# CS3600 — Systems and Networks

NORTHEASTERN UNIVERSITY

Lecture 5: Threads

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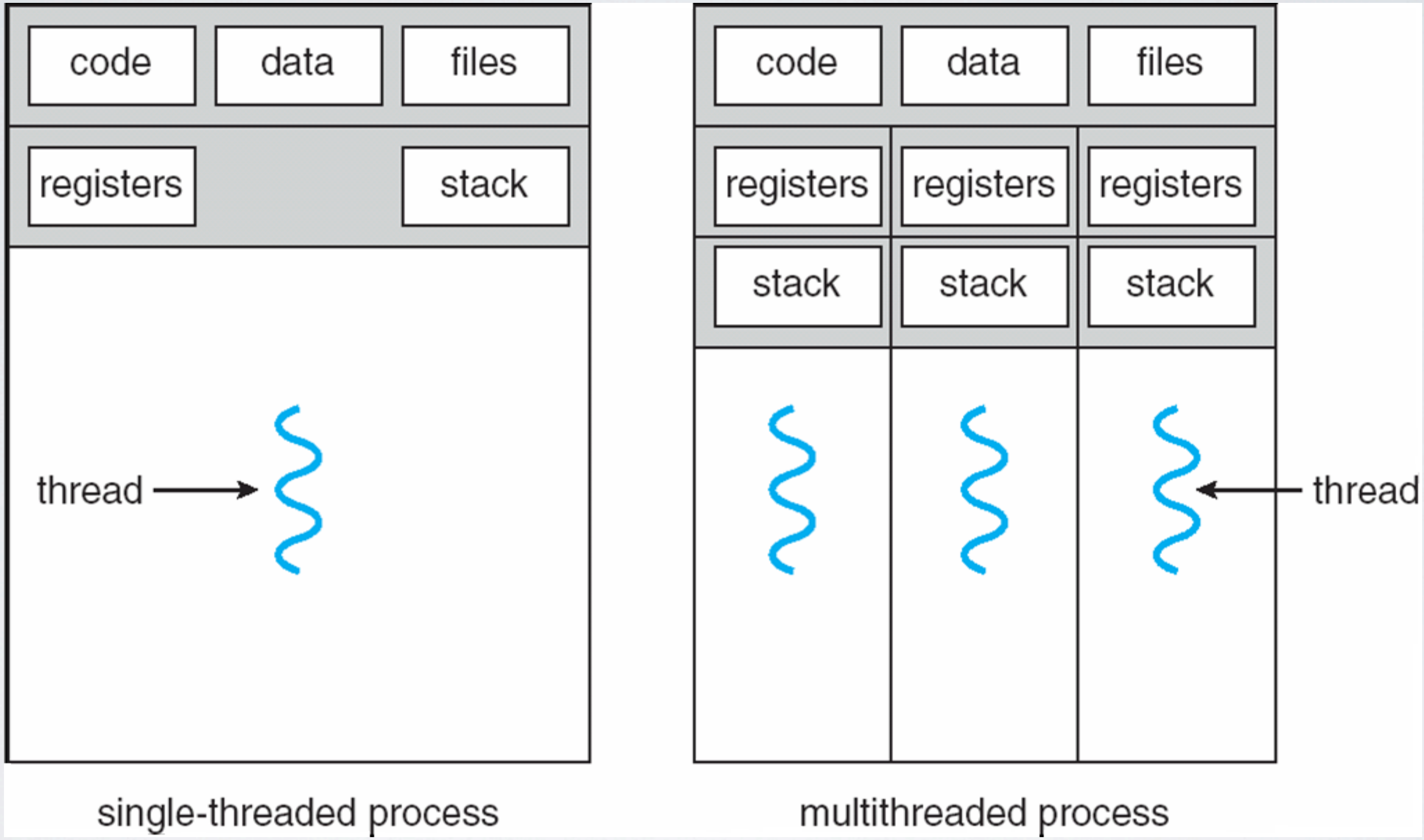
# Motivation

- Threads run within application
- Multiple tasks with the application can be implemented by separate threads
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Process creation is heavy-weight while thread creation is light-weight
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

# Single and Multithreaded Processes



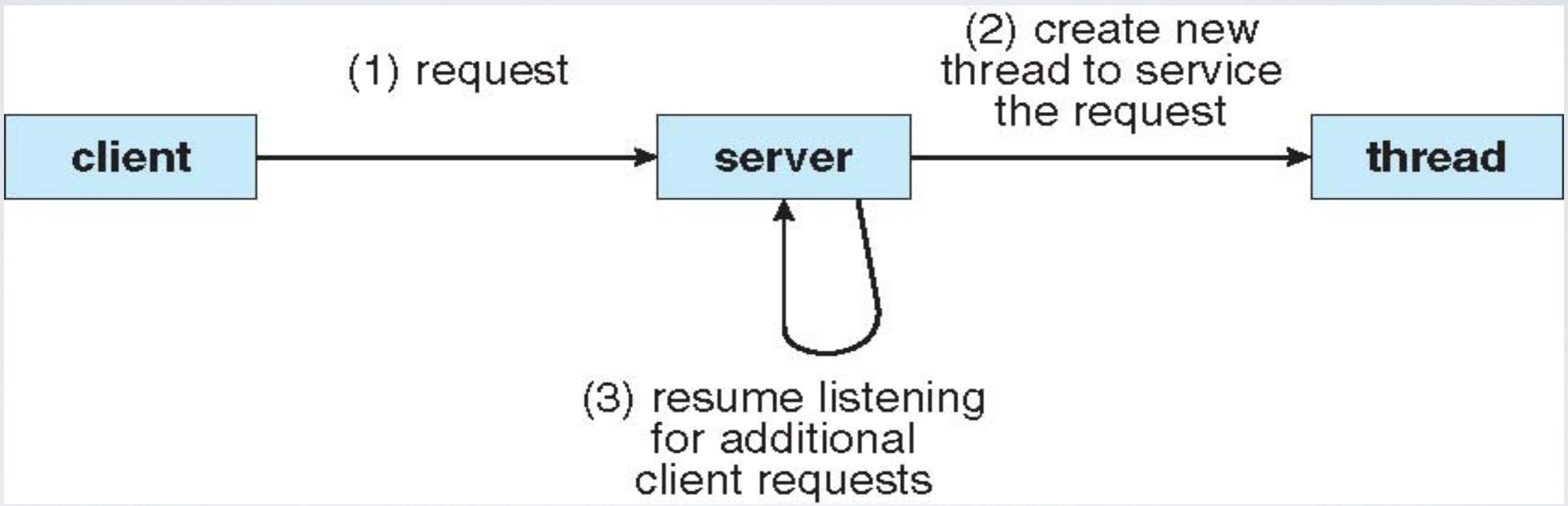
# Benefits

- **Responsiveness**
- **Resource Sharing**
- **Economy**
- **Scalability**

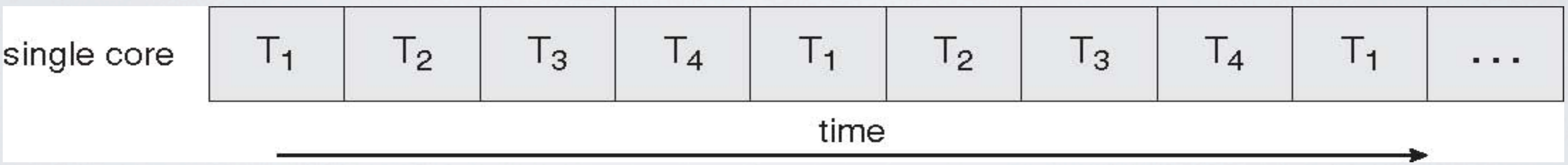
# Motivation: Multicore Programming

- Multicore systems putting pressure on programmers, challenges include:
  - **Dividing activities**
  - **Balance**
  - **Data splitting**
  - **Data dependency**
  - **Testing and debugging**

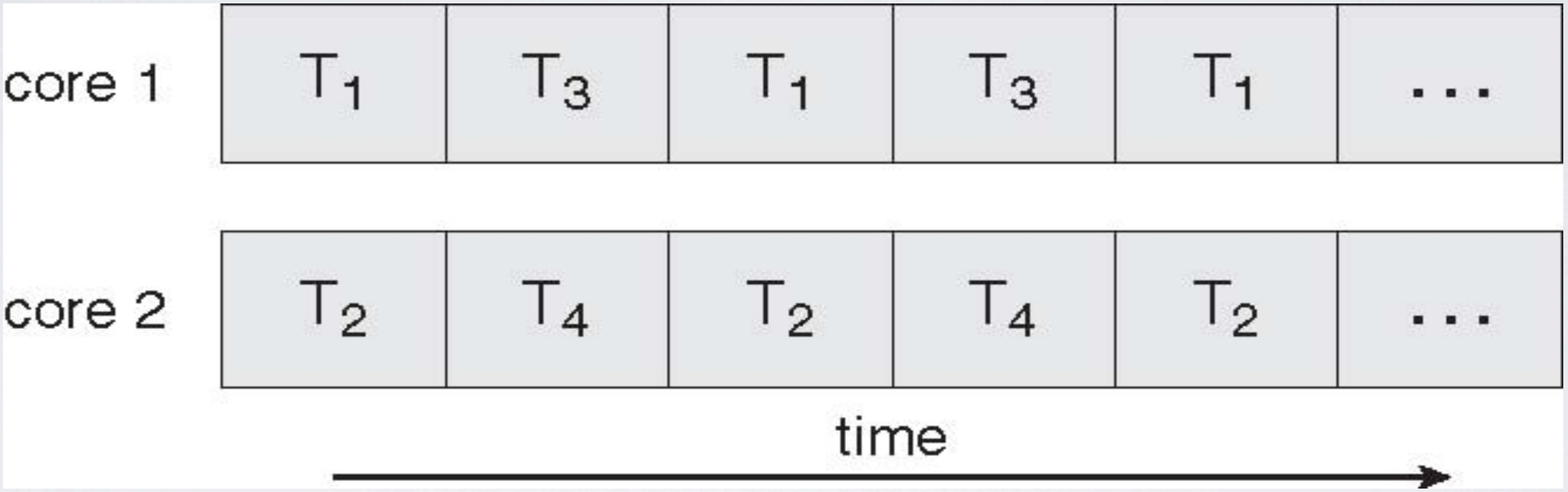
# Multithreaded Server Architecture



# Concurrent Execution on a Single-core System



# Parallel Execution on a Multicore System



# User Threads

- Thread management done by user-level threads library
  - Kernel oblivious to thread existence, scheduling done at user level
- Advantages
  - Can be implemented without kernel support
  - Faster to context switch
- Disadvantage:  Single thread can block entire process
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Win32 threads
  - Java threads

# Kernel Threads

- Supported by the Kernel
  - Kernel knows about thread, schedules it like a process

- Advantages
  - Less user-level code
  - (others from previous slide)

- Examples
  - Windows XP/2000
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

# Multithreading Models

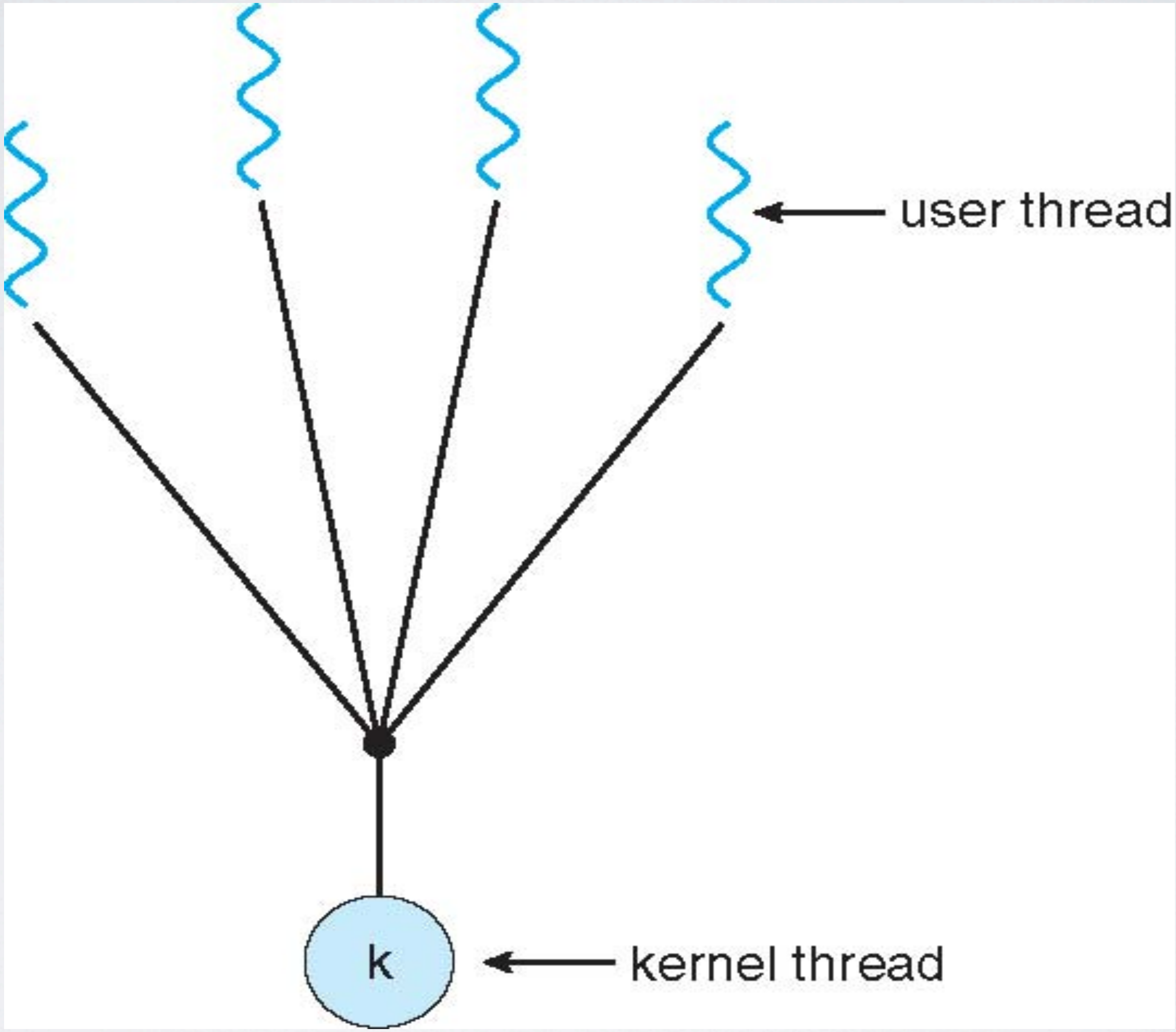
- Many-to-One
- One-to-One
- Many-to-Many

# Many-to-One

- Many user-level threads mapped to single kernel thread

- Examples:
  - **Solaris Green Threads**
  - **GNU Portable Threads**

# Many-to-One Model

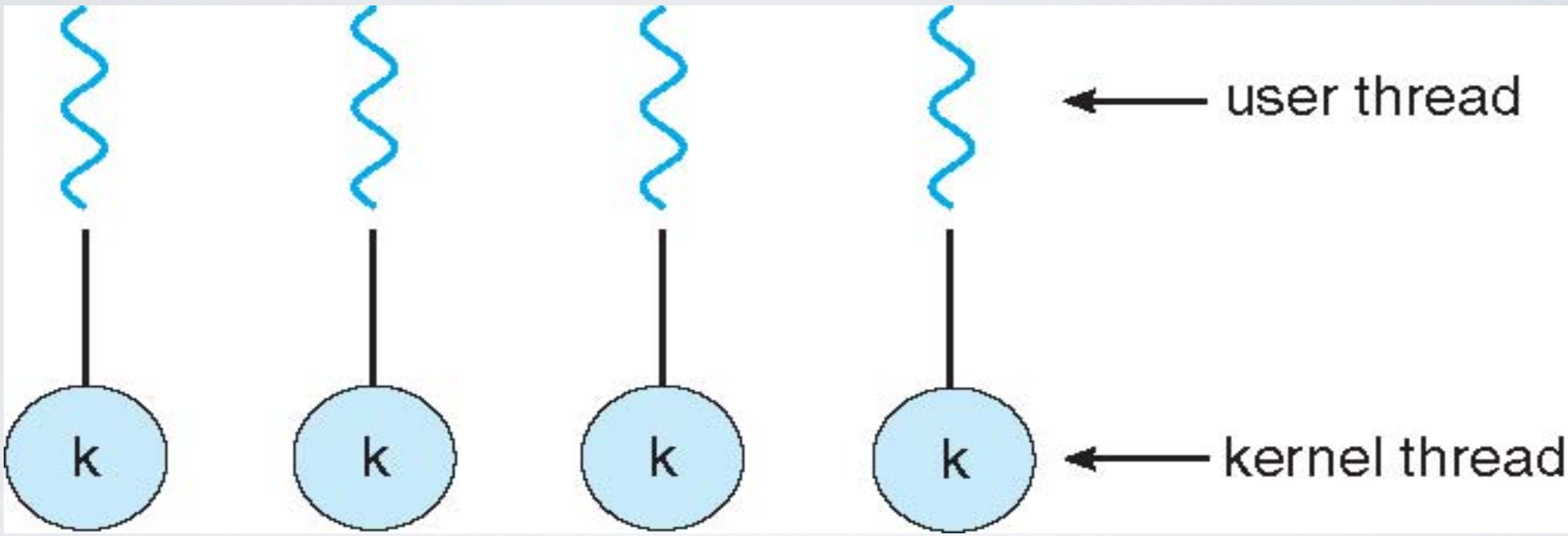


# One-to-One

- Each user-level thread maps to kernel thread

- Examples
  - Windows NT/XP/2000
  - Linux
  - Solaris 9 and later

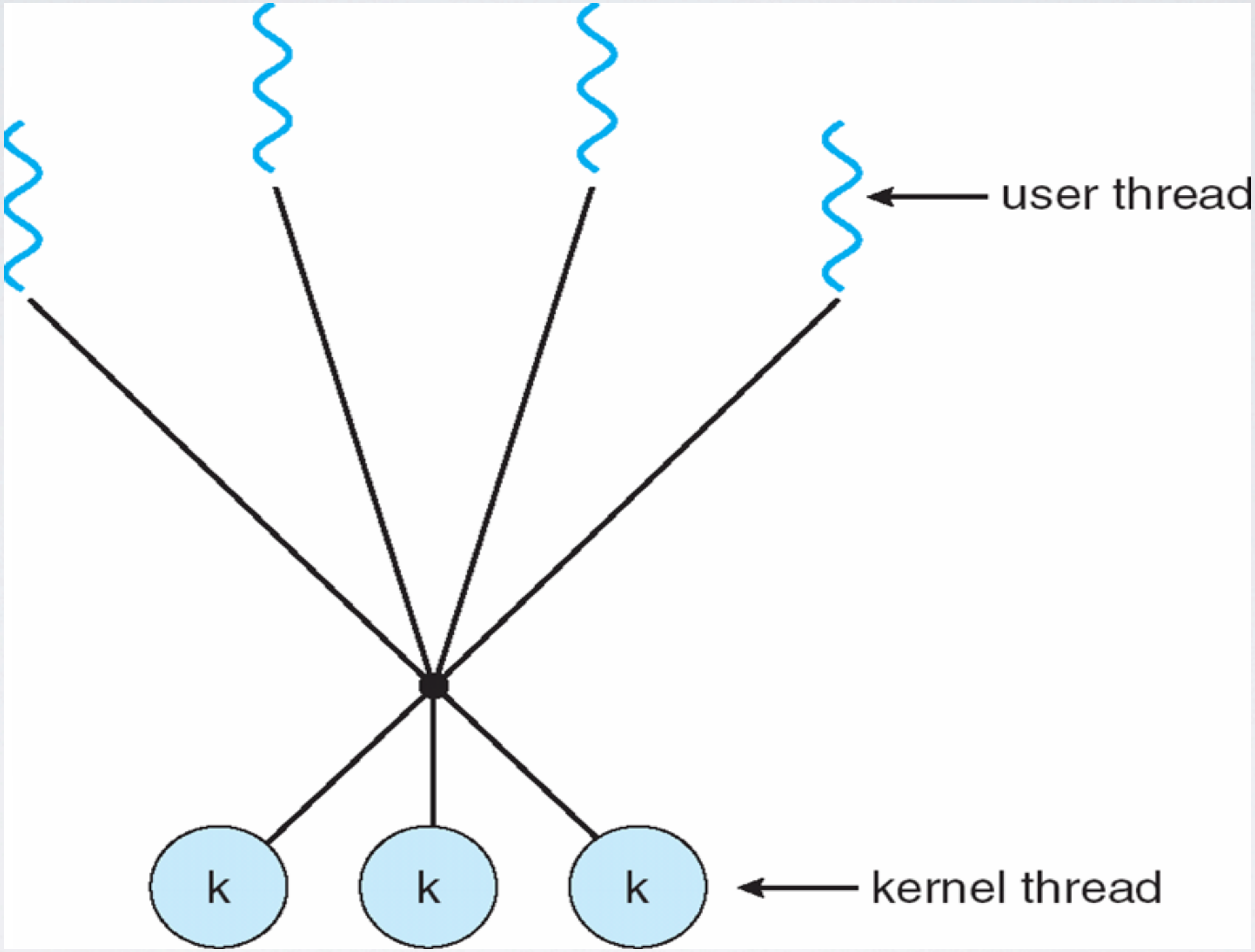
# One-to-one Model



# 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

# Thread Libraries

- **Thread library** provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS

# Pthreads

- May be provided either as user-level or kernel-level
- 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)

```c
#include <pthread.h>
#include <stdio.h>

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

int main(int argc, char *argv[])
{
  pthread_t tid; /* the thread identifier */
  pthread_attr_t attr; /* set of thread attributes */

  if (argc != 2) {
    fprintf(stderr,"usage: a.out <integer value>\n");
    return -1;
  }
  if (atoi(argv[1]) < 0) {
    fprintf(stderr,"%d must be >= 0\n",atoi(argv[1]));
    return -1;
  }
  /* get the default attributes */
  pthread_attr_init(&attr);
  /* create the thread */
  pthread_create(&tid,&attr,runner,argv[1]);
  /* wait for the thread to exit */
  pthread_join(tid,NULL);

  printf("sum = %d\n",sum);
}

/* The thread will begin control in this function */
void *runner(void *param)
{
  int i, upper = atoi(param);
  sum = 0;

  for (i = 1; i <= upper; i++)
    sum += i;

  pthread_exit(0);
}
```

**Figure 4.9** Multithreaded C program using the Pthreads API.

# Java Threads

- Java threads are managed by the JVM
- Typically implemented using the threads model provided by underlying OS
- Java threads may be created by:
  - Extending Thread class
  - Implementing the Runnable interface

# Java Multithreaded Program

```
class Sum
{
  private int sum;

  public int getSum() {
   return sum;
  }

  public void setSum(int sum) {
   this.sum = sum;
  }
}

class Summation implements Runnable
{
  private int upper;
  private Sum sumValue;

  public Summation(int upper, Sum sumValue) {
   this.upper = upper;
   this.sumValue = sumValue;
  }

  public void run() {
   int sum = 0;
   for (int i = 0; i <= upper; i++)
      sum += i;
   sumValue.setSum(sum);
  }
}
```

```
public class Driver
{
  public static void main(String[] args) {
   if (args.length > 0) {
    if (Integer.parseInt(args[0]) < 0)
     System.err.println(args[0] + " must be >= 0.");
    else {
     // create the object to be shared
     Sum sumObject = new Sum();
     int upper = Integer.parseInt(args[0]);
     Thread thrd = new Thread(new Summation(upper, sumObject));
     thrd.start();
     try {
       thrd.join();
       System.out.println
              ("The sum of "+upper+" is "+sumObject.getSum());
    } catch (InterruptedException ie) { }
    }
   }
   else
    System.err.println("Usage: Summation <integer value>"); }
}
```

**Figure 4.11** Java program for the summation of a non-negative integer.

# Threading Issues

- Semantics of **fork()** and **exec()** system calls
- **Signal** handling
  - Synchronous and asynchronous

# 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 thread 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)