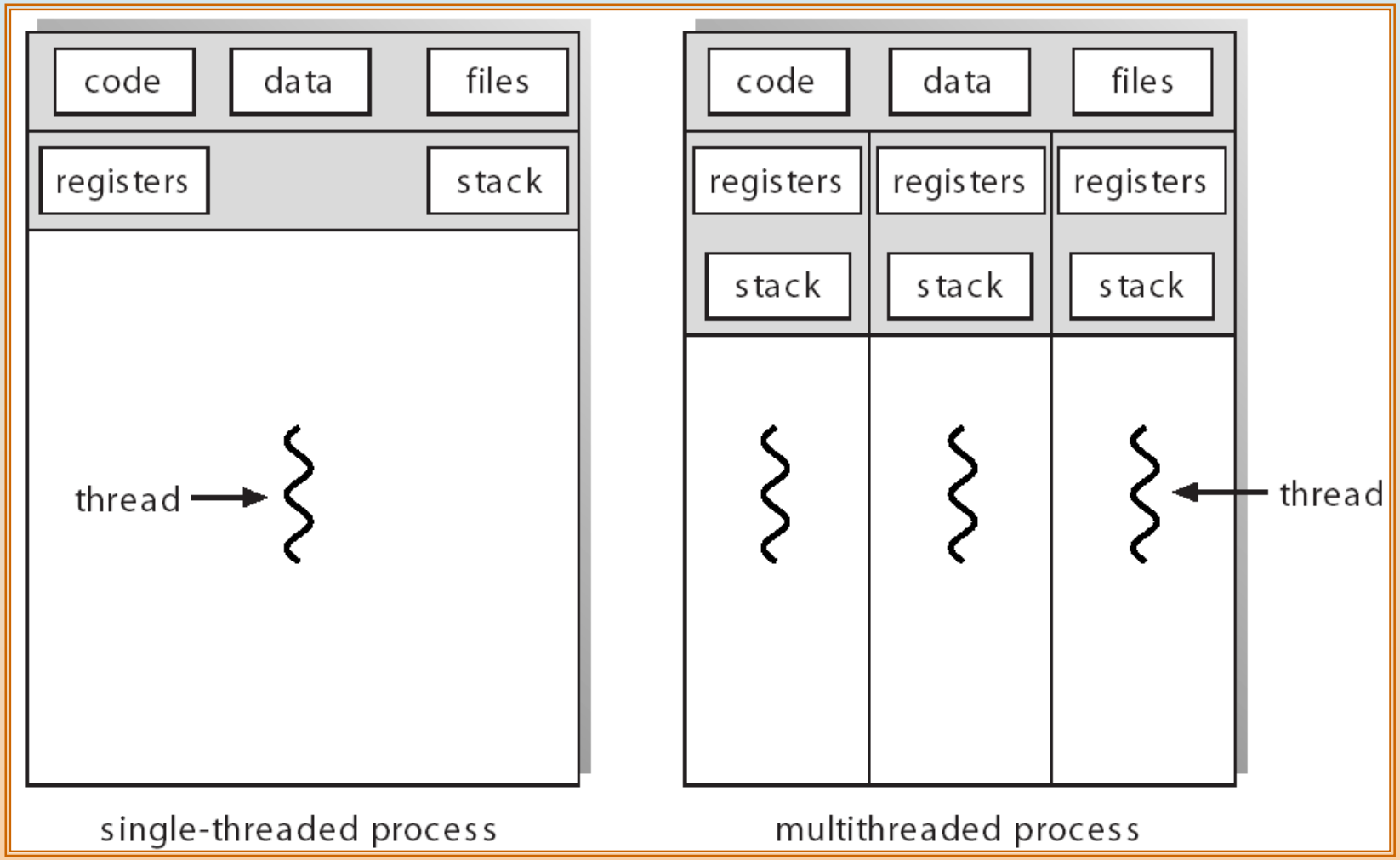
Chapter 5: Threads

- Overview
- Multithreading Models
- Threading Issues
- Pthreads
- Windows XP Threads
- Linux Threads
- Java Threads

Single and Multithreaded Processes



Benefits

- Responsiveness
- Resource Sharing
- Economy
- Utilization of MP Architectures

User Threads

- Thread management done by user-level threads library
- Three primary thread libraries:
  - POSIX Pthreads
  - Java threads
  - Win32 threads

Kernel Threads

- Supported by the Kernel
- Examples
  - Windows XP/2000
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

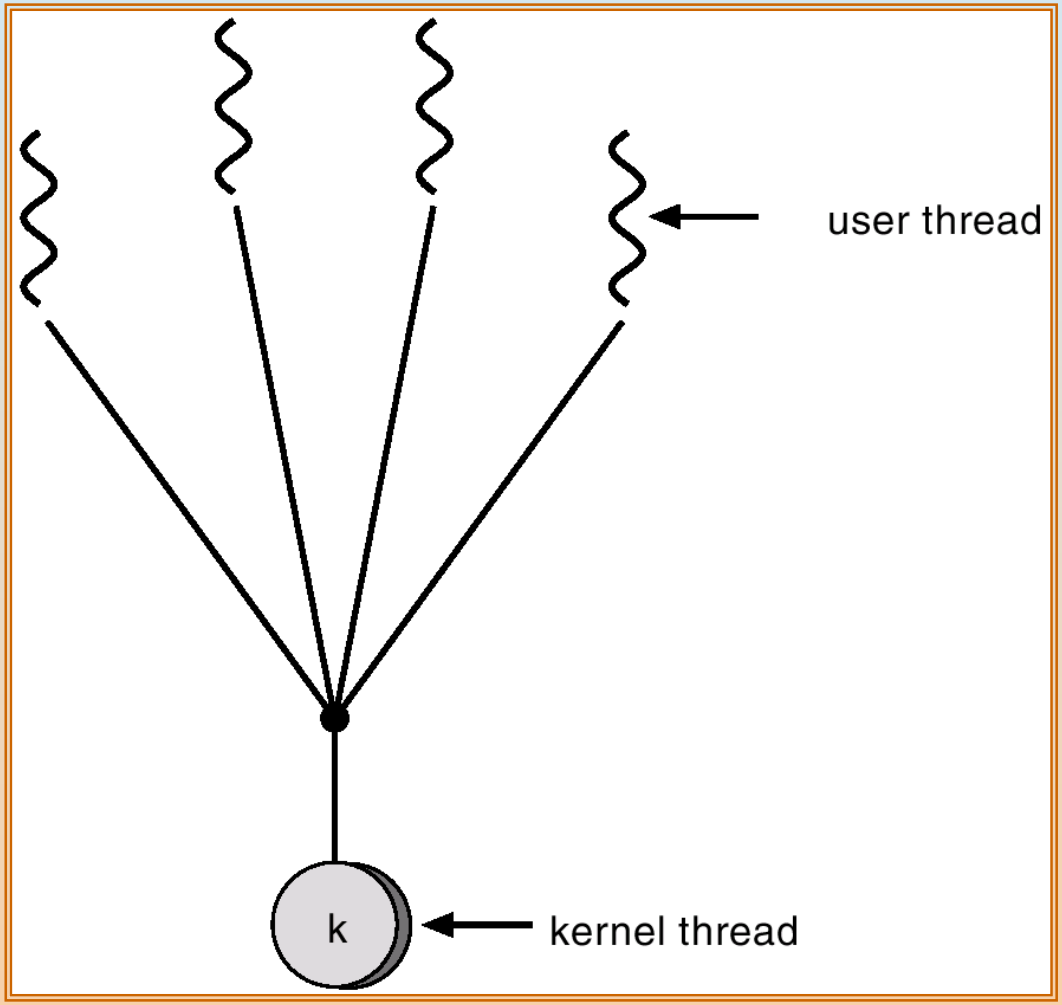
Multithreading Models

- Many-to-One
- One-to-One
- Many-to-Many

Many-to-One

- Many user-level threads mapped to single kernel thread
- Examples
  - Solaris Green Threads
  - GNU Portable Threads

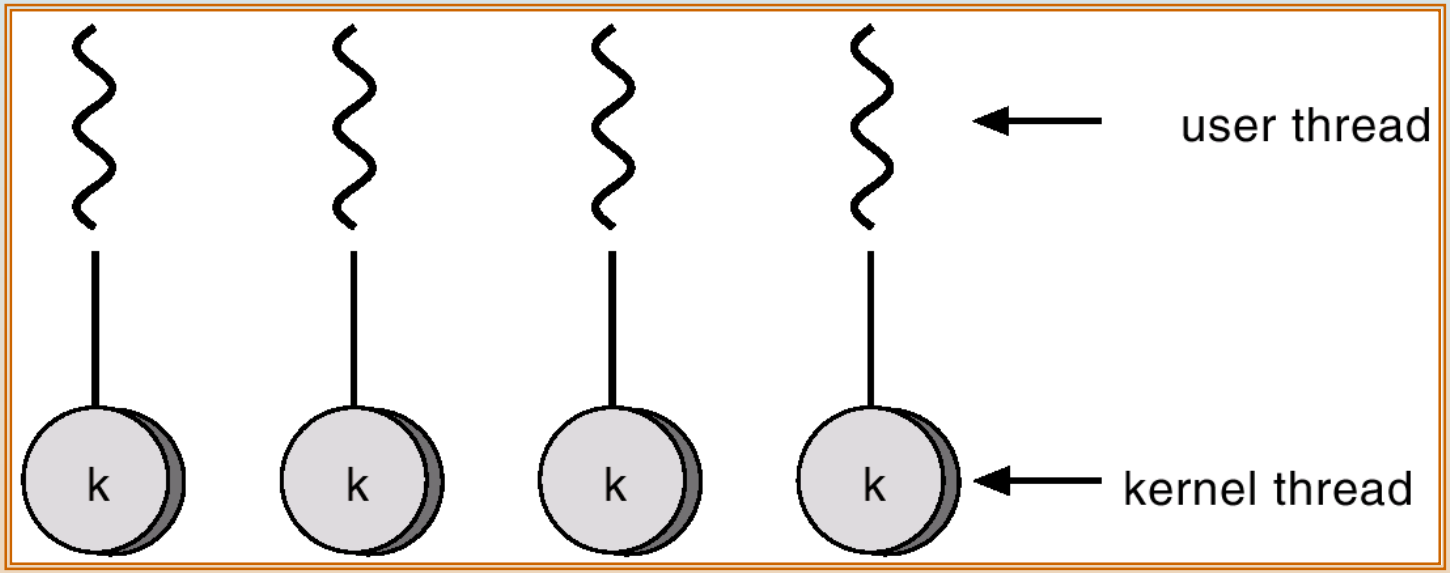
Many-to-One Model



One-to-One

- Each user-level thread maps to kernel thread
- Examples
  - Windows NT/XP/2000
  - Linux
  - Solaris 9 and later

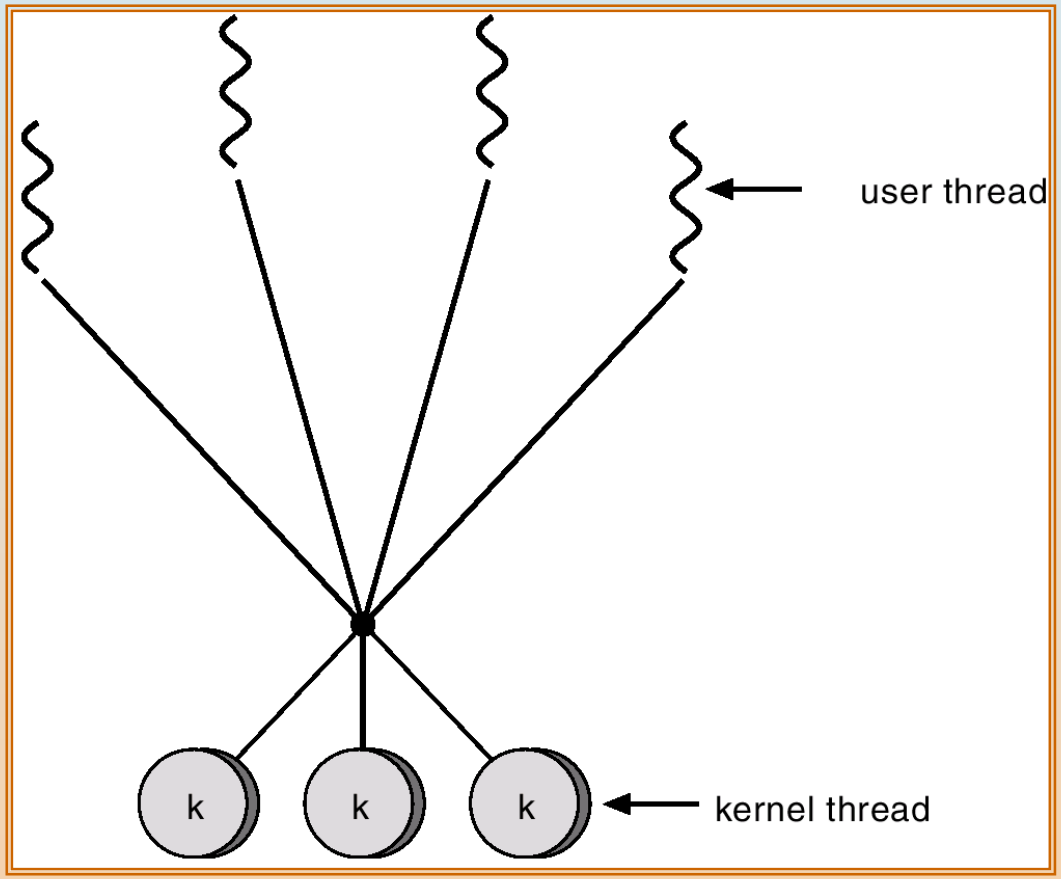
One-to-one Model



Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows NT/2000 with the *ThreadFiber* package

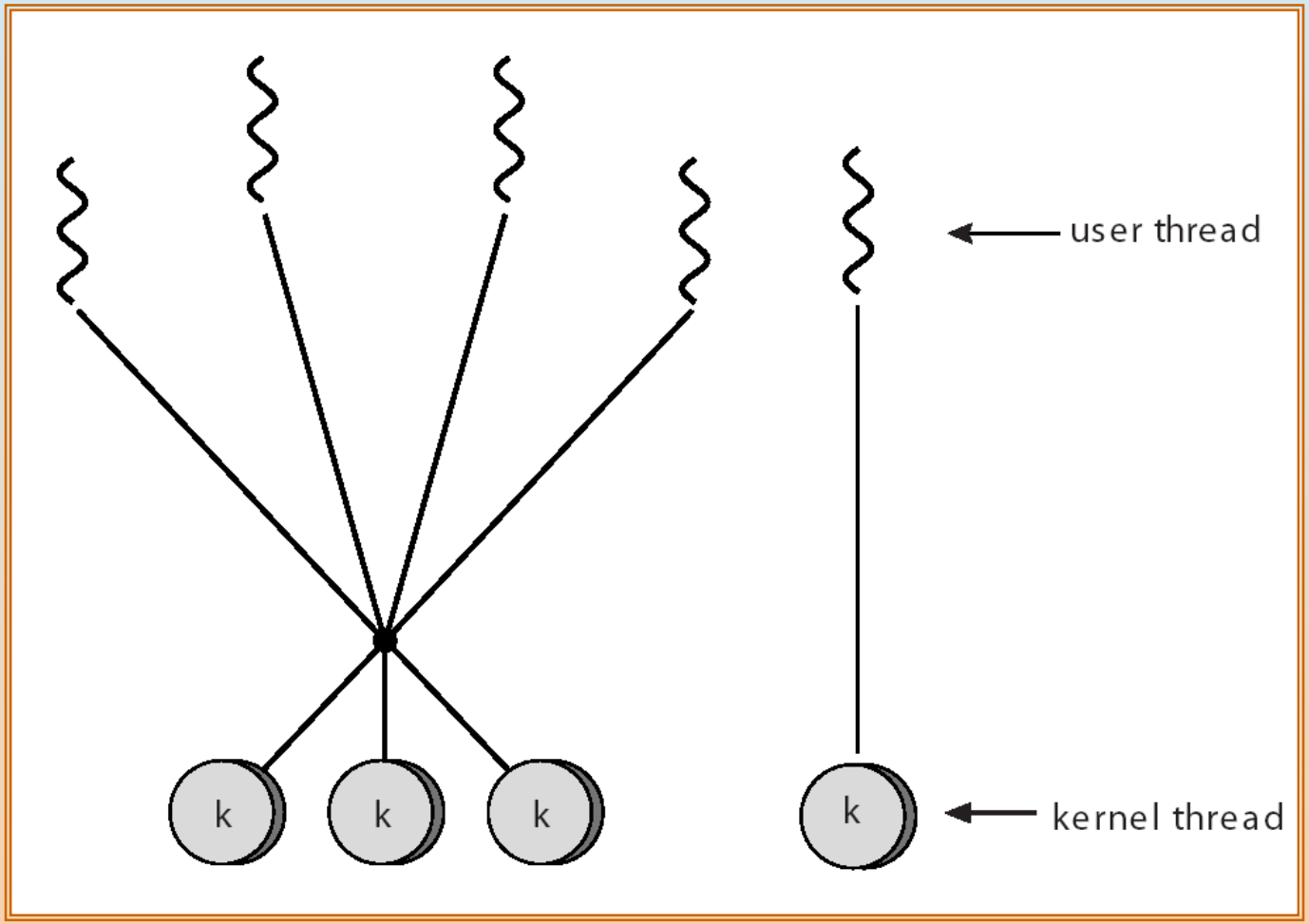
Many-to-Many Model



Two-level Model

- Similar to M:M, except that it allows a user thread to be **bound** to kernel thread
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier

Two-level Model



Threading Issues

- Semantics of **fork()** and **exec()** system calls
- Thread cancellation
- Signal handling
- Thread pools
- Thread specific data
- Scheduler activations

Semantics of fork() and exec()

- Does **fork()** duplicate only the calling thread or all threads?

Thread Cancellation

- Terminating a thread before it has finished
- Two general approaches:
  - **Asynchronous cancellation** terminates the target thread immediately
  - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled

Signal Handling

- Signals are used in UNIX systems to notify a process that a particular event has occurred
- A **signal handler** is used to process signals
  1. Signal is generated by particular event
  2. Signal is delivered to a process
  3. Signal is handled
- Options:
  - Deliver the signal to the thread to which the signal applies
  - Deliver the signal to every thread in the process
  - Deliver the signal to certain threads in the process
  - Assign a specific threa to receive all signals for the process

Thread Pools

- Create a number of threads in a pool where they await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than create a new thread
  - Allows the number of threads in the application(s) to be bound to the size of the pool

Thread Specific Data

- Allows each thread to have its own copy of data
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)

Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the thread library
- This communication allows an application to maintain the correct number kernel threads

Pthreads

- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)

Pthreads

```
int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* the thread */

main(int argc, char *argv[])
{
   pthread_t tid; /* the thread identifier */
   pthread_attr_t attr; /* set of attributes for the thread */
   /* get the default attributes */
   pthread_attr_init(&attr);
   /* create the thread */
   pthread_create(&tid,&attr,runner,argv[1]);
   /* now wait for the thread to exit */
   pthread_join(tid,NULL);
   printf("sum = %d\n",sum);
}

void *runner(void *param) {
   int upper = atoi(param);
   int i;
   sum = 0;
   if (upper > 0) {
      for (i = 1; i <= upper; i++)
         sum += i;
   }
   pthread_exit(0);
}
```

Windows XP Threads

- Implements the one-to-one mapping
- Each thread contains
  - A thread id
  - Register set
  - Separate user and kernel stacks
  - Private data storage area
- The register set, stacks, and private storage area are known as the **context** of the threads
- The primary data structures of a thread include:
  - ETHREAD (executive thread block)
  - KTHREAD (kernel thread block)
  - TEB (thread environment block)

Linux Threads

- Linux refers to them as *tasks* rather than *threads*
- Thread creation is done through **clone()** system call
- **clone()** allows a child task to share the address space of the parent task (process)

Java Threads

- Java threads are managed by the JVM
- Java threads may be created by:
  - Extending Thread class
  - Implementing the Runnable interface

Extending the Thread Class

```
class Worker1 extends Thread
{
   public void run() {
      System.out.println("I Am a Worker Thread");
   }
}

public class First
{
   public static void main(String args[]) {
      Worker1 runner = new Worker1();
      runner.start();

      System.out.println("I Am The Main Thread");
   }
}
```

The Runnable Interface

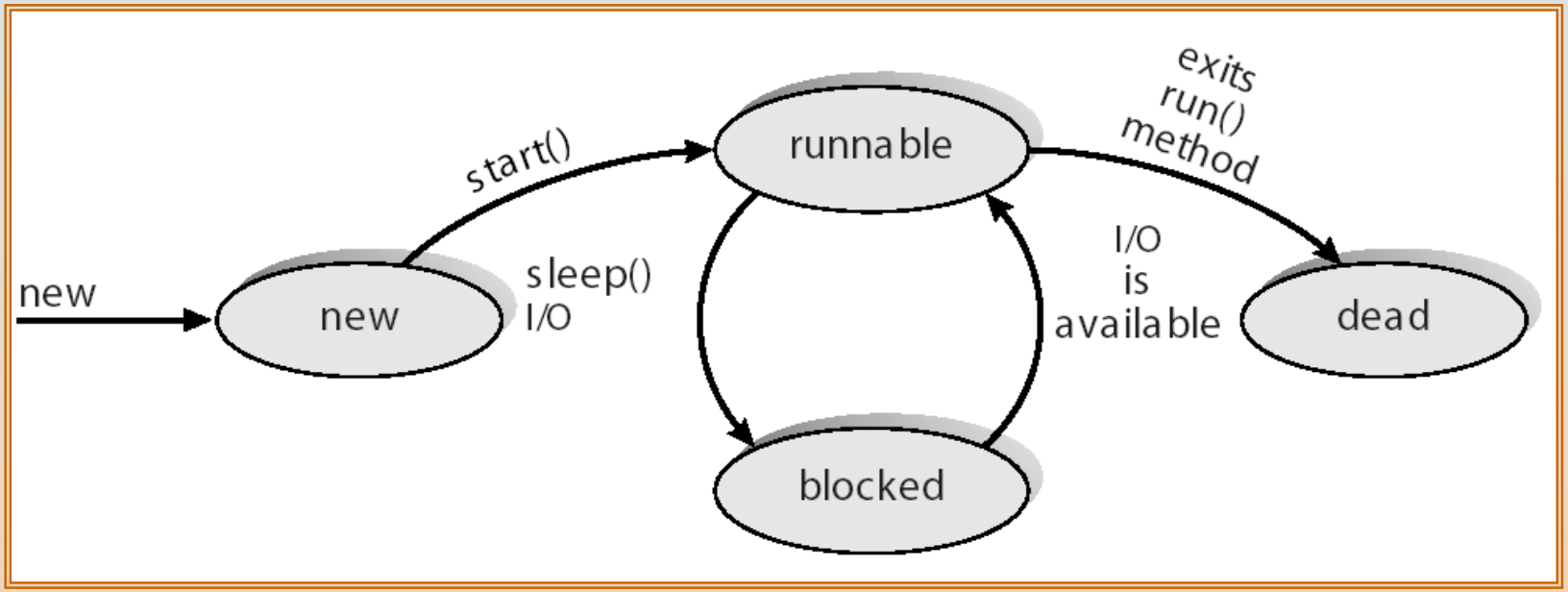
```
public interface Runnable
{
   public abstract void run();
}
```

Implementing the Runnable Interface

```
class Worker2 implements Runnable
{
   public void run() {
      System.out.println("I Am a Worker Thread ");
   }
}
public class Second
{
   public static void main(String args[]) {
      Runnable runner = new Worker2();
      Thread thrd = new Thread(runner);
      thrd.start();

      System.out.println("I Am The Main Thread");
   }
}
```

Java Thread States



Joining Threads

```
class JoinableWorker implements Runnable
{
   public void run() {
      System.out.println("Worker working");
   }
}

public class JoinExample
{
   public static void main(String[] args) {
      Thread task = new Thread(new JoinableWorker());
      task.start();

      try { task.join(); }
      catch (InterruptedException ie) { }

      System.out.println("Worker done");
   }
}
```

Thread Cancellation

```
Thread thrd = new Thread (new InterruptibleThread());
Thrd.start();

. . .

// now interrupt it
Thrd.interrupt();
```

Thread Cancellation

```
public class InterruptibleThread implements Runnable
{
   public void run() {
      while (true) {
         /**
          * do some work for awhile
          */

         if (Thread.currentThread().isInterrupted()) {
            System.out.println("I'm interrupted!");
            break;
         }
      }

      // clean up and terminate
   }
}
```

Thread Specific Data

```
class Service
{
   private static ThreadLocal errorCode = new ThreadLocal();

   public static void transaction() {
      try {
         /**
          * some operation where an error may occur
          */
      catch (Exception e) {
         errorCode.set(e);
      }
   }

   /**
    * get the error code for this transaction
    */
   public static Object getErrorCode() {
      return errorCode.get();
   }
}
```

Thread Specific Data

```
class Worker implements Runnable
{
   private static Service provider;

   public void run() {
      provider.transaction();
      System.out.println(provider.getErrorCode());
   }
}
```

Producer-Consumer Problem

```
public class Factory
{
   public Factory()   {
      // first create the message buffer
      Channel mailBox = new MessageQueue();

      // now create the producer and consumer threads
      Thread producerThread = new Thread(new Producer(mailBox));
      Thread consumerThread = new Thread(new Consumer(mailBox));

      producerThread.start();
      consumerThread.start();
   }

   public static void main(String args[]) {
      Factory server = new Factory();
   }
}
```

Producer Thread

```
class Producer implements Runnable
{
   private  Channel mbox;

   public Producer(Channel mbox) {
      this.mbox = mbox;
   }

   public void run() {
      Date message;

      while (true) {
         SleepUtilities.nap();
         message = new Date();
         System.out.println("Producer produced " + message);

         // produce an item & enter it into the buffer
         mbox.send(message);
      }
   }
}
```

Consumer Thread

```
class Consumer implements Runnable
{
   private  Channel mbox;

   public Consumer(Channel mbox) {
      this.mbox = mbox;
   }

   public void run() {
      Date message;

      while (true) {
         SleepUtilities.nap();
         // consume an item from the buffer
         System.out.println("Consumer wants to consume.");

         message = (Date)mbox.receive();
         if (message != null)
            System.out.println("Consumer consumed " + message);
      }
   }
}
```