JAVA PROGRAMMING

COURSE NAME: MCA – 5TH SEMESTER

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Threads in Java:

A thread is actually a lightweight process. Unlike many other computer languages, Java provides built-in support for multithreaded programming. A multithreaded program contains two or more parts that can run **concurrently**. Each part of such a program is called a thread and each thread defines a separate path of the execution. Thus, multithreading is a specialized form of multitasking.

Creating Threads in Java:

There are two ways to create a thread:

1. By extending Thread class
2. By implementing Runnable interface.

Extending Thread Class

Thread class provide constructors and methods to create and perform operations on a thread.Thread class extends Object class and implements Runnable interface.

Commonly used Constructors of Thread class:

- Thread()
- Thread(String name)
- Thread(Runnable r)
- Thread(Runnable r,String name)

Commonly used methods of Thread class:

1. **public void run():** is used to perform action for a thread.
2. **public void start():** starts the execution of the thread.JVM calls the run() method on the thread.
3. **public void sleep(long miliseconds):** Causes the currently executing thread to sleep (temporarily cease execution) for the specified number of milliseconds.
4. **public void join():** waits for a thread to die.
5. **public void join(long miliseconds):** waits for a thread to die for the specified miliseconds.
6. **public int getPriority():** returns the priority of the thread.
7. **public int setPriority(int priority):** changes the priority of the thread.
8. **public String getName():** returns the name of the thread.
9. **public void setName(String name):** changes the name of the thread.
10. **public Thread currentThread():** returns the reference of currently executing thread.
11. **public int getId():** returns the id of the thread.
12. **public Thread.State getState():** returns the state of the thread.
13. **public boolean isAlive():** tests if the thread is alive.
14. **public void yield():** causes the currently executing thread object to temporarily pause and

allow other threads to execute.

15. **public void suspend():** is used to suspend the thread(depricated).
16. **public void resume():** is used to resume the suspended thread(depricated).
17. **public void stop():** is used to stop the thread(depricated).
18. **public boolean isDaemon():** tests if the thread is a daemon thread.
19. **public void setDaemon(boolean b):** marks the thread as daemon or user thread.
20. **public void interrupt():** interrupts the thread.
21. **public boolean isInterrupted():** tests if the thread has been interrupted.
22. **public static boolean interrupted():** tests if the current thread has been interrupted.

Example:

```
class MultithreadingDemo extends Thread
{
   public void run()
   {
      try
      {
         // Displaying the thread that is running
         System.out.println ("Thread " +
               Thread.currentThread().getId() +
               " is running");


      }
      catch (Exception e)
      {
         // Throwing an exception
         System.out.println ("Exception is caught");
      }
   }
}

// Main Class
public class Multithread
{
   public static void main(String[] args)
   {
      int n = 8; // Number of threads
      for (int i=0; i<n; i++)
      {
         MultithreadingDemo object = new MultithreadingDemo();
         object.start();
      }
   }
}
```

Output:

Thread 10 is running
Thread 13 is running
Thread 8 is running
Thread 11 is running
Thread 12 is running
Thread 9 is running
Thread 14 is running
Thread 15 is running

Implementing Runnable:

The Runnable interface should be implemented by any class whose instances are intended to be executed by a thread. Runnable interface have only one method named run() with the general form:

public void run(): is used to perform action for a thread.

Inside run() , we will define code that constitutes the new thread. The run() method can call other methods, use other classes and declare variables just like the main thread.The only difference is that run() establishes the entry point for another, concurrent thread of execution within our program. This thread ends when run() returns.

We create a new class which implements java.lang.Runnable interface and override run() method.
Then we instantiate a Thread object and call start() method on this object.

Example:

```
class NewThread implements Runnable
{
 Thread t;
 NewThread()
{
// Create a new, second thread
t=new Thread(this,"Demo thread");
System.out.println("Child thread:  " +t);
t.start();  //start the thread
}

//This is the entry point for second thread
   public void run()
   {
      try
      {
       for(int i=5;i>0;i--)
          {
```

```
            System.out.println("Child thread : "+i);
            Thread.sleep(500);
            }

        }
        catch (InterruptedException e)
        {
            // Throwing an exception
            System.out.println ("Child interrupted");
        }
      System.out.println("Exiting child thread");
    }
}

// Main Class
class Threaddemo
{
    public static void main(String[] args)
    {
      New NewThread();   //create new thread
       try
       {
       for (int i=5; i>0; i--)
        {
            System.out.println("Main thread :"+i);
           Thread.sleep(1000);
         }
    }
    Catch(InterruptedException e)
          {
           System.out.println("Main thread interrupted");
           }
System.out.println("Main thread exiting");
}
}
```

Output :

```
Child thread: Thread[Demo Thread,5,main]
Main thread: 5
Child thread : 5
```

```
Main thread : 4
Child thread: 3
Child thread: 2
Main thread: 3
Child thread: 1
Exiting child thread
Main thread: 2
Main thread: 1
Main thread exiting
```

Thread Class vs Runnable Interface

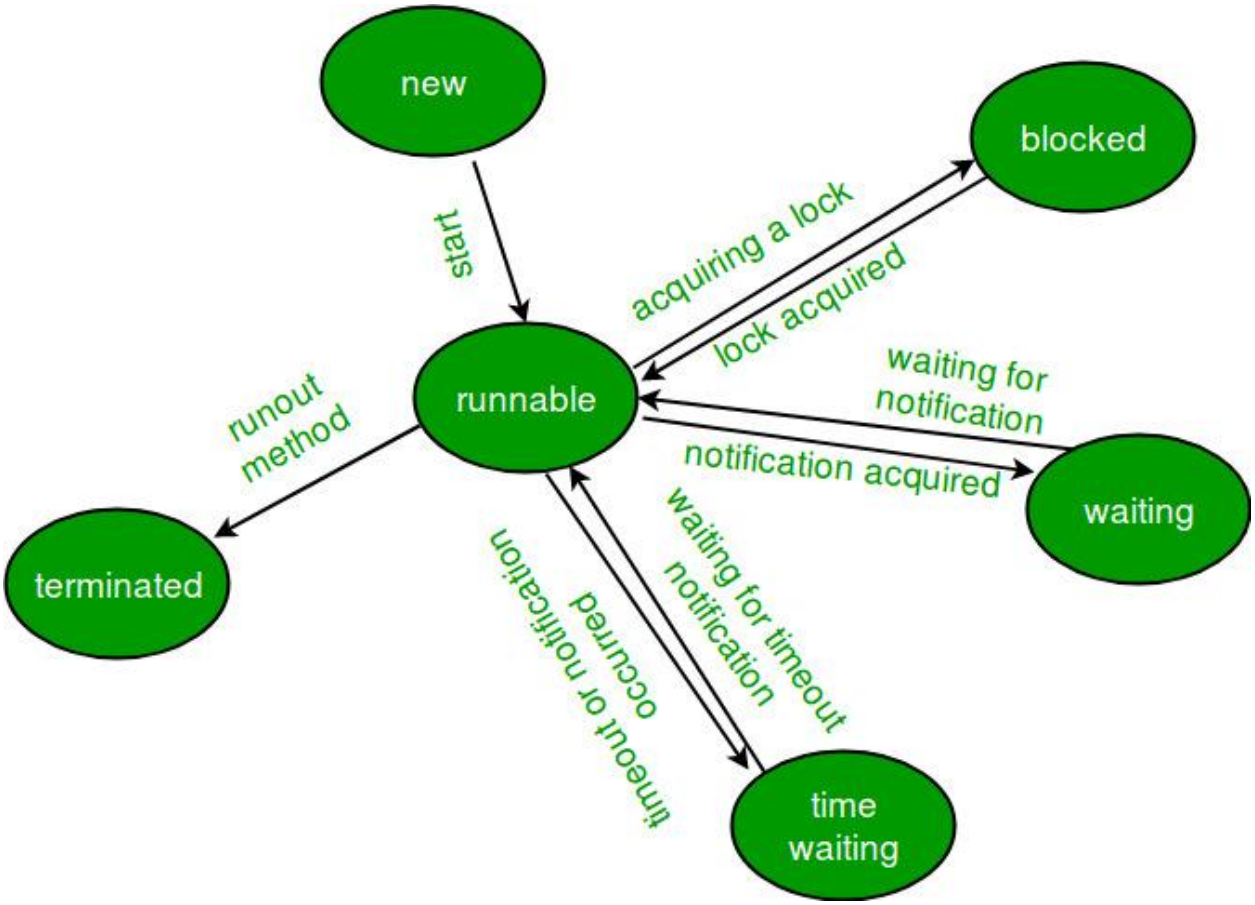
1. If we extend the Thread class, our class cannot extend any other class because Java doesn't support multiple inheritance. But, if we implement the Runnable interface, our class can still extend other base classes.
2. We can achieve basic functionality of a thread by extending Thread class because it provides some inbuilt methods like yield(), interrupt() etc. that are not available in Runnable interface.

Thread Lifecycle

A thread in Java at any point of time exists in any one of the following states. A thread lies only in one of the shown states at any instant:

1. New
2. Runnable
3. Blocked
4. Waiting
5. Timed Waiting
6. Terminated

The diagram shown below represents various states of a thread at any instant of time.



Life Cycle of a thread

1. **New Thread:** When a new thread is created, it is in the new state. The thread has not yet started to run when thread is in this state. When a thread lies in the new state, it's code is yet to be run and hasn't started to execute.

2. **Runnable State:** A thread that is ready to run is moved to runnable state. In this state, a thread might actually be running or it might be ready run at any instant of time. It is the responsibility of the thread scheduler to give the thread, time to run.
   A multi-threaded program allocates a fixed amount of time to each individual thread. Each and every thread runs for a short while and then pauses and relinquishes the CPU to another thread, so that other threads can get a chance to run. When this happens, all such threads that are ready to run, waiting for the CPU and the currently running thread lies in runnable state.

3. **Blocked/Waiting state:**When a thread is temporarily inactive, then it's in one of the following states:

   - Blocked

- Waiting

For example, when a thread is waiting for I/O to complete, it lies in the blocked state. It's the responsibility of the thread scheduler to reactivate and schedule a blocked/waiting thread. A thread in this state cannot continue its execution any further until it is moved to runnable state. Any thread in these states does not consume any CPU cycle.

A thread is in the blocked state when it tries to access a protected section of code that is currently locked by some other thread. When the protected section is unlocked, the schedule picks one of the thread which is blocked for that section and moves it to the runnable state. Whereas, a thread is in the waiting state when it waits for another thread on a condition. When this condition is fulfilled, the scheduler is notified and the waiting thread is moved to runnable state.

If a currently running thread is moved to blocked/waiting state, another thread in the runnable state is scheduled by the thread scheduler to run. It is the responsibility of thread scheduler to determine which thread to run.

4. **Timed Waiting:** A thread lies in timed waiting state when it calls a method with a time out parameter. A thread lies in this state until the timeout is completed or until a notification is received. For example, when a thread calls sleep or a conditional wait, it is moved to a timed waiting state.

5. **Terminated State:** A thread terminates because of either of the following reasons:

    - Because it exits normally. This happens when the code of thread has entirely executed by the program.

    - Because there occurred some unusual erroneous event, like segmentation fault or an unhandled exception.

A thread that lies in a terminated state does no longer consume any cycles of CPU.

MULTITHREADING IN JAVA

Creating Multiple Threads

Multithreading is a Java feature that allows concurrent execution of two or more parts of a program for maximum utilization of CPU.Our program can spawn as many threads as it needs. For example, the following program creates three child threads:

Example:

```
// Create multiple threads.
class NewThread implements Runnable
 {
String name; // name of thread
Thread t;

NewThread(String threadname)
 {
name = threadname;
t = new Thread(this, name);
System.out.println("New thread: " + t);
t.start(); // Start the thread
}

// This is the entry point for thread.
public void run()
 {
try {
for(int i = 5; i > 0; i--) {
System.out.println(name + ": " + i);
Thread.sleep(1000);
}
} catch (InterruptedException e) {
System.out.println(name + "Interrupted");
}
System.out.println(name + " exiting.");
}
}
```

```
class MultiThreadDemo {
public static void main(String args[]) {
new NewThread("One"); // start threads
new NewThread("Two");
new NewThread("Three");
try {
// wait for other threads to end
Thread.sleep(10000);
} catch (InterruptedException e) {
System.out.println("Main thread Interrupted");
}
System.out.println("Main thread exiting.");
}
}

//Output
New thread: Thread[One,5,main]
New thread: Thread[Two,5,main]
New thread: Thread[Three,5,main]
One: 5
Two: 5
Three: 5
One: 4
Two: 4
Three: 4
One: 3
Three: 3
Two: 3
One: 2
Three: 2
Two: 2
One: 1
Three: 1
Two: 1
One exiting.
Two exiting.
Three exiting.
Main thread exiting.
```

In the above program, once started, all three child threads share the CPU. However, in the above program we make a call to sleep in the main () method using **sleep (10000)**. This causes the main thread to sleep for ten seconds and ensures that it will finish last, till all other child threads have finished execution.

Using isAlive() and join()

The method **isAlive()** is used to determine whether the thread is still running or not. It takes the following general form:

final boolean isAlive()

The method returns true if the thread upon which it is called is still running. It returns false otherwise.

The join() method waits until the thread on which it is called terminates. Its name comes from the concept of the calling thread waiting until the specified thread *joins* it. Additional forms of **join( )** allow you to specify a maximum amount of time that you want to wait for the specified thread to terminate.

The following example is used to demonstrate the use of join() to ensure that the main thread is the last to stop. It also demonstrates the **isAlive( )** method.

Example

```
// Using join() to wait for threads to finish

class NewThread implements Runnable
{
String name; // name of thread
Thread t;

NewThread(String threadname)
 {
name = threadname;
t = new Thread(this, name);
System.out.println("New thread: " + t);
t.start(); // Start the thread
}

// This is the entry point for thread.
public void run() {
```

```
try {
for(int i = 5; i > 0; i--) {
System.out.println(name + ": " + i);
Thread.sleep(1000);
}
} catch (InterruptedException e) {
System.out.println(name + " interrupted.");
}
System.out.println(name + " exiting.");
}
}

class DemoJoin
{
public static void main(String args[]) {
NewThread ob1 = new NewThread("One");
NewThread ob2 = new NewThread("Two");
NewThread ob3 = new NewThread("Three");
System.out.println("Thread One is alive: " + ob1.t.isAlive());
System.out.println("Thread Two is alive: " + ob2.t.isAlive());
System.out.println("Thread Three is alive: " + ob3.t.isAlive());

// wait for threads to finish
try {
System.out.println("Waiting for threads to finish.");
ob1.t.join();
ob2.t.join();
ob3.t.join();
}
 catch (InterruptedException e) {
System.out.println("Main thread Interrupted");
}
System.out.println("Thread One is alive: " + ob1.t.isAlive());
System.out.println("Thread Two is alive: " + ob2.t.isAlive());
System.out.println("Thread Three is alive: " + ob3.t.isAlive());
System.out.println("Main thread exiting.");
}
}
```

```
//Output

New thread: Thread[One,5,main]
New thread: Thread[Two,5,main]
New thread: Thread[Three,5,main]
Thread One is alive: true
Thread Two is alive: true
Thread Three is alive: true
Waiting for threads to finish.
One: 5
Two: 5
Three: 5
One: 4
Two: 4
Three: 4
One: 3
Two: 3
Three: 3
One: 2
Two: 2
Three: 2
One: 1
Two: 1
Three: 1
Two exiting.
Three exiting.
One exiting.
Thread One is alive: false
Thread Two is alive: false
Thread Three is alive: false
Main thread exiting.
```

As evident from the above example, we see that after the calls to **join( )** return, the threads have stopped executing.

Thread Priorities:

Thread priorities are used by the thread scheduler to decide when each thread should be allowed to run. In theory, higher-priority threads get more CPU time than lower-priority threads. In practice, the amount of CPU time that a thread gets often depends on several factors besides its

priority. (For example, how an operating system implements multitasking can affect the relative availability of CPU time.) A higher-priority thread can also preempt a lower-priority one. For instance, when a lower-priority thread is running and a higher-priority thread resumes (from sleeping or waiting on I/O, for example), it will preempt the lower priority thread.

In theory, threads of equal priority should get equal access to the CPU. However, threads that share the same priority should yield control once in a while. This ensures that all threads have a chance to run under a non-preemptive operating system. In practice, even in non-preemptive environments, most threads still get a chance to run, because most threads inevitably encounter some blocking situation, such as waiting for I/O. When this happens, the blocked thread is suspended and other threads can run. But some types of tasks are CPU-intensive. Such threads dominate the CPU. For these types of threads, you want to yield control occasionally so that other threads can run.

To set a thread's priority, we can use the **setPriority( )** method, which is a member of **Thread**. Its general form is:

final void setPriority(int *level*)

Here, *level* specifies the new priority setting for the calling thread. The value of *level* must be within the range **MIN_PRIORITY** and **MAX_PRIORITY**. Currently, these values are 1 and 10, respectively. To return a thread to default priority, specify **NORM_PRIORITY**, which is currently 5. These priorities are defined as **static final** variables within **Thread**.

We can obtain the current priority setting by calling the **getPriority( )** method of **Thread**, with the following general form:

final int getPriority( )

Example:

The following example demonstrates two threads at different priorities, which do not run on a preemptive platform in the same way as they run on a non-preemptive platform. One thread is set two levels above the normal priority, as defined by **Thread.NORM_ PRIORITY**, and the other is set to two levels below it. The threads are started and allowed to run for ten seconds. Each thread executes a loop, counting the number of iterations. After ten seconds, the main thread stops both threads. The number of times that each thread made it through the loop is then displayed.

```
// Demonstrate thread priorities.
class clicker implements Runnable
 {
long click = 0;
Thread t;
private volatile boolean running = true;
```

```
public clicker(int p)
{
t = new Thread(this);
t.setPriority(p);
}

public void run()
 {
while (running) {
click++;
}
}

public void stop()
 {
running = false;
}

public void start()
{
t.start();
}
}

class HiLoPri
 {
public static void main(String args[])
 {
Thread.currentThread().setPriority(Thread.MAX_PRIORITY);
clicker hi = new clicker(Thread.NORM_PRIORITY + 2);
clicker lo = new clicker(Thread.NORM_PRIORITY - 2);
lo.start();
hi.start();
try {
Thread.sleep(10000);
} catch (InterruptedException e) {
System.out.println("Main thread interrupted.");
}
lo.stop();
hi.stop();
// Wait for child threads to terminate.
try {
```

```
hi.t.join();
lo.t.join();
} catch (InterruptedException e) {
System.out.println("InterruptedException caught");
}
System.out.println("Low-priority thread: " + lo.click);
System.out.println("High-priority thread: " + hi.click);
}
}
```

The output of this program, shown as follows when run under Windows, indicates that the threads did context switch, even though neither voluntarily yielded the CPU nor blocked for I/O. The higher-priority thread got the majority of the CPU time.

Low-priority thread: 4408112
High-priority thread: 589626904

However,, the exact output produced by this program depends on the speed of your CPU and the number of other tasks running in the system. When this same program is run under a non-preemptive system, different results will be obtained.

In the above program **running** is preceded by the keyword **volatile** .It is used to ensure that the value of **running** is examined each time the following loop iterates:

```
while (running) {
click++;
}
```

Without the use of **volatile**, Java is free to optimize the loop in such a way that a local copy of **running** is created. The use of **volatile** prevents this optimization, telling Java that **running** may change in ways not directly apparent in the immediate code.

Synchronization

When two or more threads need access to a shared resource, they need some way to ensure that the resource will be used by only one thread at a time. The process by which this is achieved is called *synchronization.* Java provides unique, language-level support for it.

Key to synchronization is the concept of the monitor (also called a *semaphore*). A *monitor* is an object that is used as a mutually exclusive lock, or *mutex.* Only one thread can *own* a monitor at a given time. When a thread acquires a lock, it is said to have *entered* the monitor. All other threads attempting to enter the locked monitor will be suspended until the first thread *exits* the monitor. These other threads are said to be *waiting* for the monitor. A thread that owns a monitor can reenter the same monitor if it so desires. Unlike C and C++ were you have to use operating

system primitives , Java implements synchronization through language elements, due to which most of the complexity associated with synchronization has been eliminated. We can synchronize our code using the synchronized keyword in either of two ways as discussed in the following section:

Using Synchronized Methods

Synchronization is easy in Java, because all objects have their own implicit monitor associated with them. To enter an object's monitor, just call a method that has been modified with the **synchronized** keyword. While a thread is inside a synchronized method, all other threads that try to call it (or any other synchronized method) on the same instance have to wait. To exit the monitor and relinquish control of the object to the next waiting thread, the owner of the monitor simply returns from the synchronized method.

To understand the need for synchronization, let's begin with a simple example that does not use it—but should. The following program has three simple classes. The first one, **Callme**, has a single method named **call( )**. The **call( )** method takes a **String** parameter called **msg**. This method tries to print the **msg** string inside of square brackets. The interesting thing to notice is that after **call( )** prints the opening bracket and the **msg** string, it calls **Thread .sleep(1000)**, which pauses the current thread for one second.

The constructor of the next class, **Caller**, takes a reference to an instance of the **Callme** class and a **String**, which are stored in **target** and **msg**, respectively. The constructor also creates a new thread that will call this object's **run( )** method. The thread is started immediately. The **run( )** method of **Caller** calls the **call( )** method on the **target** instance of **Callme**, passing in the **msg** string. Finally, the **Synch** class starts by creating a single instance of **Callme**, and three instances of **Caller**, each with a unique message string. The same instance of **Callme** is passed to each **Caller**.

// This program is not synchronized.

```
class Callme
{
void call(String msg)
 {
System.out.print("[" + msg);
try
 {
Thread.sleep(1000);
}
catch(InterruptedException e) {
System.out.println("Interrupted");
}
```

```
System.out.println("]");
}
}

class Caller implements Runnable {
String msg;
Callme target;
Thread t;
public Caller(Callme targ, String s) {
target = targ;
msg = s;
t = new Thread(this);
t.start();
}

public void run() {
target.call(msg);
}
}

class Synch {
public static void main(String args[]) {
Callme target = new Callme();
Caller ob1 = new Caller(target, "Hello");
Caller ob2 = new Caller(target, "Synchronized");
Caller ob3 = new Caller(target, "World");

// wait for threads to end

try {
ob1.t.join();
ob2.t.join();
ob3.t.join();
}
 catch(InterruptedException e) {
System.out.println("Interrupted");
}
}
}
```

Here is the output produced by this program:
Hello[Synchronized[World]
]
]
As evident from the above program, by calling **sleep( )**, the **call( )** method allows execution to switch to another thread. This results in the mixed-up output of the three message strings. In this program, nothing exists to stop all three threads from calling the same method, on the same object, at the same time. This is known as a *race condition*, because the three threads are racing each other to complete the method. This example used **sleep( )** to make the effects repeatable and obvious. In most situations, a race condition is more subtle and less predictable, because you can't be sure when the context switch will occur. This can cause a program to run right one time and wrong the next.
To fix the preceding program, we must *serialize* access to **call( )**. That is, we must restrict its access to only one thread at a time. To do this, we simply need to precede **call( )**'s definition with the keyword **synchronized**, as shown here:

```
class Callme {
synchronized void call(String msg) {
...
```

This prevents other threads from entering **call( )** while another thread is using it. After **synchronized** has been added to **call( )**, the output of the program is as follows:
[Hello]
[Synchronized]
[World]
Any time that you have a method, or group of methods, that manipulates the internal state of an object in a multithreaded situation, you should use the **synchronized** keyword to guard the state from race conditions. Once a thread enters any synchronized method on an instance, no other thread can enter any other synchronized method on the same instance. However, non-synchronized methods on that instance will continue to be callable.

The synchronized Statement
Using **synchronized** methods within classes to achieve synchronization is easy and effective but it will not work in all cases. Consider the following case. Imagine that you want to synchronize access to objects of a class that was not designed for multithreaded access. That is, the class does not use **synchronized** methods.
Further, this class was not created by you, but by a third party, and you do not have access to the source code. Thus, you can't add **synchronized** to the appropriate methods within the class. How can access to an object of this class be synchronized? To overcome this problem we simply put calls to the methods defined by this class inside a **synchronized** block as shown.

This is the general form of the **synchronized** statement:

synchronized(*object*) {
// statements to be synchronized
}

Here, *object* is a reference to the object being synchronized. A synchronized block ensures that a call to a method that is a member of *object* occurs only after the current thread has successfully entered *object*'s monitor.
Here is an alternative version of the preceding example, using a synchronized block within the **run( )** method:

// This program uses a synchronized block.

```
class Callme {
void call(String msg) {
System.out.print("[" + msg);
try {
Thread.sleep(1000);
} catch (InterruptedException e) {
System.out.println("Interrupted");
}
System.out.println("]");
}
}
class Caller implements Runnable {
String msg;
Callme target;
Thread t;
public Caller(Callme targ, String s) {
target = targ;
msg = s;
t = new Thread(this);
t.start();
}
// synchronize calls to call()
public void run() {
synchronized(target) { // synchronized block
target.call(msg);
}
```

```
}
}
class Synch1 {
public static void main(String args[]) {
Callme target = new Callme();
Caller ob1 = new Caller(target, "Hello");
Caller ob2 = new Caller(target, "Synchronized");
Caller ob3 = new Caller(target, "World");
// wait for threads to end
try {
ob1.t.join();
ob2.t.join();
ob3.t.join();
} catch(InterruptedException e) {
System.out.println("Interrupted");
}
}
}
```

Here, the **call( )** method is not modified by **synchronized**. Instead, the **synchronized** statement is used inside **Caller**'s **run( )** method. This causes the same correct output as the preceding example, because each thread waits for the prior one to finish before proceeding.

Inter-thread Communication

The preceding examples unconditionally blocked other threads from asynchronous access to certain methods. This use of the implicit monitors in Java objects is powerful, but we can achieve a more subtle level of control through inter-process communication.

Multithreading replaces event loop programming by dividing our tasks into discrete, logical units. Threads also provide a secondary benefit: they do away with polling. Polling is usually implemented by a loop that is used to check some condition repeatedly. Once the condition is true, appropriate action is taken. This wastes CPU time.

For example, consider the classic queuing problem, where one thread is producing some data and another is consuming it. Suppose that the producer has to wait until the consumer is finished before it generates more data. In a polling system, the consumer would waste many CPU cycles while it waited for the producer to produce. Once the producer was finished, it would start polling, wasting more CPU cycles waiting for the consumer to finish, and so on. Clearly, this situation is undesirable.

To avoid polling, Java includes an elegant inter-process communication mechanism via the **wait( )**, **notify( )**, and **notifyAll( )** methods. These methods are implemented as **final** methods in

Object, so all classes have them. All three methods can be called only from within a **synchronized** context.
• **wait( )** tells the calling thread to give up the monitor and go to sleep until some other thread enters the same monitor and calls **notify( )**.
• **notify( )** wakes up a thread that called **wait( )** on the same object.
• **notifyAll( )** wakes up all the threads that called **wait( )** on the same object. One of the threads will be granted access.

These methods are declared within **Object**, as shown here:
final void wait( ) throws InterruptedException
final void notify( )
final void notifyAll( )

Additional forms of **wait( )** exist that allow you to specify a period of time to wait. Although **wait( )** normally waits until **notify( )** or **notifyAll( )** is called, there is a possibility that in very rare cases the waiting thread could be awakened due to a *spurious wakeup*. In this case, a waiting thread resumes without **notify( )** or **notifyAll( )** having been called. (In essence, the thread resumes for no apparent reason.) Because of this remote possibility, Sun recommends that calls to **wait( )** should take place within a loop that checks the condition on which the thread is waiting. The following example shows this technique.

Consider an example that uses **wait( )** and **notify( )**. Firstly we consider the following sample program that incorrectly implements a simple form of the producer/ consumer problem. It consists of four classes: **Q**, the queue that you're trying to synchronize; **Producer**, the threaded object that is producing queue entries; **Consumer**, the threaded object that is consuming queue entries; and **PC**, the tiny class that creates the single **Q**, **Producer**, and **Consumer**.

// An incorrect implementation of a producer and consumer.

```
class Q {
int n;
synchronized int get() {
System.out.println("Got: " + n);
return n;
}
synchronized void put(int n) {
this.n = n;
System.out.println("Put: " + n);
}
}
class Producer implements Runnable {
```

```
Q q;
Producer(Q q) {
this.q = q;
new Thread(this, "Producer").start();
}
public void run() {
int i = 0;
while(true) {
q.put(i++);
}
}
}
class Consumer implements Runnable {
Q q;
Consumer(Q q) {
this.q = q;
new Thread(this, "Consumer").start();
}
public void run() {
while(true) {
q.get();
}
}
}
class PC {
public static void main(String args[]) {
Q q = new Q();
new Producer(q);
new Consumer(q);
System.out.println("Press Control-C to stop.");
}
}
```

Although the **put( )** and **get( )** methods on **Q** are synchronized, nothing stops the producer from overrunning the consumer, nor will anything stop the consumer from consuming the same queue value twice. Thus, we get the erroneous output shown below (the exact output will vary with processor speed and task load):

```
Put: 1
Got: 1
Got: 1
```

```
Got: 1
Got: 1
Got: 1
Put: 2
Put: 3
Put: 4
Put: 5
Put: 6
Put: 7
Got: 7
```

As evident, after the producer put 1, the consumer started and got the same 1 five times in a row. Then, the producer resumed and produced 2 through 7 without letting the consumer have a chance to consume them. The proper way to write this program in Java is to use **wait( )** and **notify( )** to signal in both directions, as shown here:

// A correct implementation of a producer and consumer.

```
class Q {
int n;
boolean valueSet = false;
synchronized int get() {
while(!valueSet)
try {
wait();
} catch(InterruptedException e) {
System.out.println("InterruptedException caught");
}
System.out.println("Got: " + n);
valueSet = false;
notify();
return n;
}
synchronized void put(int n) {
while(valueSet)
try {
wait();
} catch(InterruptedException e) {
System.out.println("InterruptedException caught");
}
this.n = n;
```

```
valueSet = true;
System.out.println("Put: " + n);
notify();
}
}
class Producer implements Runnable {
Q q;
Producer(Q q) {
this.q = q;
new Thread(this, "Producer").start();
}
public void run() {
int i = 0;
while(true) {
q.put(i++);
}
}
}
class Consumer implements Runnable {
Q q;
Consumer(Q q) {
this.q = q;
new Thread(this, "Consumer").start();
}
public void run() {
while(true) {
q.get();
}
}
}
class PCFixed {
public static void main(String args[]) {
Q q = new Q();
new Producer(q);
new Consumer(q);
System.out.println("Press Control-C to stop.");
}
}
```

Inside **get( )**, **wait( )** is called. This causes its execution to suspend until the **Producer** notifies you that some data is ready. When this happens, execution inside **get( )** resumes. After the data has been obtained, **get( )** calls **notify( )**. This tells **Producer** that it is okay to put more data in the queue. Inside **put( )**, **wait( )** suspends execution until the **Consumer** has removed the item from the queue. When execution resumes, the next item of data is put in the queue, and **notify( )** is called. This tells the **Consumer** that it should now remove it.
Here is some output from this program, which shows the clean synchronous behavior:

```
Put: 1
Got: 1
Put: 2
Got: 2
Put: 3
Got: 3
Put: 4
Got: 4
Put: 5
Got: 5
```

Deadlock

A special type of error that we need to avoid that relates specifically to multitasking is *deadlock,* which occurs when two threads have a circular dependency on a pair of synchronized objects. For example, suppose one thread enters the monitor on object X and another thread enters the monitor on object Y. If the thread in X tries to call any synchronized method on Y, it will block as expected. However, if the thread in Y, in turn, tries to call any synchronized method on X, the thread waits forever, because to access X, it would have to release its own lock on Y so that the first thread could complete. Deadlock is a difficult error to debug for two reasons:

• In general, it occurs only rarely, when the two threads time-slice in just the right way.

• It may involve more than two threads and two synchronized objects. (That is, deadlock can occur through a more convoluted sequence of events.)

Consider an example that creates two classes, **A** and **B**, with methods **foo( )** and **bar( )**, respectively, which pause briefly before trying to call a method in the other class. The main class, named **Deadlock**, creates an **A** and a **B** instance, and then starts a second thread to set up the deadlock condition. The **foo( )** and **bar( )** methods use **sleep( )** as a way to force the deadlock condition to occur.

// An example of deadlock.

```
class A {
synchronized void foo(B b) {
String name = Thread.currentThread().getName();
```

```
System.out.println(name + " entered A.foo");
try {
Thread.sleep(1000);
} catch(Exception e) {
System.out.println("A Interrupted");
}
System.out.println(name + " trying to call B.last()");
b.last();
}
synchronized void last() {
System.out.println("Inside A.last");
}
}
class B {
synchronized void bar(A a) {
String name = Thread.currentThread().getName();
System.out.println(name + " entered B.bar");
try {
Thread.sleep(1000);
} catch(Exception e) {
System.out.println("B Interrupted");
}
System.out.println(name + " trying to call A.last()");
a.last();
}
synchronized void last() {
System.out.println("Inside A.last");
}
}
class Deadlock implements Runnable {
A a = new A();
B b = new B();
Deadlock() {
Thread.currentThread().setName("MainThread");
Thread t = new Thread(this, "RacingThread");
t.start();
a.foo(b); // get lock on a in this thread.
System.out.println("Back in main thread");
}
public void run() {
```

```
b.bar(a); // get lock on b in other thread.
System.out.println("Back in other thread");
}
public static void main(String args[]) {
new Deadlock();
}
}
```

When we run this program, we will see the output shown here:

```
MainThread entered A.foo
RacingThread entered B.bar
MainThread trying to call B.last()
RacingThread trying to call A.last()
```

Because the program has deadlocked, we need to press CTRL-C to end the program. We can see a full thread and monitor cache dump by pressing CTRL-BREAK on a PC . We will see that **RacingThread** owns the monitor on **b**, while it is waiting for the monitor on **a**. At the same time, **MainThread** owns **a** and is waiting to get **b**. This program will never complete. As this example illustrates, if our multithreaded program locks up occasionally, deadlock is one of the first conditions that you should check for.

Suspending, Resuming, and Stopping Threads

Sometimes, suspending execution of a thread is useful. For example, a separate thread can be used to display the time of day. If the user doesn't want a clock, then its thread can be suspended. The mechanisms to suspend, stop, and resume threads differ between early versions of Java, such as Java 1.0, and modern versions, beginning with Java 2. Although we should use the modern approach for all new code, we still need to understand how these operations were accomplished for earlier Java environments.

Suspending, Resuming, and Stopping Threads Using Java 1.1 and Earlier

Prior to Java 2, a program used **suspend( )** and **resume( )**, which are methods defined by **Thread**, to pause and restart the execution of a thread. They have the form shown below:

```
final void suspend( )
final void resume( )
```

The following program demonstrates these methods:

// Using suspend() and resume().

```
class NewThread implements Runnable {
String name; // name of thread
Thread t;
NewThread(String threadname) {
name = threadname;
t = new Thread(this, name);
System.out.println("New thread: " + t);
t.start(); // Start the thread
}
// This is the entry point for thread.
public void run() {
try {
for(int i = 15; i > 0; i--) {
System.out.println(name + ": " + i);
Thread.sleep(200);
}
} catch (InterruptedException e) {
System.out.println(name + " interrupted.");
}
System.out.println(name + " exiting.");
}
}
class SuspendResume {
public static void main(String args[]) {
NewThread ob1 = new NewThread("One");
NewThread ob2 = new NewThread("Two");
try {
Thread.sleep(1000);
ob1.t.suspend();
System.out.println("Suspending thread One");
Thread.sleep(1000);
ob1.t.resume();
System.out.println("Resuming thread One");
ob2.t.suspend();
System.out.println("Suspending thread Two");
Thread.sleep(1000);
ob2.t.resume();
System.out.println("Resuming thread Two");
```

```
} catch (InterruptedException e) {
System.out.println("Main thread Interrupted");
}
// wait for threads to finish
try {
System.out.println("Waiting for threads to finish.");
ob1.t.join();
ob2.t.join();
} catch (InterruptedException e) {
System.out.println("Main thread Interrupted");
}
System.out.println("Main thread exiting.");
}
}
```

Sample output from this program is shown here. (Your output may differ based on processor speed and task load.)

```
New thread: Thread[One,5,main]
One: 15
New thread: Thread[Two,5,main]
Two: 15
One: 14
Two: 14
One: 13
Two: 13
One: 12
Two: 12
One: 11
Two: 11
Suspending thread One
Two: 10
Two: 9
Two: 8
Two: 7
Two: 6
Resuming thread One
Suspending thread Two
One: 10
One: 9
One: 8
One: 7
```

```
One: 6
Resuming thread Two
Waiting for threads to finish.
Two: 5
One: 5
Two: 4
One: 4
Two: 3
One: 3
Two: 2
One: 2
Two: 1
One: 1
Two exiting.
One exiting.
Main thread exiting.
```

The **Thread** class also defines a method called **stop( )** that stops a thread. Its signature is shown here:

final void stop( )

Once a thread has been stopped, it cannot be restarted using **resume( )**.

The Modern Way of Suspending, Resuming, and Stopping Threads

While the **suspend( )**, **resume( )**, and **stop( )** methods defined by **Thread** seem to be a perfectly reasonable and convenient approach to managing the execution of threads, they must not be used for new Java programs because the **suspend( )** method of the **Thread** class was deprecated by Java 2 several years ago. This was done because **suspend( )** can sometimes cause serious system failures. Assume that a thread has obtained locks on critical data structures. If that thread is suspended at that point, those locks are not relinquished. Other threads that may be waiting for those resources can be deadlocked. The **resume( )** method is also deprecated. It does not cause problems, but cannot be used without the **suspend( )** method as its counterpart. The **stop( )** method of the **Thread** class, too, was deprecated by Java 2. This was done because this method can sometimes cause serious system failures. Assume that a thread is writing to a critically important data structure and has completed only part of its changes. If that thread is stopped at that point, that data structure might be left in a corrupted state.

In the modern approach a thread must be designed so that the **run( )** method periodically checks to determine whether that thread should suspend, resume, or stop its own execution. Typically, this is accomplished by establishing a flag variable that indicates the execution state of the thread. As long as this flag is set to "running," the **run( )** method must continue to let the thread

execute. If this variable is set to “suspend,” the thread must pause. If it is set to “stop,” the thread must terminate.

The following example illustrates how the **wait( )** and **notify( )** methods that are inherited from **Object** can be used to control the execution of a thread. This example is similar to the program in the previous section. However, the deprecated method calls have been removed. Let us consider the operation of this program.

The **NewThread** class contains a **boolean** instance variable named **suspendFlag**, which is used to control the execution of the thread. It is initialized to **false** by the constructor. The **run( )** method contains a **synchronized** statement block that checks **suspendFlag**. If that variable is **true**, the **wait( )** method is invoked to suspend the execution of the thread. The **mysuspend( )** method sets **suspendFlag** to **true**. The **myresume( )** method sets **suspendFlag** to **false** and invokes **notify( )** to wake up the thread. Finally, the **main( )** method has been modified to invoke the **mysuspend( )** and **myresume( )** methods.

// Suspending and resuming a thread the modern way.

```
class NewThread implements Runnable {
String name; // name of thread
Thread t;
boolean suspendFlag;
NewThread(String threadname) {
name = threadname;
t = new Thread(this, name);
System.out.println("New thread: " + t);
suspendFlag = false;
t.start(); // Start the thread
}
// This is the entry point for thread.
public void run() {
try {
for(int i = 15; i > 0; i--) {
System.out.println(name + ": " + i);
Thread.sleep(200);
synchronized(this) {
while(suspendFlag) {
wait();
}
}
}
} catch (InterruptedException e) {
```

```
System.out.println(name + " interrupted.");
}
System.out.println(name + " exiting.");
}
void mysuspend() {
suspendFlag = true;
}
synchronized void myresume() {
suspendFlag = false;
notify();
}
}
class SuspendResume {
public static void main(String args[]) {
NewThread ob1 = new NewThread("One");
NewThread ob2 = new NewThread("Two");
try {
Thread.sleep(1000);
ob1.mysuspend();
System.out.println("Suspending thread One");
Thread.sleep(1000);
ob1.myresume();
System.out.println("Resuming thread One");
ob2.mysuspend();
System.out.println("Suspending thread Two");
Thread.sleep(1000);
ob2.myresume();
System.out.println("Resuming thread Two");
} catch (InterruptedException e) {
System.out.println("Main thread Interrupted");
}
// wait for threads to finish
try {
System.out.println("Waiting for threads to finish.");
ob1.t.join();
ob2.t.join();
} catch (InterruptedException e) {
System.out.println("Main thread Interrupted");
}
System.out.println("Main thread exiting.");
```

```
}
}
```