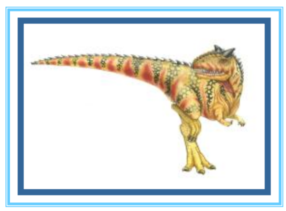
Chapter 4: Threads



Chapter 4: Threads

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples
- Windows XP Threads
- Linux Threads

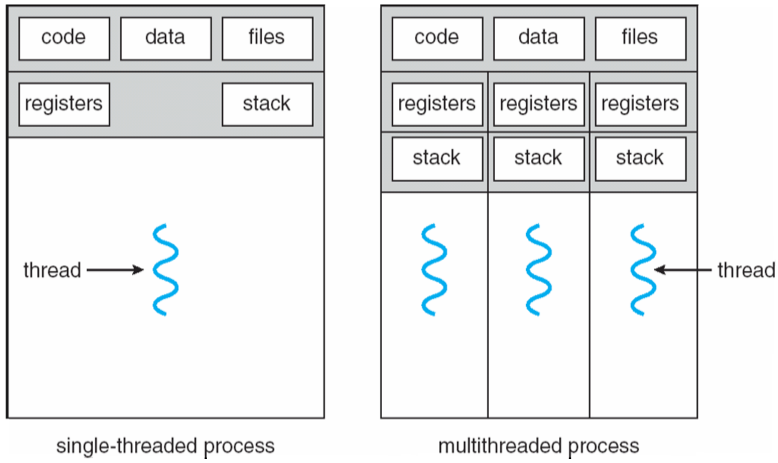
Objectives

- 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, Win32, and Java thread libraries
- To examine issues related to multithreaded programming

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



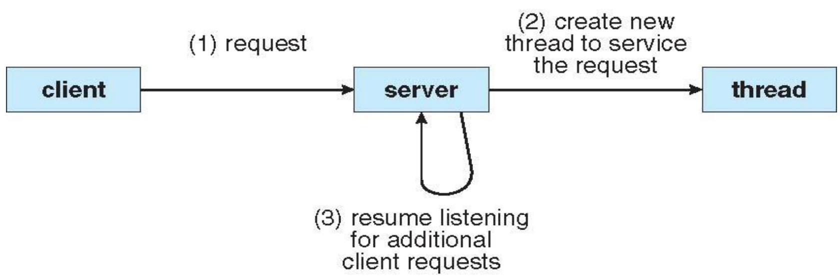
Benefits

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

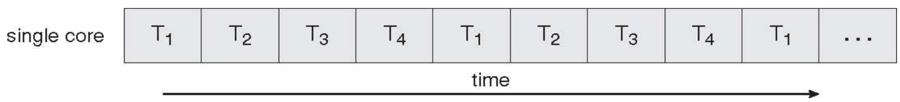
Multicore Programming

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

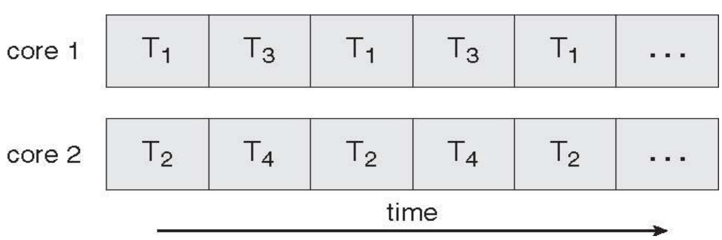
Multithreaded Server Architecture



Concurrent Execution on a Single-core System



Parallel Execution on a Multicore System



User Threads

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

Kernel Threads

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

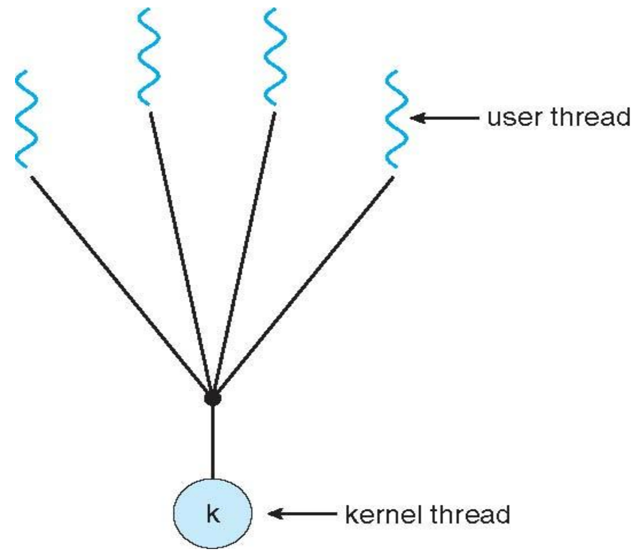
Multithreading Models

- 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**

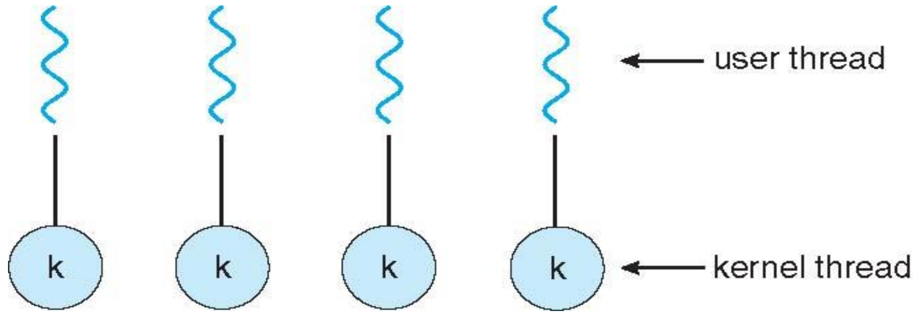
Many-to-One Model



One-to-One

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

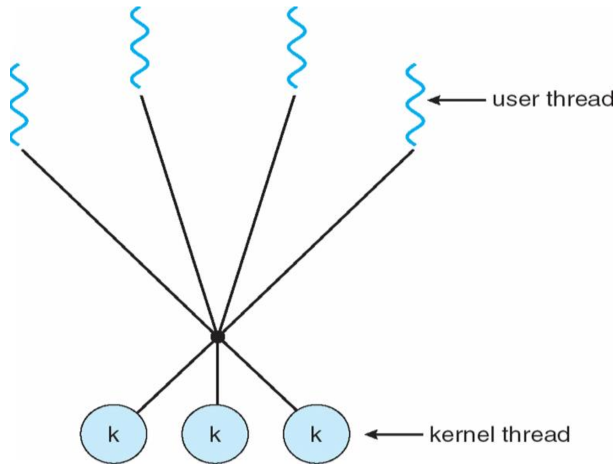
One-to-one Model



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

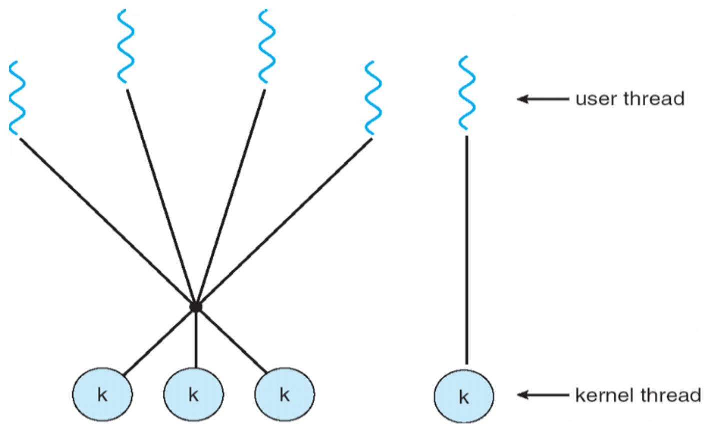
Many-to-Many Model



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



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)

Pthreads Example

```
#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;
  }
```

Pthreads Example (Cont.)

```c
   /* 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.

A Simple pthreads Example

pthread1.c

```c
int main(int argc, char *argv[]) {

  pthread_t threads[NUM_THREADS];     // Thread identifiers
  int i, rc, *taskid[NUM_THREADS];    // Id numbers for each thread

  // Initialize the salutations for each thread
  messages[0] = "English: Hello World!";
  messages[1] = "French: Bonjour, le monde!";
  messages[2] = "Spanish: Hola al mundo";
  messages[3] = "Klingon: Nuq neH!";
  messages[4] = "German: Guten Tag, Welt!";

  for(i=0; i<NUM_THREADS; i++) {
    // Allocte an array for arguments to the threads
    taskid[i] = (int *) malloc(sizeof(int));
    *taskid[i] = i;
    // Create a thread with its argument in taskid[i]
    rc = pthread_create(&threads[i], NULL, PrintHello, (void *) taskid[i]);
    if (rc) { // Check for errors
      printf("ERROR; return code from pthread_create() is %d\n", rc);
      exit(-1);
    }
  }
  pthread_exit(0);
}
```

```
lucid@ubuntu:~/Downloads/threads$ ./P1
Thread 2: Spanish: Hola al mundo
Thread 3: Klingon: Nuq neH!
Thread 4: German: Guten Tag, Welt!
Thread 1: French: Bonjour, le monde!
Thread 0: English: Hello World!
lucid@ubuntu:~/Downloads/threads$
```

```c
void *PrintHello(void *threadid) {
   int *myarg;
   sleep(1);                       // Sleep for a second
   myarg = (int *) threadid;       // Get own id from the argument
   printf("Thread %d: %s\n", *myarg, messages[*myarg]);
   pthread_exit(NULL);
}
```

A Not So Simple pthreads Example

pthread2.c

```c
int main(int argc, char *argv[]) {
  pthread_t threads[NUM_THREADS];
  int rc, i, sum;

  sum=0;
  messages[0] = "English: Hello World!";
  messages[1] = "French: Bonjour, le monde
  messages[2] = "Spanish: Hola al mundo";
  messages[3] = "Klingon: Nuq neH!";
  messages[4] = "German: Guten Tag, Welt!"

  for(i=0; i<NUM_THREADS; i++) {
    // Initialize arguments to a thread
    sum = sum + i;
    thread_data_array[i].thread_id = i;
    thread_data_array[i].sum = sum;
    thread_data_array[i].message = messages[i];
    // Create a thread
    rc = pthread_create(&threads[i], NULL, PrintHello, &thread_data_array[i]);
    if (rc) {
      printf("ERROR; return code from pthread_create() is %d\n", rc);
      exit(-1);
    }
  }
  pthread_exit(NULL);
}
```

```c
void *PrintHello(void *threadarg) {
  int myid, sum;
  char *hello_msg;
  struct thread_data *my_data;

  sleep(1);
  my_data = (struct thread_data *) threadarg;
  myid = my_data->thread_id;
  sum = my_data->sum;
  hello_msg = my_data->message;
  printf("Thread %d: %s  Sum=%d\n", myid, hello_msg, sum);
  pthread_exit(NULL);
}
```

```
lucid@ubuntu:~/Downloads/threads$ ./P2
Thread 3: Klingon: Nuq neH!  Sum=6
Thread 4: German: Guten Tag, Welt!  Sum=10
Thread 2: Spanish: Hola al mundo  Sum=3
Thread 1: French: Bonjour, le monde!  Sum=1
Thread 0: English: Hello World!  Sum=0
lucid@ubuntu:~/Downloads/threads$
```


Win32 API Multithreaded C Program

```c
#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;
   /* perform some basic error checking */
   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;
   }
```

Win32 API 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);
    }
}
```

Figure 4.10 Multithreaded C program using the Win32 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);
  }
}
```


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 {
     // 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
- **Thread cancellation** of **target thread**
  - Asynchronous or deferred
- **Signal** handling
  - Synchronous and asynchronous

Threading Issues (Cont.)

- **Thread pools**
- **Thread-specific data**
  - Create Facility needed for data private to thread
- **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 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

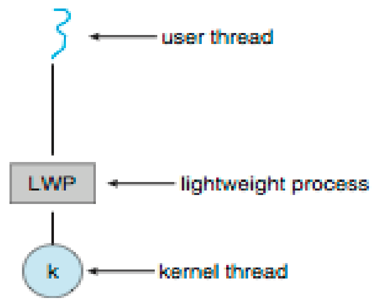
Thread Specific Data

- 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)

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

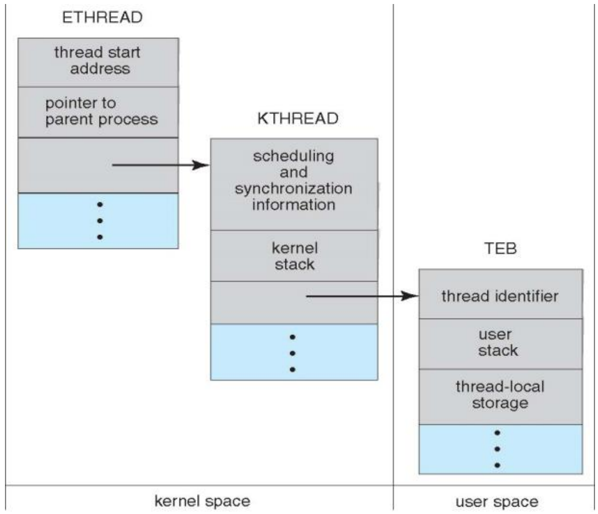
Lightweight Processes



Operating System Examples

- Windows XP Threads
- Linux Thread

Windows XP Threads Data Structures



Windows XP Threads

- Implements the one-to-one mapping, kernel-level
- 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)
- `struct task_struct` points to process data structures (shared or unique)

Linux Threads

- `fork()` and `clone()` system calls
- Doesn't distinguish between process and thread
  - Uses term *task* rather than thread
- `clone()` takes options to determine sharing on process create
- `struct task_struct` points to process data structures (shared or unique)

flag	meaning
CLONE_FS	File-system information is shared.
CLONE_VM	The same memory space is shared.
CLONE_SIGHAND	Signal handlers are shared.
CLONE_FILES	The set of open files is shared.

End of Chapter 4