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Operating Systems (10th Ed., by A. Silberschatz)

Chapter 4 Threads & Concurrency

Heonchang Yu

Distributed and Cloud Computing Lab.

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- Overview
- Multicore Programming
- Multithreading Models
- Thread Libraries
- Implicit Threading
- Threading Issues
- Operating-System Examples

Objectives

- Identify the basic components of a thread, and contrast threads and processes.
- Describe the major benefits and significant challenges of designing multithreaded processes.
- Illustrate different approaches to implicit threading, including thread pools, fork-join, and Grand Central Dispatch.
- Describe how the Windows and Linux operating systems represent threads.
- Design multithreaded applications using the Pthreads, Java, and Windows threading APIs.

Overview

- Thread – a light-weight process
  - ✓ A basic unit of CPU utilization – It comprises a thread ID, a program counter (PC), a register set, and a stack.
  - ✓ It shares with other threads belonging to the same process its code section, data section, and other operating-system resources
  - ✓ An application is implemented as a separate process with several threads of control.
    - ❖ An application that creates photo thumbnails from a collection of images may use a separate thread to generate a thumbnail from each separate image.
    - ❖ A web browser might have one thread display images or text while another thread retrieves data from the network.
    - ❖ A word processor may have a thread for displaying graphics, another thread for responding to keystrokes from the user, and a third thread for performing spelling and grammar checking in the background.

Single and Multithreaded Processes

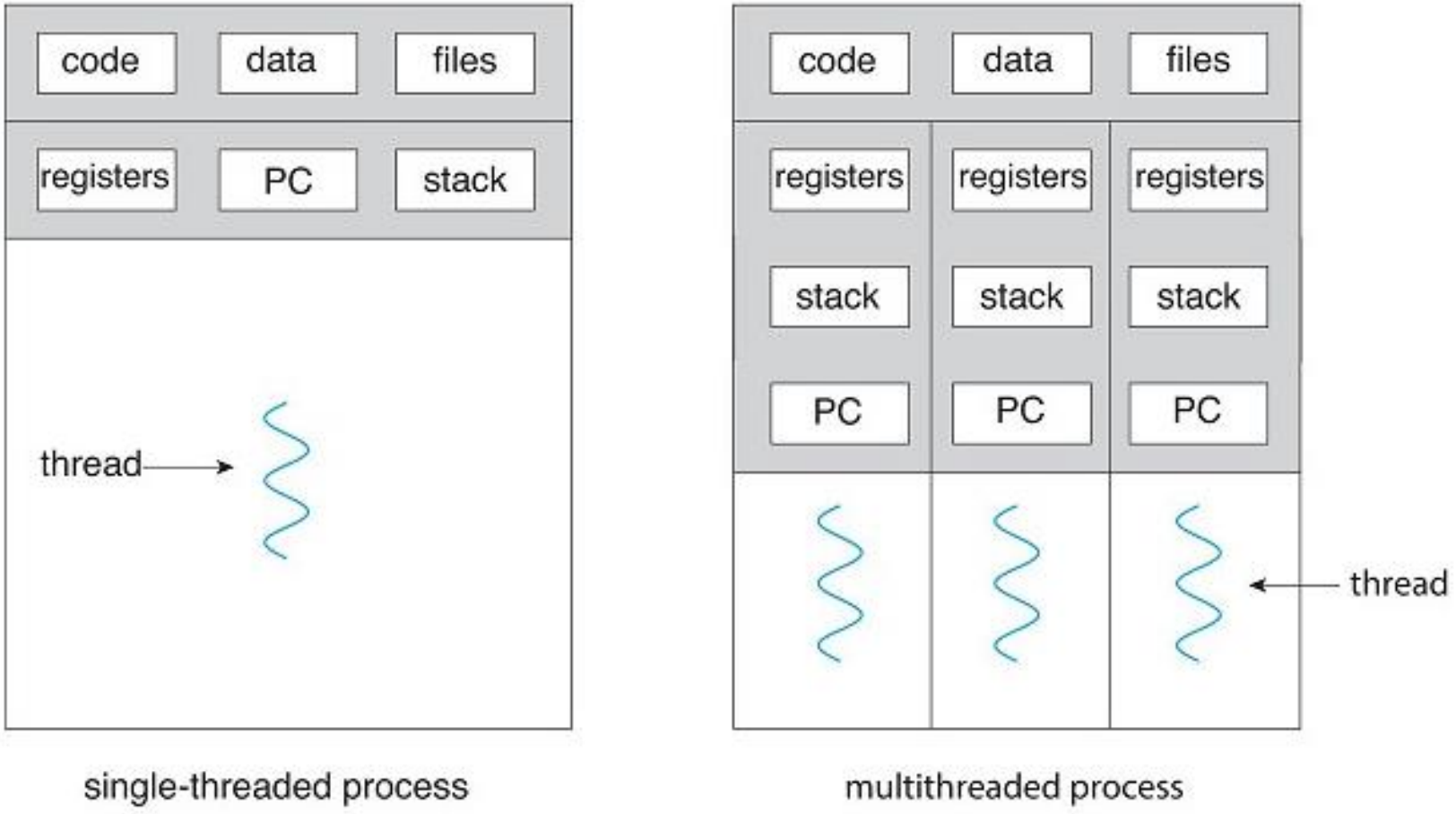


Figure 4.1 Single-threaded and multithreaded processes.

Overview

- ✓ A single application may be required to perform several similar tasks.
  - ❖ A web server accepts client requests for Web pages, images, sound, and so forth.
- ✓ One solution is to have the server run as a single process that accepts requests. When the server receives a request, it creates a separate process to service that request. – Process creation is time consuming and resource intensive.
- ✓ If the web-server process is multithreaded, the server will create a separate thread that listens for client requests.
- ✓ When a request is made, rather than creating another process, the server will create a new thread to service the request and resume listening for additional requests

Multithreaded Server Architecture

- Most operating system kernels are typically multithreaded.
  - ✓ As an example, during system boot time on Linux systems, several kernel threads are created. Each thread performs a specific task, such as managing devices, memory management, or interrupt handling.

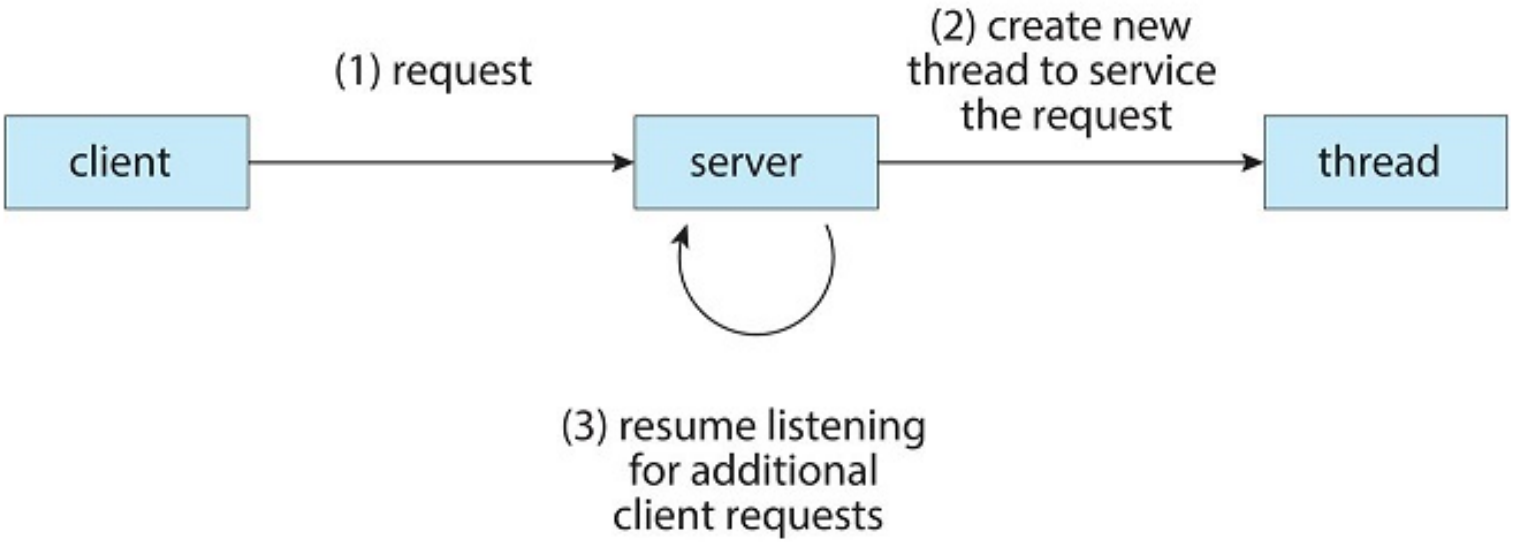


Figure 4.2 Multithreaded server architecture.

Overview

- Benefits
  - Responsiveness
    - ✓ To continue running even if part of it is blocked or is performing a lengthy operation
  - Resource Sharing
    - ✓ Processes can share resources only through techniques such as shared memory and message passing.
  - Economy
    - ✓ Because threads share the resources of the process to which they belong, it is more economical to create and context-switch threads
  - Scalability
    - ✓ Can be even greater in a multiprocessor architecture, where threads may be running in parallel on different processing cores

Multicore Programming

– Multicore Programming

- Multithreaded programming provides a mechanism for more efficient use of multiple computing cores and improved concurrency.
- On a system with a single computing core
  - ✓ Concurrency means that the execution of the threads will be interleaved over time, because the processing core is capable of executing only one thread at a time.
- On a system with multiple cores
  - ✓ Concurrency means that some threads can run in parallel, because the system can assign a separate thread to each core
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** supports more than one task by allowing all the tasks to make progress

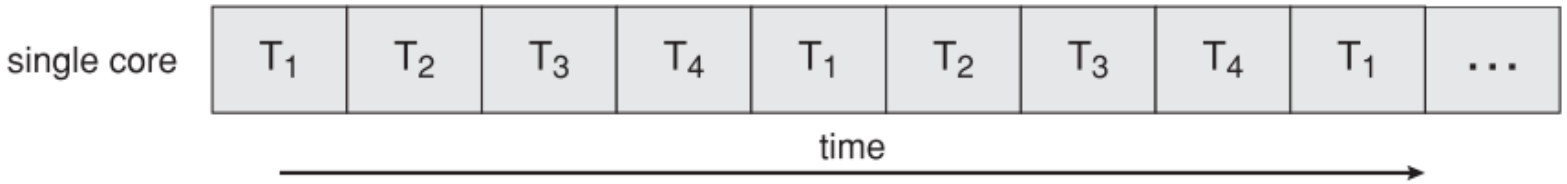


Figure 4.3 Concurrent execution on a single-core system.

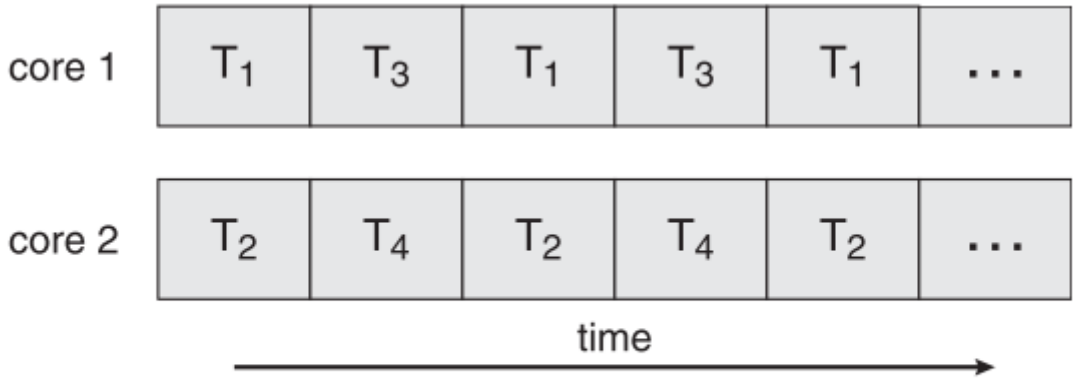


Figure 4.4 Parallel execution on a multicore system.

Multicore Programming

– Five areas present challenges in programming for multicore system

- Identifying tasks
  - ✓ To find areas that can be divided into separate, concurrent tasks
- Balance
  - ✓ Ensure that the tasks perform equal work of equal value
- Data splitting
  - ✓ The data accessed and manipulated by the tasks must be divided to run on separate cores
- Data dependency
  - ✓ The data accessed by the tasks must be examined for dependencies between two or more tasks
- Testing and debugging
  - ✓ Testing and debugging such concurrent programs is inherently more difficult than testing and debugging single-threaded applications

Multicore Programming – Types of Parallelism

- Data parallelism – distributing subsets of the same data across multiple computing cores and performing the same operation on each core
- Task parallelism – distributing not data but tasks (threads) across multiple computing cores

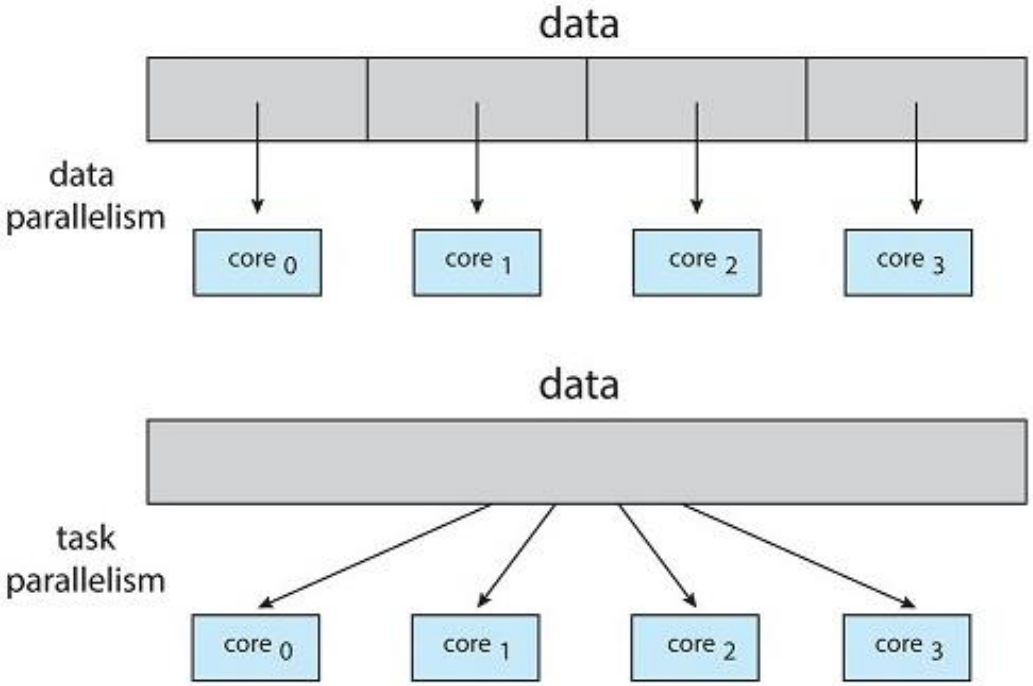


Figure 4.5 Data and task parallelism.

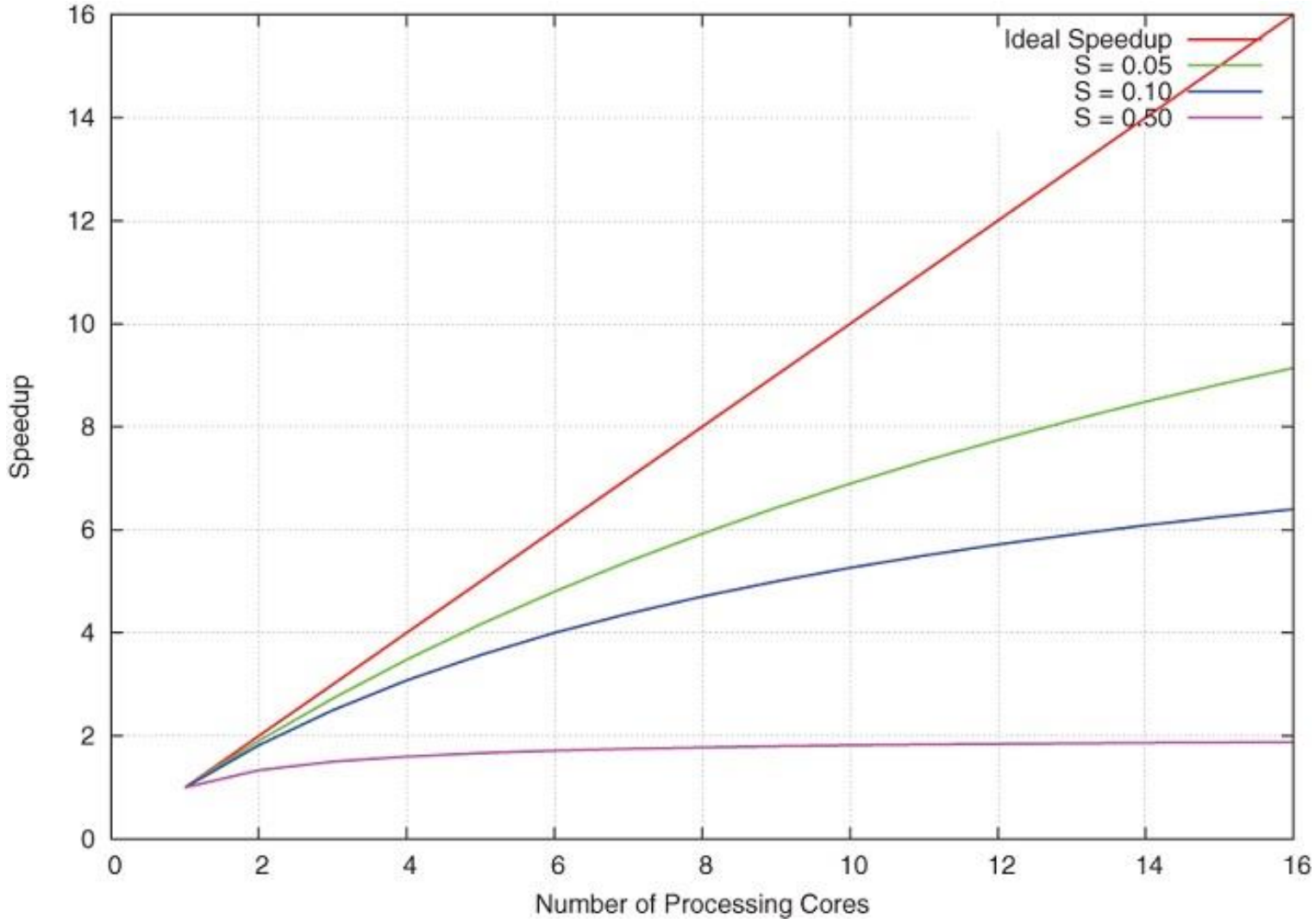
Amdahl's Law

- Identifies performance gains from adding additional computing cores to an application that has both serial and parallel components
- *S* is the portion of the application that must be performed serially on a system with *N* processing cores

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

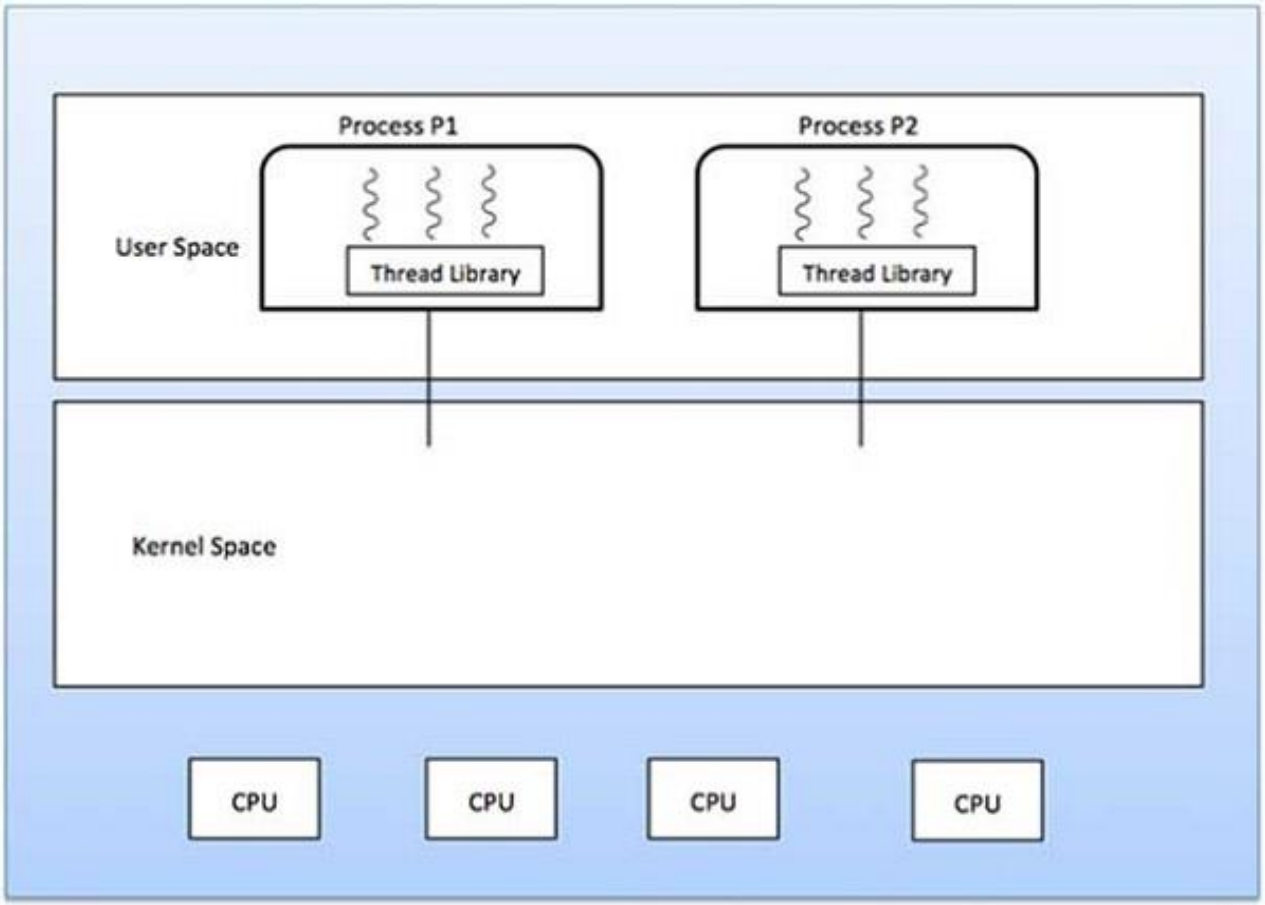
- If application is 75% parallel / 25% serial, moving from 1 to 2 cores results in speedup of 1.6 times
- As *N* approaches infinity, the speedup converges to 1 / *S*.
  Serial portion of an application can have a disproportionate effect on the performance gained by adding additional computing cores.
- Some argue that Amdahl's law does not take into account the hardware performance enhancements used in the design of contemporary multicore systems.

Amdahl's Law


Ideal Speedup
S = 0.05
S = 0.10
S = 0.50
Speedup
Number of Processing Cores
0
2
4
6
8
10
12
14
16

Multithreading Models

- User threads
  - Supported above the kernel and are managed without kernel support



Multithreading Models

- User threads
  - Thread library contains code for creating and destroying threads, for passing message and data between threads, for scheduling thread execution and for saving and restoring thread contexts.
- Advantages
  - Thread switching does not require kernel mode privileges.
  - User threads can run on any operating system.
  - User threads are fast to create and manage.
- Disadvantages
  - The entire process is blocked if one user thread performs blocking operation.
  - Multithreaded application cannot take advantage of multiprocessing.

Multithreading Models

- Kernel threads
  - Supported and managed directly by the operating system
- Advantages
  - Multiple threads of the same process can be scheduled on different processors in kernel threads.
  - If one thread in a process is blocked, the kernel can schedule another thread of the same process.
- Disadvantages
  - A mode switch to kernel mode is required to transfer control from one thread to another in a process.
  - Thread operations are hundreds of times slower compared to user threads.

Multithreading Models

– Many-to-One Model

- Maps many user-level threads to one kernel thread
- Because only one thread can access the kernel at a time, multiple threads are unable to run in parallel on multicore systems
- Examples:
  - ✓ Solaris Green Threads
- Very few systems continue to use the model because of its inability to take advantage of multiple processing cores.

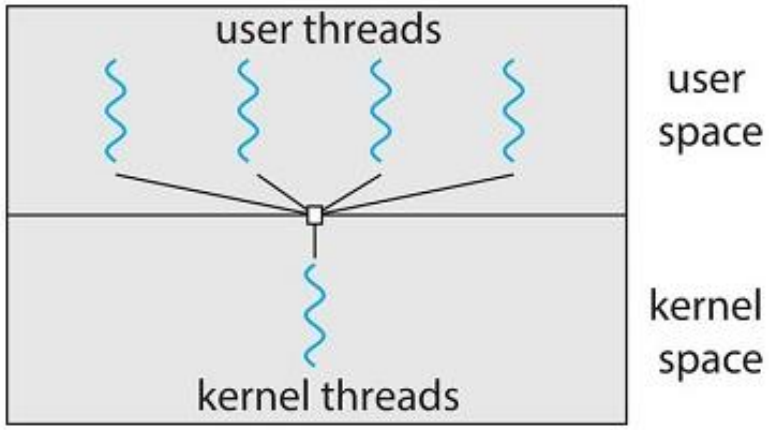


Figure 4.7 Many-to-one model.

Multithreading Models

– One-to-One Model

- Maps each user thread to a kernel thread
- It provides more concurrency than the many-to-one model
- To run in parallel on multiprocessors
- The only drawback to this model is that creating a user thread requires creating the corresponding kernel thread, and a large number of kernel threads may burden the performance of a system.
- Examples
  - ✓ Family of Windows OS
  - ✓ Linux

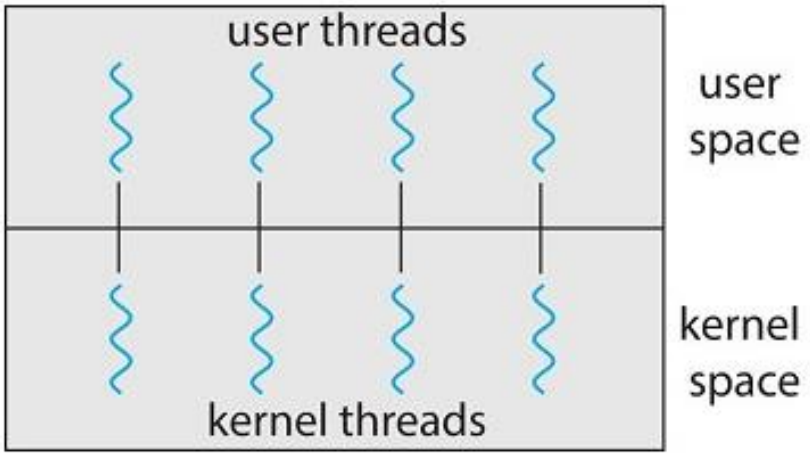


Figure 4.8 One-to-one model.

Multithreading Models

– Many-to-Many Model

- Multiplexes many user-level threads to a smaller or equal number of kernel threads
- The number of kernel threads may be specific to either a particular application or a particular machine.

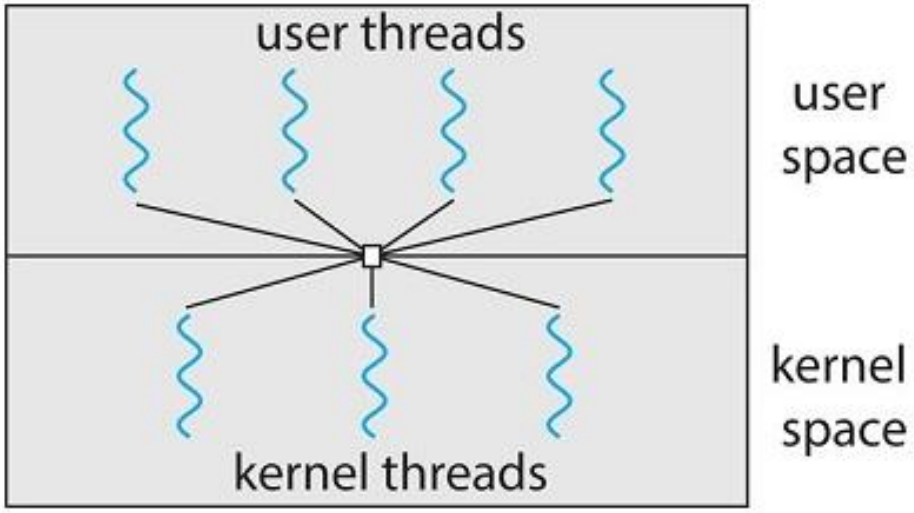


Figure 4.9 Many-to-many model.

Multithreading Models

– Many-to-Many Model

- Shortcomings of other models
  - ✓ Whereas the many-to-one model allows the developer to create as many user threads as she wishes, it does not result in parallelism, because the kernel can schedule only one thread at a time.
  - ✓ The one-to-one model allows greater concurrency, but the developer has to be careful not to create too many threads within an application
- The many-to-many model suffers from neither of these shortcomings:
  - ✓ Developers can create as many user threads as necessary, and the corresponding kernel threads can run in parallel on a multiprocessor.
  - ✓ Also, when a thread performs a blocking system call, the kernel can schedule another thread for execution.

Multithreading Models

– Two-level Model

- Multiplexes many user-level threads to a smaller or equal number of kernel threads but also allows a user-level thread to be bound to a kernel thread
- Example
  - ✓ Solaris 8 and earlier

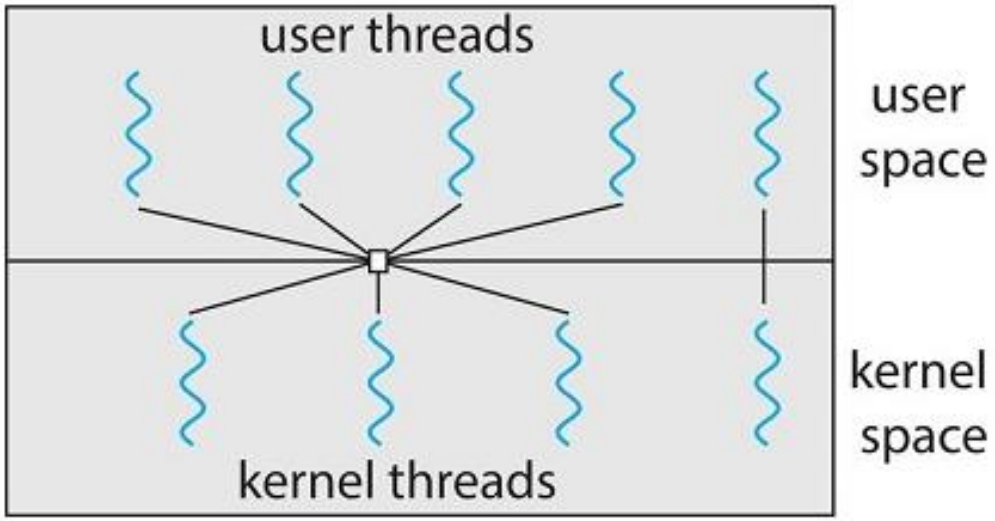


Figure 4.10 Two-level model.