CS 580 Client-Server Programming
Spring Semester, 2010
Doc 8 Threads
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References

The Java Programming Language, 2nd Ed. Arnold & Gosling, Addison-Wesley, 1998

The Java Language Specification, Gosling, Joy, Steele, Addison-Wesley, 1996, Chapter 17 Threads and Locks.

Java 1.6.0 on-line documentation http://java.sun.com/javase/6/docs/api/

Cancellable Activities, Doug Lea, October 1998, http://gee.cs.oswego.edu/dl/cpj/cancel.html

Concurrent Programming in Java: Design Principles and Patterns, Doug Lea, Addison-Wesley, 1997

Java's Atomic Assignment, Art Jolin, Java Report, August 1998, pp 27-36.

Concurrent Programming

Safety

Liveness

Nondeterminism

Communication

Processes verses Threads

Processes (Heavy Weight)

Child process gets a copy of parent's variables

Relatively expensive to start

No concurrent access to variables

Thread (Light Weight Process)

Child process shares parents variables

Relatively cheap to start

Concurrent access to variables is an issue

Creating Threads by Inheritance

```
class  ExtendingThreadExample  extends Thread {
    public void run() {
        for  ( int  count = 0;  count < 4; count++)
            System.out.println( "Message " + count +
                " From: Mom" );
    }

    public static void main( String[]  args ) {
        ExtendingThreadExample  parallel  =
            new ExtendingThreadExample();
        System.out.println( "Create the thread");
        parallel.start();
        System.out.println( "Started the thread " + parallel.getId() );); 
        System.out.println( "End" );
    }
}
```

Output

```
Create the thread
Message 0 From: Mom
Message 1 From: Mom
Message 2 From: Mom
Message 3 From: Mom
Started the thread 7
End
```

Creating Threads by Composition

```
class  SecondMethod  implements  Runnable {
    public  void  run() {
        for  ( int  count = 0;  count < 4; count++)
            System.out.println( "Message " + count +
                    " From: Dad");
    }

    public static void main( String[]  args ) {
        SecondMethod  notAThread  = new SecondMethod();
        Thread  parallel  =  new Thread( notAThread );

        System.out.println( "Create the thread");
        parallel.start();
        System.out.println( "Started the thread" );
        System.out.println( "End" );
    }
}
```

Output

```
Create the thread
Message 0 From: Dad
Message 1 From: Dad
Message 2 From: Dad
Message 3 From: Dad
Started the thread
End
```

Thread with a Name

```
public class  WithNames  implements  Runnable {
     public  void  run() {
          for  ( int  count = 0;  count < 2; count++)
               System.out.println( "Message " + count +
                " From: " +
Thread.currentThread().getName() );
     }

     public static void main( String[]  args ) {
          Thread  a  =  new Thread(new WithNames(),
"Mom" );
          Thread  b  =  new Thread(new WithNames(),
"Dad" );

          System.out.println( "Create the thread");
          a.start();
          b.start();
          System.out.println( "End" );
     }
}
```

Output

```
Create the thread
Message 0 From: Mom
Message 1 From: Mom
Message 0 From: Dad
Message 1 From: Dad
End
```

Ruby Threads

```ruby
a = Thread.new { 4.times {|k| puts k} }
a.join
```

Output

0
1
2
3

```ruby
x = 5
a = Thread.new(x) do |size|
  size.times {|k| puts k}
end
a.join
```

Output

0
1
2
3
5

For Future Examples

```
public class  SimpleThread  extends Thread {
        private  int  maxCount =  32;

        public  SimpleThread(  String  name ) {
                super( name );
        }

        public  SimpleThread(  String  name, int repetitions ) {
                super( name );
                maxCount  =  repetitions;
        }

        public  SimpleThread(  int repetitions ) {
                maxCount  =  repetitions;
        }

        public  void run() {
                for  ( int  count = 0;  count < maxCount; count++) {
                        System.out.println( count + " From: " + getName() );
                }
        }
}
```

Some Parallelism

```
public class  RunSimpleThread {
	public static void main( String[]  args ) {
		SimpleThread  first      = new 
SimpleThread( 5 );
		SimpleThread  second  = new 
SimpleThread( 5 );
		first.start();
		second.start();
		System.out.println( "End" );
	}
}
```

Output On Rohan

```
End
0 From: Thread-0
1 From: Thread-0
2 From: Thread-0
0 From: Thread-1
1 From: Thread-1
2 From: Thread-1
3 From: Thread-0
3 From: Thread-1
4 From: Thread-0
4 From: Thread-1
```

Java on a Solaris machine with multiple processors can run threads on different processors

Thread Scheduling

Priorities

Time-slicing

Priorities

Each thread has a priority

If there are two or more active threads

If one has higher priority than others

The higher priority thread is run until it is done or not active

Java Thread Priorities

java.lang.Thread field	Value
Thread.MAX_PRIORITY	10
Thread.NORM_PRIORITY	5
Thread.MIN_PRIORITY	0

Ruby Thread Priorities

Any float between

-2147483649

2147483648

May be machine dependent

Java Priority

```
public class  PriorityExample {
    public static void main( String[]  args ) {
        SimpleThread  first      = new SimpleThread( 5 );
        SimpleThread  second  = new SimpleThread( 5 );
        second.setPriority( 8 );
        first.start();
        second.start();
        System.out.println( "End" );
    }
}
```

On Single Processor 0 From: Thread-5 1 From: Thread-5 2 From: Thread-5 3 From: Thread-5 4 From: Thread-5 0 From: Thread-4 1 From: Thread-4 2 From: Thread-4 3 From: Thread-4 4 From: Thread-4 End	

Threads Run Once

Can't restart a thread

```
public class RunOnceExample extends Thread {
	public void run() {
		System.out.println(  "I ran" );
	}

	public static void main( String args[] ) throws Exception {
		RunOnceExample onceOnly = new RunOnceExample();
		onceOnly.setPriority( 6 );
		onceOnly.start();

		System.out.println( "Try restart");
		onceOnly.start();                    Causes Exception

		System.out.println( "The End");
	}
}
```

Time-Slicing

A thread is run for a short time slice and suspended,
It resumes only when it gets its next "turn"

Threads of the same priority share turns

Non time-sliced threads run until:

- They end
- They are terminated
- They are interrupted
- Higher priority threads interrupts lower priority threads
- They go to sleep
- They block on some call
- Reading a socket
- Waiting for another thread

Java spec allows time-sliced or non-time-sliced threads

Ruby docs don't talk about this

Testing for Time-slicing

If time-sliced output will be mixed

```java
public class  InfinityThread  extends Thread
    {
    public  void run()
        {
        while ( true )
            System.out.println(  "From: " + getName() );
        }

    public static void main( String[]  args )
        {
        InfinityThread  first      = new InfinityThread( );
        InfinityThread  second  = new InfinityThread( );
        first.start();
        second.start();
        }
    }
```

```ruby
a = Thread.new do
  10.times {|k| puts "a #{k}"}
end

b = Thread.new do
  10.times {|k| puts "b #{k}"}
end
a.join
b.join
```

Java user & daemon Threads

Daemon thread

Expendable

When all user threads are done

the program ends

all daemon threads are stopped

User thread

Not expendable

Execute until

Their run method ends or

An exception propagates beyond the run method.

When a Java Program Ends

Runtime.exit(int) has been called and the security manager permits the exit operation to take place.

or

Only daemon threads are running

Daemon Example

```
public class DaemonExample extends Thread {
	public  static  void  main( String  args[] ) {
		DaemonExample  shortLived      = new
DaemonExample( );
		shortLived.setDaemon( true );
		shortLived.start();
		System.out.println( "Bye");
	}

	public  void run() {
		while (true) {
			System.out.println(  "From: " + getName()  );
			System.out.flush();
		}
	}
}
```

Output

From: Thread-0 (Repeated many times)

Bye

From: Thread-0 (Repeated some more, then the program ends)

Thread States

Executing

Only one thread per processor can be running at a time

Runnable

A thread is ready to run but is not currently running

Not Runnable

A thread that is suspended or waiting for a resource

Yield

Allow another thread of the same priority to run

Thread is still runable

```
public class  YieldThread  extends Thread {
      public  void run() {
            for  ( int  count = 0;  count < 4; count++) {
                  System.out.println( count + " From: " + getName() );
                  yield();
            }
      }

      public static void main( String[]  args )  {
            YieldThread  first      = new YieldThread();
            YieldThread  second  = new YieldThread();
            first.setPriority( 1);
            second.setPriority( 1);
            first.start();
            second.start();
            System.out.println( "End" );
      }
}
```

Output (Explain this)

```
0 From: Thread-0
0 From: Thread-1
1 From: Thread-0
1 From: Thread-1
2 From: Thread-0
2 From: Thread-1
3 From: Thread-0
End
3 From: Thread-1
```

Java sleep

Put calling thread in not-runnable state for specified milliseconds

```
public class  NiceThread  extends Thread {
	public void run() {
		try {
			System.out.println( "Thread started");
			sleep( 5 );
			System.out.println(  "From: " + getName()  );
			System.out.println( "Clean up operations" );
		}
		catch ( InterruptedException interrupted ) {
			System.out.println( "In catch" );
		}
	}

	public static void main( String args[] )  {
		NiceThread  missManners  = new NiceThread( );
		missManners.start();
		System.out.println( "Main after start" );
	}
}
```

Output

Thread started
Main after start
From: Thread-0
Clean up operations

Java sleep

Put **calling** thread in not-runnable state for specified milliseconds

```
public class  NiceThread  extends Thread {
    public void run() {
        System.out.println( "Thread started");
        System.out.println(  "From: " + getName()  );
        System.out.println( "Clean up operations" );
    }

    public static void main( String args[] ) throws InterruptedException  {
        NiceThread  missManners  = new NiceThread( );
        missManners.start();
        missManners.sleep(50);        //Who is sleeping
        System.out.println( "Main after start" );
    }
}
```

Output

```
Thread started
From: Thread-0
Clean up operations
Main after start
```

Java deprecated Thread methods

The following Thread methods are not thread safe

suspend
resume
stop
destroy

Interrupt

The following program does not end

The interrupt just sets the interrupt flag!

```
public class NoInterruptThread extends Thread {
	public void run() {
		while ( true) {
			System.out.println(  "From: " + getName()  );
		}
	}

	public static void main(String args[]) throws InterruptedException{
		NoInterruptThread focused  = new NoInterruptThread( );
		focused.setPriority( 2 );
		focused.start();
		Thread.currentThread().sleep( 5 ); // Let other thread run
		focused.interrupt();
		System.out.println( "End of main");
	}
}
```

Output

```
From: Thread-0		(repeated many times)
End of main
From: Thread-0		(repeated until program is killed)
```

Using Thread.interrupted

```
public class RepeatableNiceThread extends Thread {
	public void run() {
		while ( true ) {
			while ( !Thread.interrupted() )
				System.out.println(  "From: " + getName()  );

			System.out.println( "Clean up operations" );
		}
	}

	public static void main(String args[]) throws InterruptedException{
		RepeatableNiceThread  missManners  =
				new RepeatableNiceThread( );
		missManners.setPriority( 2 );
		missManners.start();
		Thread.currentThread().sleep( 5 );
		missManners.interrupt();
	}
}
```

Output

From: Thread-0
Clean up operations
From: Thread-0
From: Thread-0 (repeated)

Interrupt and sleep, join & wait

```
public class  NiceThread  extends Thread {
	public void run() {
		try {
			System.out.println( "Thread started");
			while ( !isInterrupted() ) {
				sleep( 5 );
				System.out.println(  "From: " + getName()  );
			}
			System.out.println( "Clean up operations" );
		} catch ( InterruptedException interrupted ) {
			System.out.println( "In catch" );
		}
	}

	public static void main( String args[] )  {
		NiceThread  missManners  = new NiceThread( );
		missManners.setPriority( 6 );
		missManners.start();
		missManners.interrupt();
	}
}
```

Output

```
Thread started
From: Thread-0
From: Thread-0
In catch
```

Java interrupt ()

Sent to a thread to interrupt it

If thread is blocked on a call to wait, join or sleep

InterruptedException is thrown &

The interrupted status flag is cleared

if the thread is blocked on I/O operation on an interruptible channel (NIO)

ClosedByInterruptException is thrown

The interrupted status flag is set

If the thread is blocked by a selector (NIO)

Interrupt status is set

The thread returns from the selector call as normal

If none of the other conditions hold then the thread's interrupt status is set

Details

If thread is blocked on a call to wait, join or sleep

InterruptedException is thrown &

The interrupted status flag is cleared

if the thread is blocked on I/O operation on an interruptible channel (NIO)

ClosedByInterruptException is thrown

The interrupted status flag is set

If the thread is blocked by a selector (NIO)

Interrupt status is set

The thread returns from the selector call as normal

If none of the other conditions hold then the thread's interrupt status is set

Interrupt and Pre JDK 1.4 NIO operations

If a thread is blocked on a read/write to a:

- Stream
- Reader/Writer
- Pre-JDK 1.4 style socket read/write

The interrupt does not interrupt the read/write operation!

The threads interrupt flag is set

Until the IO is complete the interrupt has no effect

This is one motivation for the NIO package

Safety - Mutual Access

What happens when one thread reads a value while another is modifying it?

Java Safety - Synchronize

A call to a synchronized method locks the object

Object remains locked until synchronized method is done

Any other thread's call to any synchronized method on the same object will block until the object is unlocked

Java Safety - Synchronize

```
class SynchronizeExample {
	int[]  data;

	public String toString() {
		return "array length " + data.length + " array values " + data[0];
	}

	public synchronized void initialize( int size,  int  startValue){
		data  =  new  int[ size ];
		for  ( int  index  = 0; index < size;  index++ )
			data[ index ]  =  (int ) Math.sin( index * startValue );
	}

	public  void unSafeSetValue( int  newValue) {
		for  ( int  index  = 0; index < data.length;  index++ )
			data[ index ]  =  (int ) Math.sin( index * newValue );
	}

	public  synchronized void safeSetValue( int  newValue) {
		for  ( int  index  = 0; index < data.length;  index++ )
			data[ index ]  =  (int ) Math.sin( index * newValue );
	}
}
```

Synchronized Static Methods

Locks class

Blocks other synchronized class methods

```
class SynchronizeExample {
	int[]  data;

	public String toString() {
		return "array length " + data.length + " array values " + data[0];
	}

	public synchronized void initialize( int size,  int  startValue){
		data  =  new  int[ size ];
		for  ( int  index  = 0; index < size;  index++ )
			data[ index ]  =  (int ) Math.sin( index * startValue );
	}

	public  void unSafeSetValue( int  newValue) {
		for  ( int  index  = 0; index < data.length;  index++ )
			data[ index ]  =  (int ) Math.sin( index * newValue );
	}

	public  synchronized void safeSetValue( int  newValue) {
		for  ( int  index  = 0; index < data.length;  index++ )
			data[ index ]  =  (int ) Math.sin( index * newValue );
	}
}
```

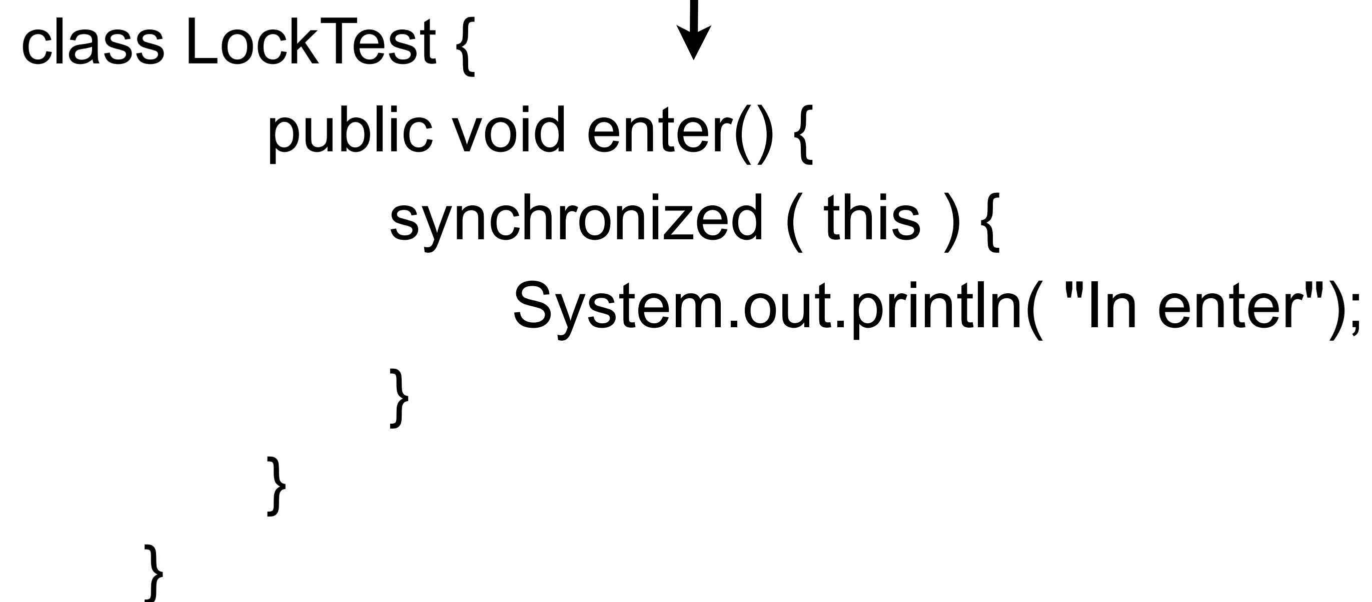
Synchronized Statements

```
synchronized
( expression ) {
    statements
}
```

expression must evaluate to an object

That object is locked

```
class LockTest {
    public synchronized void enter() {
        System.out.println( "In enter");
    }
}
```



```
class LockTest {
    public void enter() {
        synchronized ( this ) {
            System.out.println( "In enter");
        }
    }
}
```

Lock for Block and Method

```
public class LockExample extends Thread {
	private Lock myLock;

	public LockExample( Lock aLock ) {
		myLock = aLock;
	}
	public void run() 	{
		System.out.println( "Start run");
		myLock.enter();
		System.out.println( "End run");
	}
	public static void main( String args[] ) throws Exception {
		Lock aLock = new Lock();
		LockExample tester = new LockExample( aLock );

		synchronized ( aLock ) {
			System.out.println( "In Block");
			tester.start();
			System.out.println( "Before sleep");
			Thread.currentThread().sleep( 5000);
			System.out.println( "End Block");
		}
	}
}
```

```
class Lock {
	public synchronized void enter() {
		System.out.println( "In enter");
	}
}
```

Output

In Block
Start run
Before sleep
End Block
In enter
End run (why is this at the end?)

Synchronized and Inheritance

methods do not inherit synchronized

```
class Top {
    public void synchronized left() {
        // do stuff
    }

    public void synchronized right() {
        // do stuff
    }
}

class Bottom extends Top {
    public void left() {
        // not synchronized
    }

    public void right() {
        // do stuff not synchronized
        super.right(); // synchronized here
        // do stuff not synchronized
    }
```

wait and notify

public final void wait(timeout) throws InterruptedException

public final void wait(timeout, nanos) throws InterruptedException

public final void wait() throws InterruptedException

Causes a thread to wait until it is notified or the specified timeout expires.

Throws: IllegalMonitorStateException

If the current thread is not the owner of the Object's monitor.

Throws: InterruptedException

Another thread has interrupted this thread.

public final void notify()

public final void notifyAll()

Notifies threads waiting for a condition to change.

wait - How to use

The thread waiting for a condition should look like:

```
synchronized void waitingMethod()
	{
	while ( ! condition )
		wait();

	Now do what you need to do when condition is true
	}
```

Everything is executed in a synchronized method

The test condition is in loop not in an if statement

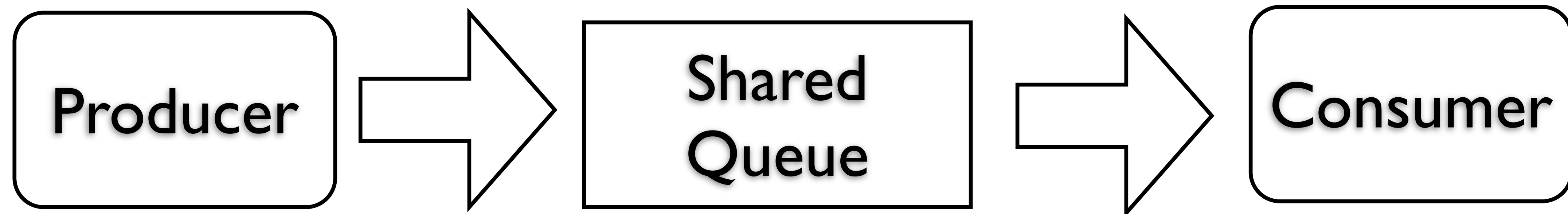
The wait suspends the thread it atomically releases the lock on the object

notify - How to Use

```
synchronized void changeMethod()
    {
    Change some value used in a condition test

    notify();
    }
```

wait and notify Example

When can Consumer read from queue?



wait and notify - Producer

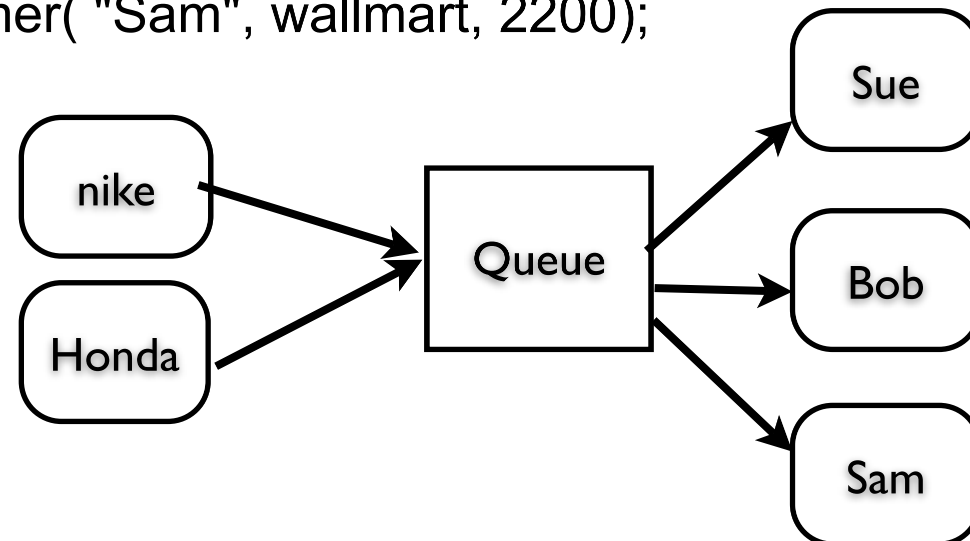
```
import java.util.concurrent.*;

public class Producer extends Thread {
	BlockingQueue<String> factory;
	int workSpeed;

	public Producer( String name, BlockingQueue<String> output, int speed ) {
		setName(name);
		factory = output;
		workSpeed = speed;
	}

	public void run() {
		try {
			int product = 0;
			while (true) {
				System.out.println( getName() + " produced " + product);
				factory.add( getName() + String.valueOf( product) );
				product++;
				sleep( workSpeed);
			}
		}
		catch ( InterruptedException workedToDeath ) {
			return;
		}
	}
}
```

wait and notify - Consumer

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

class Consumer extends Thread {
	BlockingQueue<String> localMall;
	int sleepDuration;

	public Consumer( String name, BlockingQueue<String> input, int speed ) {
		setName(name);
		localMall = input;
		sleepDuration = speed;
	}

	public void run() {
		try {
			while (true) {
				System.out.println( getName() + " got " +  localMall.take());
				sleep( sleepDuration );
			}
		}
		catch ( InterruptedException endOfCreditCard ) {
			return;
		}
	}
}
```

wait and notify - Driver Program

```
import java.util.concurrent.*;
public class ProducerConsumerExample {
	public  static  void  main( String  args[] ) throws Exception {
		BlockingQueue<String> wallmart = new ArrayBlockingQueue(100, true);
		Producer nike = new Producer( "Nike", wallmart, 500 );
		Producer honda = new Producer( "Honda", wallmart, 1200 );
		Consumer valleyGirl = new Consumer( "Sue", wallmart, 400);
		Consumer valleyBoy = new Consumer( "Bob", wallmart, 900);
		Consumer dink = new Consumer( "Sam", wallmart, 2200);
		nike.start();
		honda.start();
		valleyGirl.start();
		valleyBoy.start();
		dink.start();
	}
}
```



Nike produced 0	Nike produced 2	Nike produced 4
Honda produced 0	Sue got Nike2	Sue got Nike4
Sue got Nike0	Honda produced 1	Honda produced
Bob got Honda0	Bob got Honda1	Bob got Honda2
Nike produced 1	Nike produced 3	Nike produced 5
Sam got Nike1	Sue got Nike3	Sue got Nike5

Java Blocking Queues

ArrayBlockingQueue
DelayQueue
LinkedBlockingQueue
PriorityBlockingQueue
SynchronousQueue

Java ThreadPoolExecuter

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

public class ThreadPoolExample extends Object
{
    public static void main(String[] args)
    {
        int corePoolSize = 2;
        int maximumPoolSize = 5;
        long keepAliveTime = 60 * 10;
        TimeUnit keepAliveUnit = TimeUnit.SECONDS;
        BlockingQueue<Runnable> surplusJobs = new LinkedBlockingQueue<Runnable>();
        ThreadPoolExecutor workers = new ThreadPoolExecutor(corePoolSize,
                maximumPoolSize, keepAliveTime, keepAliveUnit, surplusJobs);

        for (int k = 0;k< 5; k++)
            workers.execute( new SimpleThread(k + 5));
    }
}
```