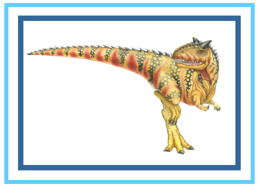
Chapter 4: Threads



Chapter 4: Threads

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

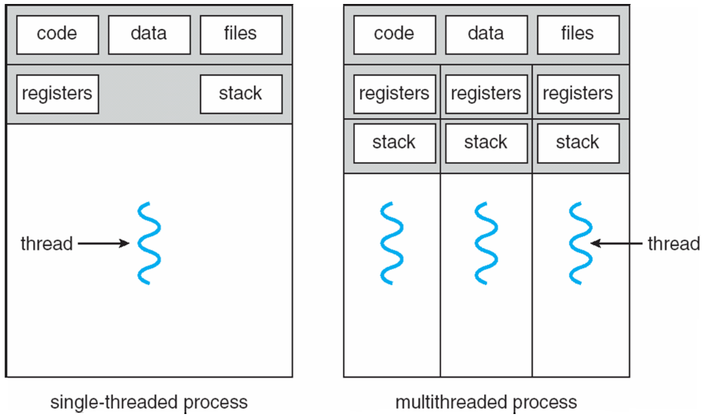
Objectives

- 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



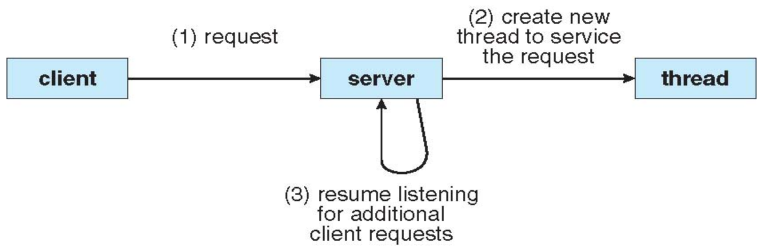
Benefits

- Responsiveness
- Resource Sharing
- Economy
- Scalability

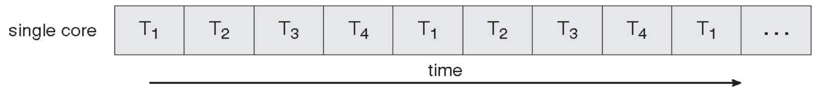
Multicore Programming

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

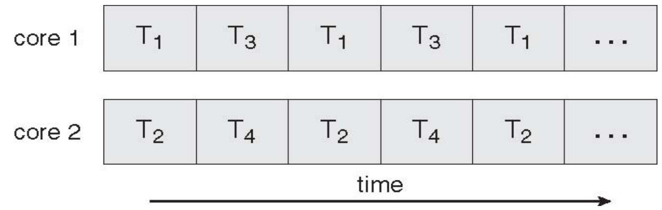
Multithreaded Server Architecture



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

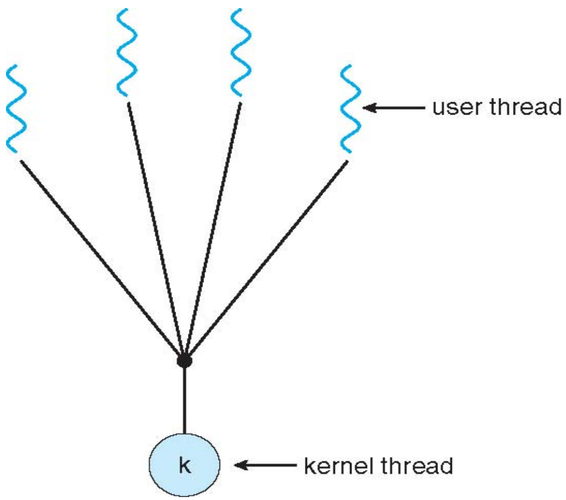
Multithreading Models

- 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**

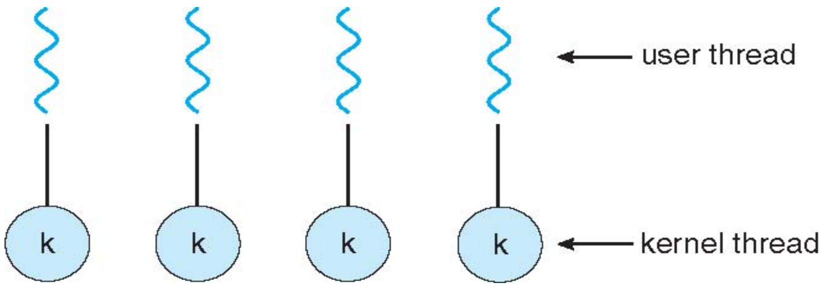
Many-to-One Model



One-to-One

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

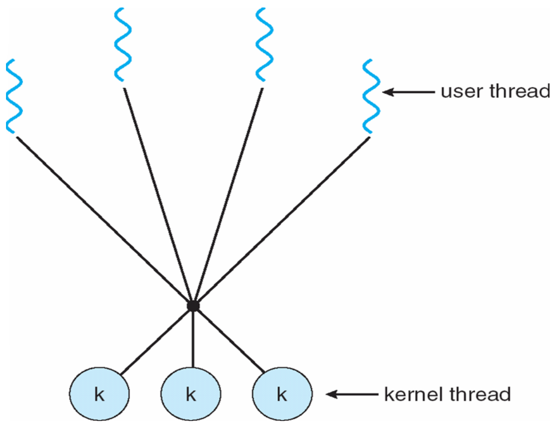
One-to-one Model



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

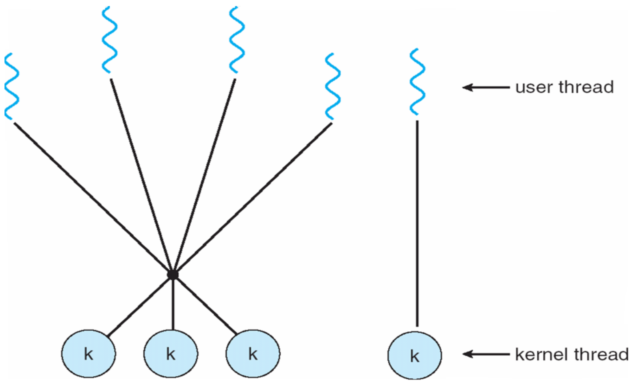
Many-to-Many Model



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.)

```
    /* 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.

Win32 API 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;
   /* 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);
    }
}
```


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 {
        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>"); }
}
```


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

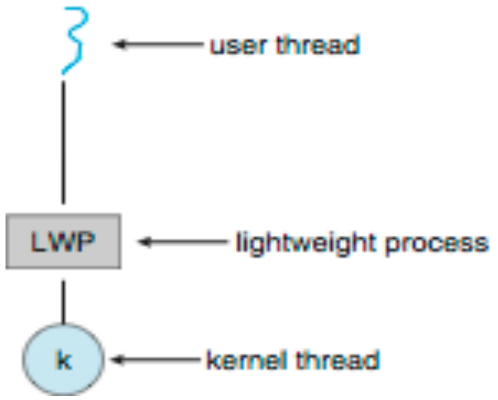
Thread Specific Data

- 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



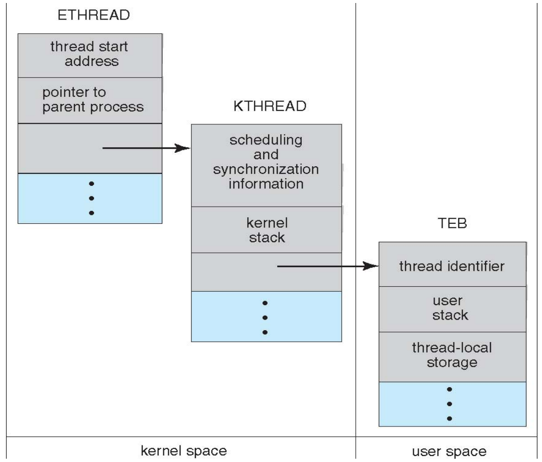
Operating System Examples

- Windows XP Threads
- Linux Thread

Windows XP Threads

- 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)

Windows XP Threads Data Structures



Linux Threads

- Provides `fork()` and `clone()` system calls
  - `fork()`: traditional functionality of duplicating a process
  - `clone()`: create thread and allows a child task to share the address space of the parent task (process)
- Doesn't distinguish between process and thread; uses the term ***task*** —rather than ***process*** or ***thread***
- Unique kernel data structure `(struct task_struct)` exists for each task in the system

Linux Threads

- Data of new task
  - `fork()`: new task is created; copy of all the associated data structures of the parent process
  - `clone()` : new task is created and **points** to the data structures of the parent task, depending on the set of flags passed to clone()
  - if none of these flags is set: no sharing takes place, functionality similar to that provided by the fork() system call

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