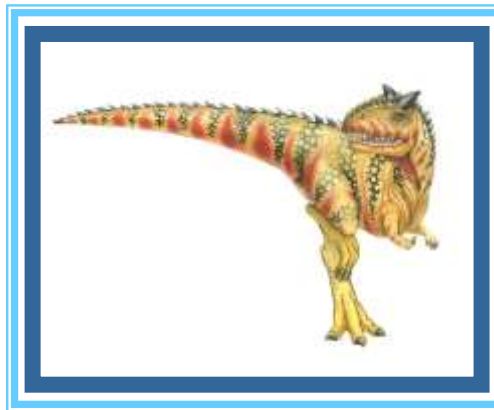


Topic 4

(Textbook - Chapter 4)

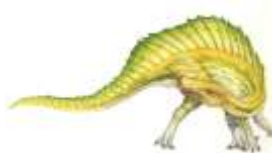
Threads





Chapter 4: Threads

- Overview
- Multicore Programming
- Multithreading Models
- Thread Libraries
- Threading Issues





Objectives

- To introduce the notion of a thread - a fundamental unit of CPU utilization that forms the basis of multithreaded computer systems
- To discuss the APIs for the Pthreads, Windows, and Java thread libraries
- To examine issues related to multithreaded programming





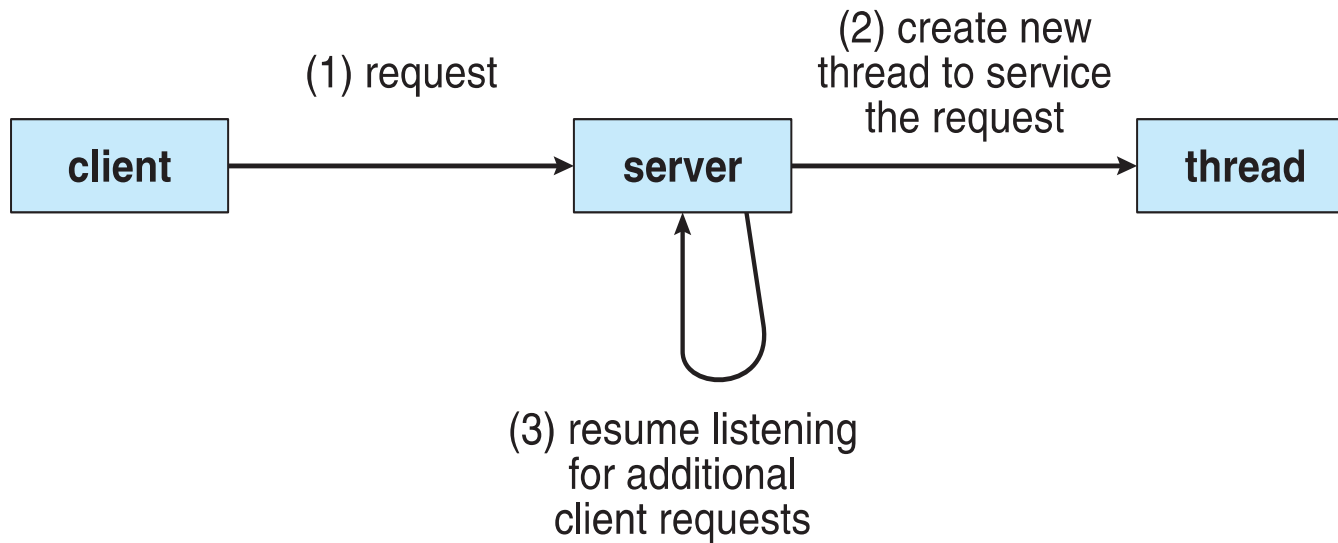
Motivation

- Most modern applications are multithreaded
- 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
- Traditional Heavy-weight Process have a single thread of control.
- Can simplify code, increase efficiency
- Kernels are generally multithreaded





Multithreaded Server Architecture





Benefits

- **Responsiveness** – may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing** – threads share resources of process, easier than shared memory or message passing
- **Economy** – cheaper than process creation, thread switching lower overhead than context switching
- **Scalability** – process can take advantage of multiprocessor architectures





Multicore Programming

- **Multicore** or **multiprocessor** systems putting pressure on programmers, challenges include:
 - **Identifying tasks**
 - **Balance**
 - **Data splitting**
 - **Data dependency**
 - **Testing and debugging**
- **Parallelism** implies a system can perform more than one task simultaneously
- **Concurrency** supports more than one task making progress
 - Single processor / core, scheduler providing concurrency





Multicore Programming (Cont.)

- Types of parallelism
 - **Data parallelism** – distributes subsets of the same data across multiple cores, same operation on each
 - **Task parallelism** – distributing threads across cores, each thread performing unique operation
- As # of threads grows, so does architectural support for threading
 - CPUs have cores as well as *hardware threads*
 - Consider Oracle SPARC T4 with 8 cores, and 8 hardware threads per core



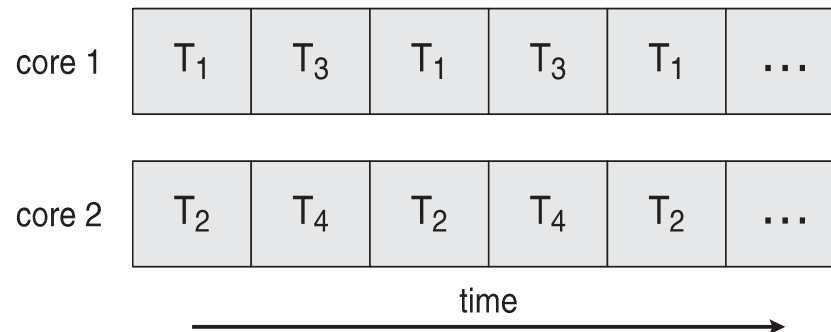


Concurrency vs. Parallelism

■ Concurrent execution on single-core system:

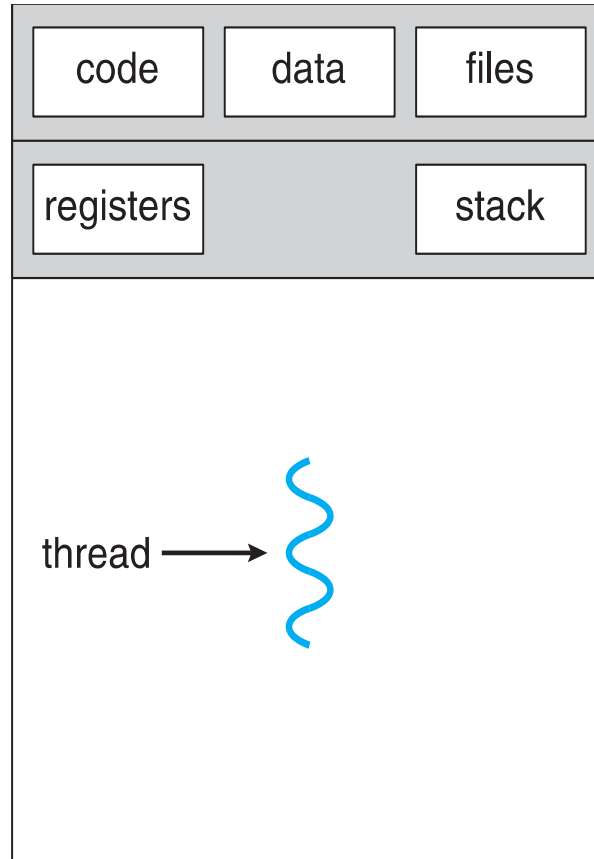


■ Parallelism on a multi-core system:

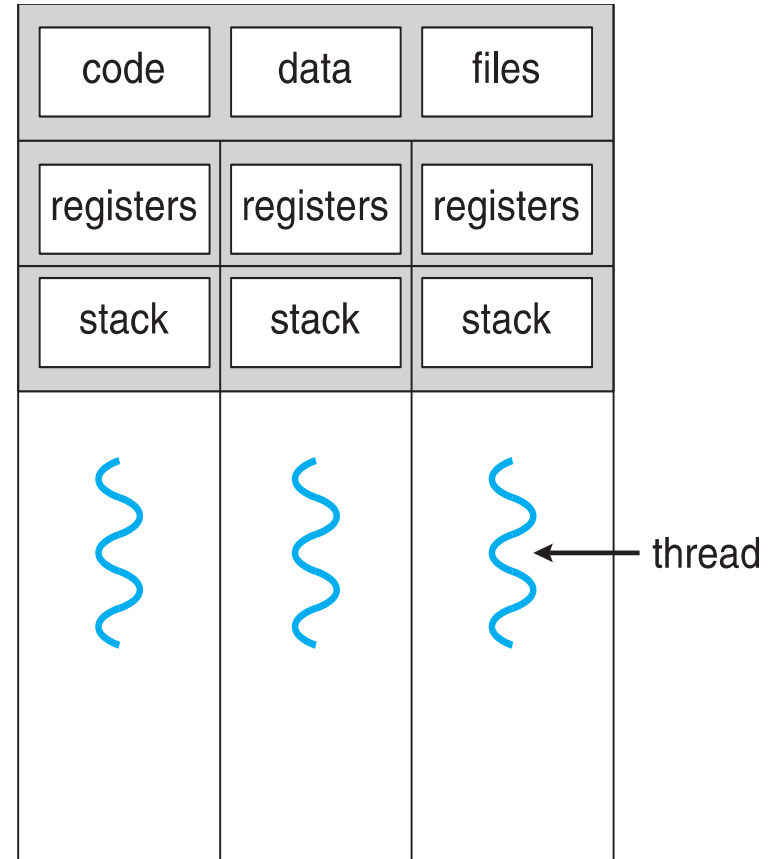




Single and Multithreaded Processes



single-threaded process



multithreaded process





Programming Challenges

- In general, five areas present challenges in programming for multicore
- **Identifying Tasks** – distributes subsets of the same data across multiple cores, same operation on each
- **Balance**
- **Data splitting**
- **Data dependency**
- **Testing and debugging**





Amdahl's Law

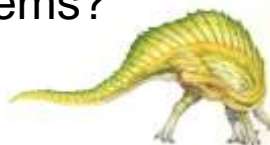
- Identifies performance gains from adding additional cores to an application that has both serial and parallel components
- S is serial portion
- N processing cores

$$speedup \leq \frac{1}{S + \frac{(1-S)}{N}}$$

- That is, if application is 75% parallel / 25% serial, moving from 1 to 2 cores results in speedup of 1.6 times
- As N approaches infinity, speedup approaches $1 / S$

Serial portion of an application has disproportionate effect on performance gained by adding additional cores

- But does the law take into account contemporary multicore systems?





User Threads and Kernel Threads

- **User threads** - management done by user-level threads library
- Three primary thread libraries:
 - POSIX **Pthreads**
 - Windows threads
 - Java threads
- **Kernel threads** - Supported by the Kernel
- Examples – virtually all general purpose operating systems, including:
 - Windows
 - Solaris
 - Linux
 - Tru64 UNIX
 - Mac OS X





Multithreading Models

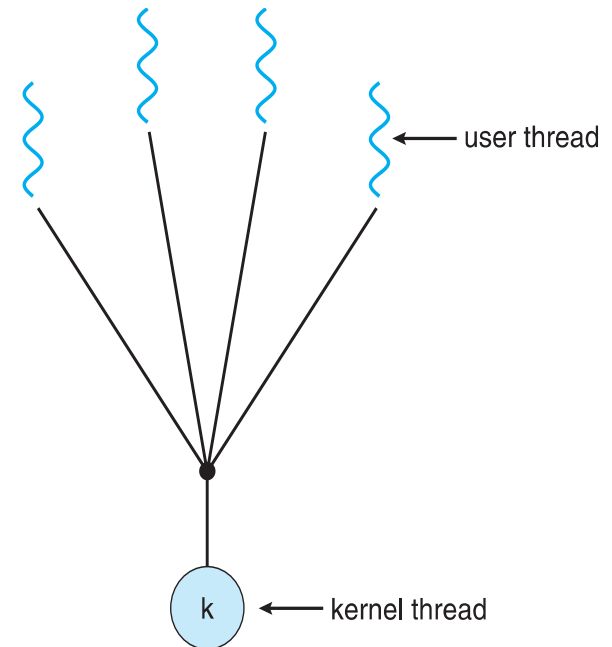
- Many-to-One
- One-to-One
- Many-to-Many





Many-to-One

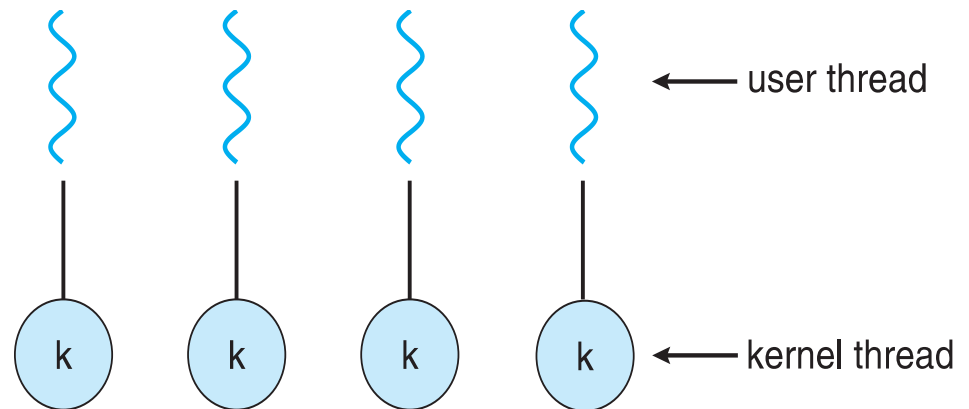
- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on multicore system because only one may be in kernel at a time
- Few systems currently use this model
- Examples:
 - **Solaris Green Threads**
 - **GNU Portable Threads**





One-to-One

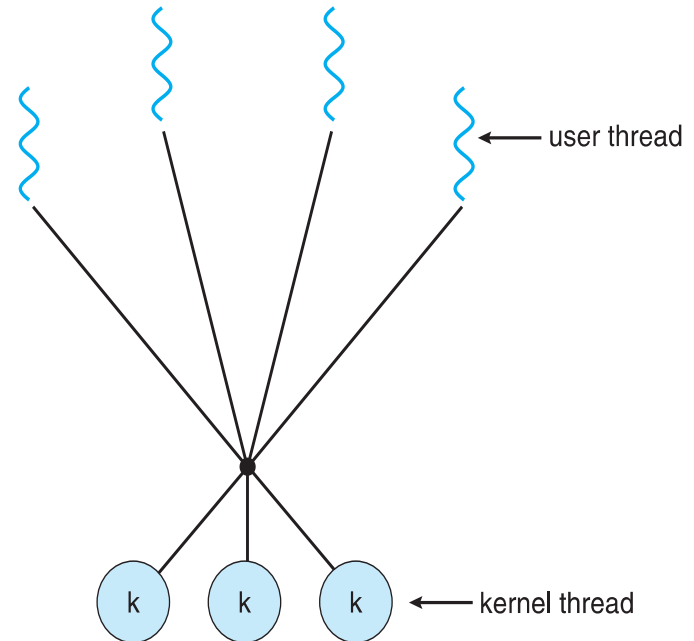
- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead
- Examples
 - Windows
 - Linux
 - Solaris 9 and later





Many-to-Many Model

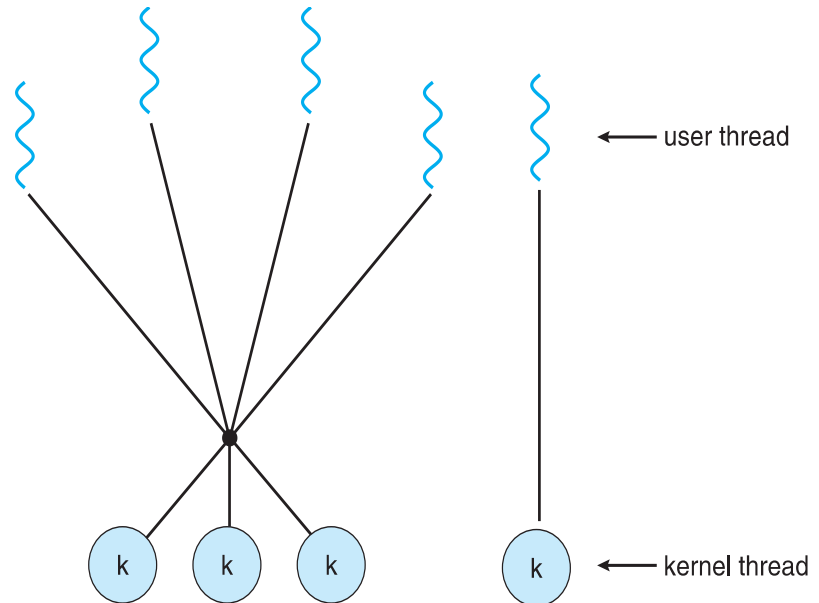
- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows with the *ThreadFiber* package





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
- ***Specification***, not ***implementation***
- 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 Example

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

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

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;
    }
}
```





Pthreads Example (Cont.)

```
    /* 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);
}
```





Pthreads Code for Joining 10 Threads

```
#define NUM_THREADS 10

/* an array of threads to be joined upon */
pthread_t workers[NUM_THREADS];

for (int i = 0; i < NUM_THREADS; i++)
    pthread_join(workers[i], NULL);
```





Windows Multithreaded C Program

```
#include <windows.h>
#include <stdio.h>
DWORD Sum; /* data is shared by the thread(s) */

/* the thread runs in this separate function */
DWORD WINAPI Summation(LPVOID Param)
{
    DWORD Upper = *(DWORD*)Param;
    for (DWORD i = 0; i <= Upper; i++)
        Sum += i;
    return 0;
}

int main(int argc, char *argv[])
{
    DWORD ThreadId;
    HANDLE ThreadHandle;
    int Param;

    if (argc != 2) {
        fprintf(stderr, "An integer parameter is required\n");
        return -1;
    }
    Param = atoi(argv[1]);
    if (Param < 0) {
        fprintf(stderr, "An integer >= 0 is required\n");
        return -1;
    }
}
```





Windows Multithreaded C Program (Cont.)

```
/* create the thread */
ThreadHandle = CreateThread(
    NULL, /* default security attributes */
    0, /* default stack size */
    Summation, /* thread function */
    &Param, /* parameter to thread function */
    0, /* default creation flags */
    &ThreadId); /* returns the thread identifier */

if (ThreadHandle != NULL) {
    /* now wait for the thread to finish */
    WaitForSingleObject(ThreadHandle, INFINITE);

    /* close the thread handle */
    CloseHandle(ThreadHandle);

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





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 and override its run() method.
or
 - Implementing the Runnable interface

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





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);
    }
}
```





Java Multithreaded Program (Cont.)

```
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 {
                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>");
    }
}
```





2. Creating threads

(1) Inheriting from the Thread class

■ The general approach is

- (1) Define a class by extending the Thread class and overriding the run method.
 - ▶ In the run method, you should write the code that you wish to run when this particular thread has started.
- (2) Create an instance of the above class
- (3) Start running the instance using the start method that is defined in

The output

```
public class WhereAmI extends Thread {
    int n;
    // constructor
    public WhereAmI(int number) {
        n = number;
    }
    // override the run method
    public void run() {
        for (int i = 0; i < 100; i++)
            System.out.println("I'm in thread " + n);
    }
}
```

```
public class ThreadTester {
    public static void main(String[] args) {
        // create the threads
        WhereAmI place1 = new WhereAmI(1);
        WhereAmI place2 = new WhereAmI(2);
        WhereAmI place3 = new WhereAmI(3);
        // start the threads
        place1.start();
        place2.start();
        place3.start();
    }
}
```

```
I'm in thread 3
I'm in thread 1
I'm in thread 3
I'm in thread 1
I'm in thread 3
I'm in thread 1
I'm in thread 3
I'm in thread 2
I'm in thread 3
I'm in thread 2
I'm in thread 3
I'm in thread 2
I'm in thread 3
I'm in thread 2
```



2. Creating threads

(2) Implementing the `Runnable` interface

■ The general approach is

- (1) Define a class that implements `Runnable` and overriding the `run` method.
- (2) Create an instance of the above class.
- (3) Create a thread that runs this instance.
- (4) Start running the instance using the `start` method.

```
public class WhereAmI2 implements Runnable{
    int n;
    // constructor
    public WhereAmI2(int number) {
        n = number;
    }
    // override the run method
    public void run() {
        for (int i = 0; i < 100; i++)
            System.out.println("I'm in thread " + n);
    }
}
```

```
public class ThreadTester2 {
    public static void main(String[] args) {
        // create a runnable objects,
        // and the thread to run them.
        WhereAmI2 place1 = new WhereAmI2(1);
        Thread thread1 = new Thread(place1);
        WhereAmI2 place2 = new WhereAmI2(2);
        Thread thread2 = new Thread(place2);
        WhereAmI2 place3 = new WhereAmI2(3);
        Thread thread3 = new Thread(place3);
        // start the threads
        thread1.start();
        thread2.start();
        thread3.start();
    }
}
```

The output

```
I'm in thread 3
I'm in thread 1
I'm in thread 3
I'm in thread 1
I'm in thread 3
I'm in thread 1
I'm in thread 3
I'm in thread 2
I'm in thread 3
I'm in thread 2
I'm in thread 3
I'm in thread 2
I'm in thread 2
```



Threading Issues

- Semantics of **fork()** and **exec()** system calls change in a multithreaded program.
- Signal handling
 - Synchronous and asynchronous
- Thread cancellation of target thread
 - Asynchronous or deferred
- Thread-local storage
- Scheduler Activations





Semantics of `fork()` and `exec()`

- Does `fork()` duplicate only the calling thread or all threads?
 - Some UNIXes have two versions of `fork`
- `exec()` usually works as normal – replace the running process including all threads





Signal Handling

- n **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- n 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 by one of two signal handlers:
 1. default
 2. user-defined
- n Every signal has **default handler** that kernel runs when handling signal
 - | **User-defined signal handler** can override default
 - | For single-threaded, signal delivered to process





Signal Handling (Cont.)

- n Where should a signal be delivered for multi-threaded?
 - | 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 Cancellation

- Terminating a thread before it has finished
- Thread to be canceled is **target thread**
- Two general approaches:
 - **Asynchronous cancellation** terminates the target thread immediately
 - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
- Pthread code to create and cancel a thread:

```
pthread_t tid;  
  
/* create the thread */  
pthread_create(&tid, 0, worker, NULL);  
  
. . .  
  
/* cancel the thread */  
pthread_cancel(tid);
```





Thread Cancellation (Cont.)

- Invoking thread cancellation requests cancellation, but actual cancellation depends on thread state

Mode	State	Type
Off	Disabled	–
Deferred	Enabled	Deferred
Asynchronous	Enabled	Asynchronous

- If thread has cancellation disabled, cancellation remains pending until thread enables it
- Default type is deferred
 - Cancellation only occurs when thread reaches **cancellation point**
 - ▶ i.e. `pthread_testcancel()`
 - ▶ Then **cleanup handler** is invoked
- On Linux systems, thread cancellation is handled through signals





Thread-Local Storage

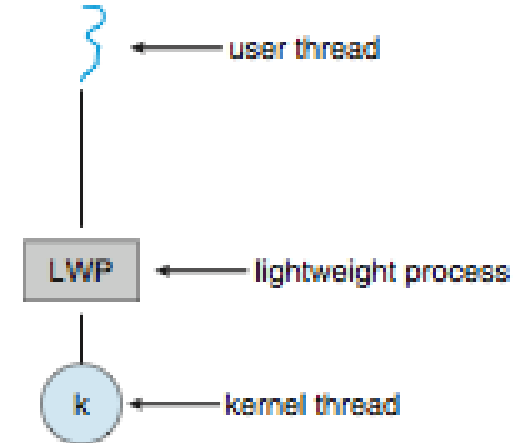
- **Thread-local storage (TLS)** allows each thread to have its own copy of data
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)
- Different from local variables
 - Local variables visible only during single function invocation
 - TLS visible across function invocations
- Similar to **static** data
 - TLS is unique to each thread





Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Typically use an intermediate data structure between user and kernel threads – **lightweight process (LWP)**
 - Appears to be a virtual processor on which process can schedule user thread to run
 - Each LWP attached to kernel thread
 - How many LWPs to create?
- Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the **upcall handler** in the thread library
- This communication allows an application to maintain the correct number of kernel threads



End of Chapter 4

