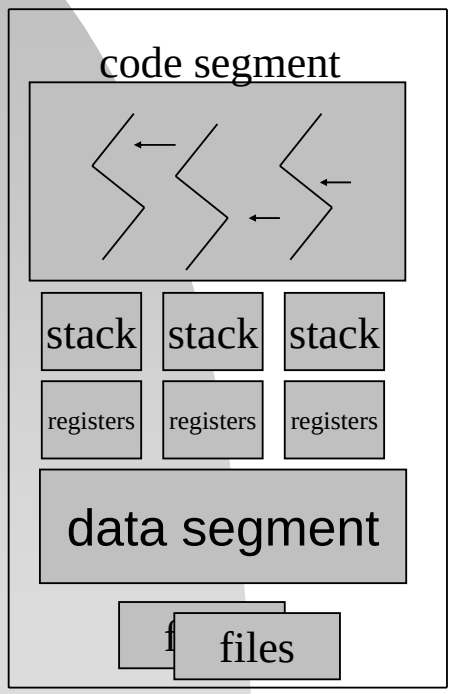
Chapter 4
Multithreaded Programming

Threads

- Objectives:
  - Concepts and issues associated with multithreaded computer systems.
- Thread – Lightweight process(LWP)
  - a basic unit of CPU utilization
    - A thread ID, program counter, a register set, and a stack space
  - Process – heavyweight process
    - A single thread of control

Threads

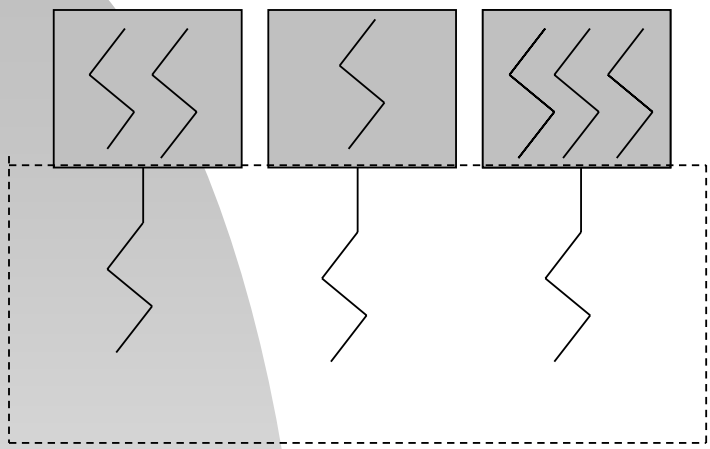


- Motivation
  - A web browser
    - Data retrieval
    - Text/image displaying
  - A word processor
    - Displaying
    - Keystroke reading
    - Spelling and grammar checking
  - A web server
    - Clients' services
    - Request listening

Threads

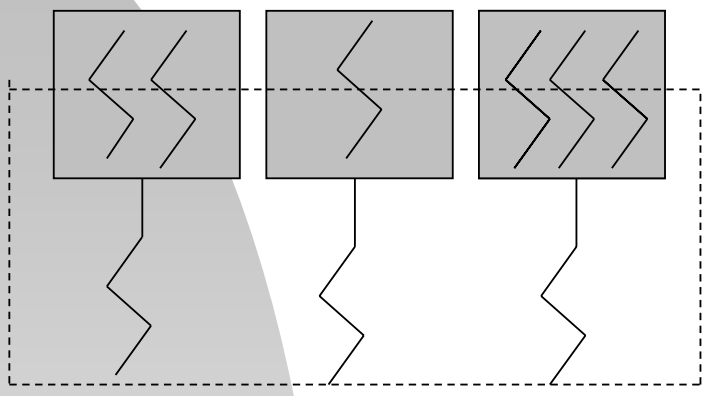
- Benefits
  - Responsiveness
  - Resource Sharing
  - Economy
    - Creation and context switching
      - 30 times slower in process creation in Solaris 2
      - 5 times slower in process context switching in Solaris 2
  - Utilization of Multiprocessor Architectures

User-Level Threads



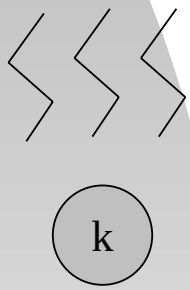
- User-level threads are implemented by a thread library at the user level.
- Examples:
  - POSIX Pthreads, Mach C-threads, Solaris 2 UI-threads
- Advantages
  - Context switching among them is extremely fast
- Disadvantages
  - Blocking of a thread in executing a system call can block the entire process.

Kernel-Level Threads



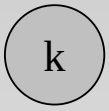
- Kernel-level threads are provided a set of system calls similar to those of processes
- Examples
  - Windows 2000, Solaris 2, True64UNIX
- Advantage
  - Blocking of a thread will not block its entire task.
- Disadvantage
  - Context switching cost is a little bit higher because the kernel must do the switching.

Multithreading Models



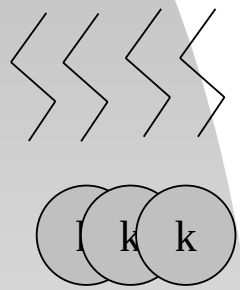
- Many-to-One Model
  - Many user-level threads to one kernel thread
  - Advantage:
    - Efficiency
  - Disadvantage:
    - One blocking system call blocks all.
    - No parallelism for multiple processors
  - Example: Green threads for Solaris 2

Multithreading Models



- One-to-One Model
  - One user-level thread to one kernel thread
  - Advantage: One system call blocks one thread.
  - Disadvantage: Overheads in creating a kernel thread.
  - Example: Windows NT, Windows 2000, OS/2

Multithreading Models



- Many-to-Many Model
  - Many user-level threads to many kernel threads
  - Advantage:
    - A combination of parallelism and efficiency
  - Example: Solaris 2, IRIX, HP-UX,Tru64 UNIX

Thread Libraries

- Goal: Provide an API for creating and managing threads!
- Two Approaches:
  - User Thread Library
  - Kernel-Level Thread Library
- Well-Known Examples
  - POSIX Pthreads – User or Kernel Level
  - Win32 threads – Kernel Level
  - Java threads – Level Depending on the Thread Library on the Host System

Pthreads

- Pthreads (IEEE 1003.1c)
  - API Specification for Thread Creation and Synchronization
  - UNIX-Based Systems, Such As Solaris 2.
- User-Level Library (??)
- Header File: <pthread.h>
- pthread_attr_init(), pthread_create(), pthread_exit(), pthread_join(), etc.

Pthreads

```
#include <pthread.h>
main(int argc, char *argv[]) {
    …
    pthread_attr_init(&attr);
    pthread_create(&tid, &attr, runner, argv[1]);
    pthread_join(tid, NULL);
… }

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

Win32 Threads

- Kernel-Level Threads

```
DWORD Sum; /* shared by threads */
DWORD WINAPI Summation(LPVOID Param) {
        DWOR Upper = *(DWORD *) Param;
        for (DWORD I = 0; I <= Upper; i++)
                Sum += i';
        return 0; }
Int main(int argc, char *argv[]) {
…
        Param = atoi(argv[1]);
…
        ThreadHandle = CreateThread(
          NULL, // default security attributes
          0, // default stack size
          Summation, // thread function
          &Param, // parameter
          0, // default creation flags
          &ThreadID);
…
        WaitForSingleObject(ThreadHandle, INFINITE);
… }
```


Java

- Thread Support at the Language Level
  - Mapping of Java Threads to Kernel Threads on the Underlying OS?
    - Windows 2000: 1:1 Model
- Thread Creation
  - Create a new class derived from the Thread class
  - Run its start method
    - Allocate memory and initialize a new thread in the JVM
    - start() calls the run method, making the thread eligible to be run by the JVM.

Java

```
class Summation extends Thread
  { public Summation(int n) {
          upper = n; }
     public void run() {
          int sum = 0;
          … }
    …}
public class ThreadTester
{ …
    Summation thrd = new
    Summation(Integer.ParseInt(args[0]));
    thrd.start();
…}
```


Threading Issues

- Fork and Exec System Calls
  - Fork: Duplicate all threads or create a duplicate with one thread?
  - Exec: Replace the entire process, including all threads and LWPs.
  - Fork → exec?

Threading Issues

- Thread Cancellation
  - Target thread
  - Two scenarios:
    - Asynchronous cancellation
    - Deferred cancellation
      - *Cancellation points* in Pthread.
  - Difficulty
    - Resources have been allocated to a cancelled thread.
    - A thread is cancelled while it is updating data.

Threading Issues

- Signal Handling
  - Signal
    - Synchronous – delivered to the same process that performed the operation causing the signal,
      - e.g., illegal memory access or division by zero
    - Asynchronous
      - e.g., ^C or timer expiration
  - Default or user-defined signal handler
  - Signal masking

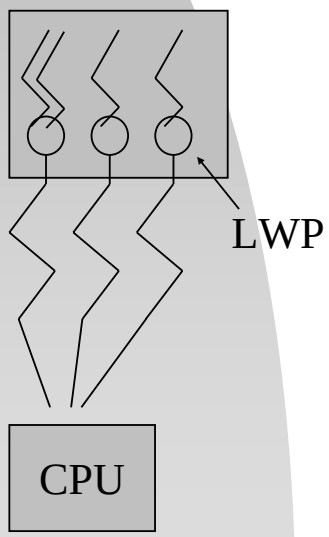
Threading Issues

- Delivery of a Signal
  - To the thread to which the signal applies
    - e.g., division-by-zero
  - To every thread in the process
    - e.g., ^C
  - To certain threads in the process
  - Assign a specific thread to receive all threads for the process
    - Solaris 2
- Asynchronous Procedure Calls (APCs)
  - To a particular thread rather than a process

Threading Issues

- Thread Pools
  - Motivations
    - Dynamic creation of threads
    - Limit on the number of active threads
  - Awake and pass a request to a thread in the pool
  - Benefits
    - Faster for service delivery and limit on the # of threads
  - Dynamic or static thread pools
- Thread-specific data – Win32 & Pthreads

Scheduler Activations



- Definition: A scheme for communication between the user-thread library and the kernel
  - The kernel provides an application with a set of virtual processors, i.e., light weight processes (LWP's)
    - An upcall handler to stop or resume the execution of a thread
  - User threads on a LWP are blocked if any of the user threads is blocked!

Windows XP

- Win32 API
  - One-to-One Model
  - Fiber Library for the M:M Model
- A Thread Contains
  - A Thread ID
  - Context: A Register Set, A User Stack, A Kernel Stack, A Private Storage Space for Run-Time Libraries, and DLL's

Windows XP

- Data Structures
  - ETHREAD (executive thread block)
    - A ptr to the process,a ptr to KTHREAD, the address of the starting routine
  - KTHREAD (kernel thread block)
    - Scheduling and synchronization information, a kernel stack, a ptr to TEB
  - TEB (thread environment block)
    - A user stack, an array for thread-specific data.

Kernel Space

User Space

Linux

- Threads introduced in Version 2.2
  - clone() versus fork()
    - Term task for process& thread
    - Several per-process data structures, e.g., pointers to the same data structures for open files, signal handling, virtual memory, etc.
    - Flag setting in clone() invocation.
      - CLONE_FS, CLONE_VM, CLONE_SIGHAND, CLONE_FILES
        - Setting → Threads or Processes