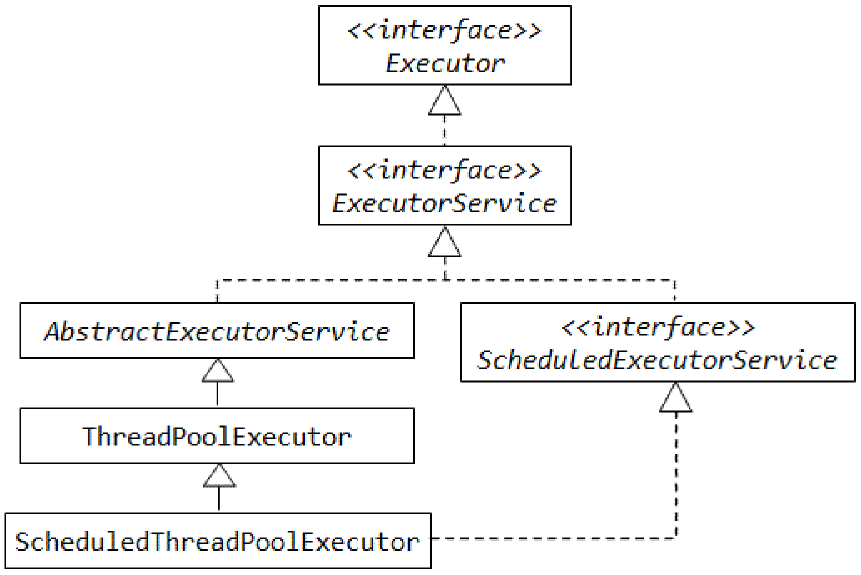
Threads are essential to build a responsive graphical user interface. These are the typical situations where a new thread should be used:

- To fork out a new thread for a time-consuming initialization task (such as disk I/O) in the main thread, so that the GUI comes up faster.
- To fork out a new thread for a time-consuming task (within an event handler) in the event dispatch thread, so that the GUI remains responsive.
- Use timer for a repetitive task, which runs at regular time interval or after a certain time delay.
- To fork out a new thread if the operations need to wait for a message from another thread or program.

In addition, the compute-intensive threads must be co-operative and yield control to others.

7. Thread Pool, Executor, Callable/Future (JDK 1.5)

The thread pool supporting classes are introduced in package `java.lang.concurrent`, in JDK 1.5.



<<interface>> Executor
<<interface>> ExecutorService
AbstractExecutorService
<<interface>> ScheduledExecutorService
ThreadPoolExecutor
ScheduledThreadPoolExecutor

7.1 Thread Pool

A *thread pool* is a managed collection of threads that are available to execute tasks. When a large number of tasks is executed using a thread pool, the performance improves as the threads are re-cycled to execute the tasks, which reduces the per-task invocation overhead.

To use a thread pool, you can use an implementation of the interface `ExecutorService`, such as `ThreadPoolExecutor` or `ScheduledThreadPoolExecutor`. However, more convenient factory methods are provided in the `Executors` class as follows:

- `Executors.newSingleThreadExecutor()`: creates a single background thread.
- `Executors.newFixedThreadPool(int numThreads)`: creates a fixed size thread pool.
- `Executors.newCachedThreadPool()`: create a unbounded thread pool, with automatic thread reclamation.

The steps of using thread pool are:

1. Write you worker thread class which implements `Runnable` interface. The `run()` method specifies the behavior of the running thread.
2. Create a thread pool (`ExecutorService`) using one the factory methods provided by the `Executors` class. The thread pool could have a single thread, a fixed number of threads, or an unbounded number of threads.

3. Create instances of your worker thread class. Use `execute(Runnable r)` method of the thread pool to add a `Runnable` task into the thread pool. The task will be scheduled and executes if there is an available thread in the pool.

7.2 Interface `java.util.concurrent.Executor`

An `Executor` object can execute `Runnable` tasks submitted. The interface declares an `abstract` method:

```
public void execute(Runnable r)
```

It executes the given task at some time in the future. The task may be executed in a new thread, in a thread pool, or in the calling thread, depending on the implementation of `Executor` (e.g. single thread or thread pool)

7.3 Interface `java.util.concurrent.ExecutorService`

Interface `ExecutorService` declares many `abstract` methods. The important ones are:

```
public void shutdown();
   // Initiates an orderly shutdown of the thread pool.
   // The previously executed/submitted tasks are allowed to complete,
   // but no new tasks will be scheduled.
public <T> Future<T> submit(Callable<T> task);
   // Submit or schedule the callable task for execution, which returns a Future object.
```

7.4 Class `java.util.concurrent.Executors`

The class `Executors` provides factory methods for creating `Executor` object. For example:

```
static ExecutorService newSingleThreadExecutor()
static ExecutorService newFixedThreadPool(int nThreads)
static ExecutorService newCachedThreadPool()
static ScheduledExecutorService newSingleThreadScheduledExecutor()
static ScheduledExecutorService newScheduledThreadPool(int size)
```

Example

```
public class WorkerThread implements Runnable {
   private int workerNumber;

   WorkerThread(int workerNumber) {
      this.workerNumber = workerNumber;
   }

   public void run() {
      // The thread simply prints 1 to 5
      for (int i = 1; i <= 5; ++i) {
         System.out.printf("Worker %d: %d\n", workerNumber, i);
         try {
            // sleep for 0 to 0.5 second
            Thread.sleep((int)(Math.random() * 500));
         } catch (InterruptedException e) {}
      }
   }
}
```

```
import java.util.concurrent.ExecutorService;
import java.util.concurrent.Executors;

public class ThreadPoolTest {
   public static void main(String[] args) {
      int numWorkers = Integer.parseInt(args[0]);
      int threadPoolSize = Integer.parseInt(args[1]);

      ExecutorService pool =
            Executors.newFixedThreadPool(threadPoolSize);
      WorkerThread[] workers = new WorkerThread[numWorkers];
      for (int i = 0; i < numWorkers; ++i) {
         workers[i] = new WorkerThread(i+1);
         pool.execute(workers[i]);
      }
      pool.shutdown();
   }
}
```

```
//2 threads, 5 workers
> java ThreadPoolTest 5 2
Worker 1: 1
Worker 2: 1
Worker 1: 2
Worker 1: 3
Worker 2: 2
Worker 1: 4
Worker 2: 3
Worker 1: 5
Worker 3: 1
Worker 3: 2
Worker 2: 4
Worker 3: 3
Worker 2: 5
Worker 3: 4
Worker 3: 5
Worker 4: 1
Worker 4: 2
Worker 5: 1
Worker 4: 3
Worker 5: 2
Worker 5: 3
Worker 4: 4
Worker 5: 4
Worker 5: 5
Worker 4: 5
```

Worker 1 and 2 were first scheduled for execution using the 2 threads in the pool, followed by worker 3, 4 and 5. After the task using the thread completes, the thread is returned to the pool. Another task can then be scheduled and begin execution.

You can use `pool.shutdown()` to shutdown all the threads in the pool.

7.5 Interface `java.util.concurrent.Callable<V>` and `Future<V>`

A `Callable` is similar to a `Runnable`. However, `Callable` provides a way to return a result or `Exception` to the thread that spin this `Callable`. `Callable` declares an `abstract` method `call()` (instead of `run()` in the `Runnable`).

```
public V call()
   // Call() returns a result of type <V>, or throws an exception if unable to do so.
```

In the thread pool, instead of using `execute(Runnable r)`, you use `submit(Callable r)`, which returns a `Future<V>` object (declared in the `ExecutorService` interface). When the result is required, you can retrieve using `get()` method on the `Future` object. If the result is ready, it is returned, otherwise, the calling thread is blocked until the result is available.

The interface `Future<V>` declares the following `abstract` methods:

```
V get()           // wait if necessary, retrieve result
V get(long timeout, TimeUnit unit)
boolean cancel(boolean mayInterruptIfRunning)
boolean isCancelled()
boolean isDone()  // return true if this task completed
```

Example

```
import java.util.concurrent.Callable;

public class CallableWorkerThread implements Callable<String> {
   private int workerNumber;

   CallableWorkerThread(int workerNumber) {
      this.workerNumber = workerNumber;
   }

   public String call() {    // use call() instead of run()
      for (int i = 1; i <= 5; ++i) {    // just print 1 to 5
         System.out.printf("Worker %d: %d\n", workerNumber, i);
         try {
            Thread.sleep((int)(Math.random() * 1000));
         } catch (InterruptedException e) {}
      }
      return "worker " + workerNumber;
   }
}
```

```
import java.util.concurrent.*;

public class CallableThreadPoolTest {
   public static void main(String[] args) {
      int numWorkers = Integer.parseInt(args[0]);

      ExecutorService pool = Executors.newCachedThreadPool();
      CallableWorkerThread workers[] = new CallableWorkerThread[numWorkers];
      Future[] futures = new Future[numWorkers];

      for (int i = 0; i < numWorkers; ++i) {
         workers[i] = new CallableWorkerThread(i + 1);
         futures[i] = pool.submit(workers[i]);
      }
      for (int i = 0; i < numWorkers; ++i) {
         try {
            System.out.println(futures[i].get() + " ended");
         } catch (InterruptedException ex) {
            ex.printStackTrace();
         } catch (ExecutionException ex) {
            ex.printStackTrace();
         }
      }
   }
}
```

Output with 3 workers, unbound number of threads is as follows:

```
> java CallableThreadPoolTest 3
Worker 1: 1
Worker 3: 1
Worker 2: 1
Worker 3: 2
Worker 1: 2
Worker 2: 2
Worker 2: 3
Worker 2: 4
Worker 2: 5
Worker 1: 3
Worker 3: 3
Worker 3: 4
Worker 3: 5
Worker 1: 4
Worker 1: 5
worker 1 ended
worker 2 ended
worker 3 ended
```

7.6 Other New Thread Features in JDK 1.5

- Lock
- ReadWriteLock
- Semaphores
- Atomics
- Blocking Queue

[TODO]

LINK TO JAVA REFERENCES & RESOURCES

MORE REFERENCES & RESOURCES

1. Swing Tutorial's "Concurrency in Swing".

2. John O'Conner, "Improve Application Performance With SwingWorker in Java SE 6" @ http://java.sun.com/developer/technicalArticles/javase/swingworker/.

Latest version tested: JDK 1.7
Last modified: April, 2012