Chapter 4: Multithreaded Programming

- 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
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

1. request
2. create new thread to service the request
3. resume listening for additional client requests

Concurrent Execution on a Single-core System

Single core: T1, T2, T3, T4, T1, T2, T3, T4, T1, ...

Time
### Parallel Execution on a Multicore System

<table>
<thead>
<tr>
<th>core 1</th>
<th>T₁</th>
<th>T₃</th>
<th>T₁</th>
<th>T₃</th>
<th>T₁</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>core 2</td>
<td>T₂</td>
<td>T₄</td>
<td>T₂</td>
<td>T₄</td>
<td>T₂</td>
<td>...</td>
</tr>
</tbody>
</table>

#### 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

- User thread
- Kernel thread
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
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).
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

Threading Issues

- Semantics of `fork()` and `exec()` system calls
- Thread cancellation of target thread
  - Asynchronous or deferred
- Signal handling
- Thread pools
- Thread-specific data
- 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 a 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
Operating System Examples

- Windows XP Threads
- Linux Thread

Windows XP Threads

![Diagram of ETHREAD and KTHREAD structures with TEB and kernel/user space]

- ETHREAD includes:
  - thread start address
  - pointer to parent process

- KTHREAD includes:
  - scheduling and synchronization information
  - kernel stack

- TEB includes:
  - thread identifier
  - user stack
  - thread-local storage

Kernel space

User space
### Linux Threads

<table>
<thead>
<tr>
<th>flag</th>
<th>meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLONE_FS</td>
<td>File-system information is shared.</td>
</tr>
<tr>
<td>CLONE_VM</td>
<td>The same memory space is shared.</td>
</tr>
<tr>
<td>CLONE_SIGHAND</td>
<td>Signal handlers are shared.</td>
</tr>
<tr>
<td>CLONE_FILES</td>
<td>The set of open files is shared.</td>
</tr>
</tbody>
</table>

### 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 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).

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End of Chapter 4