Threads

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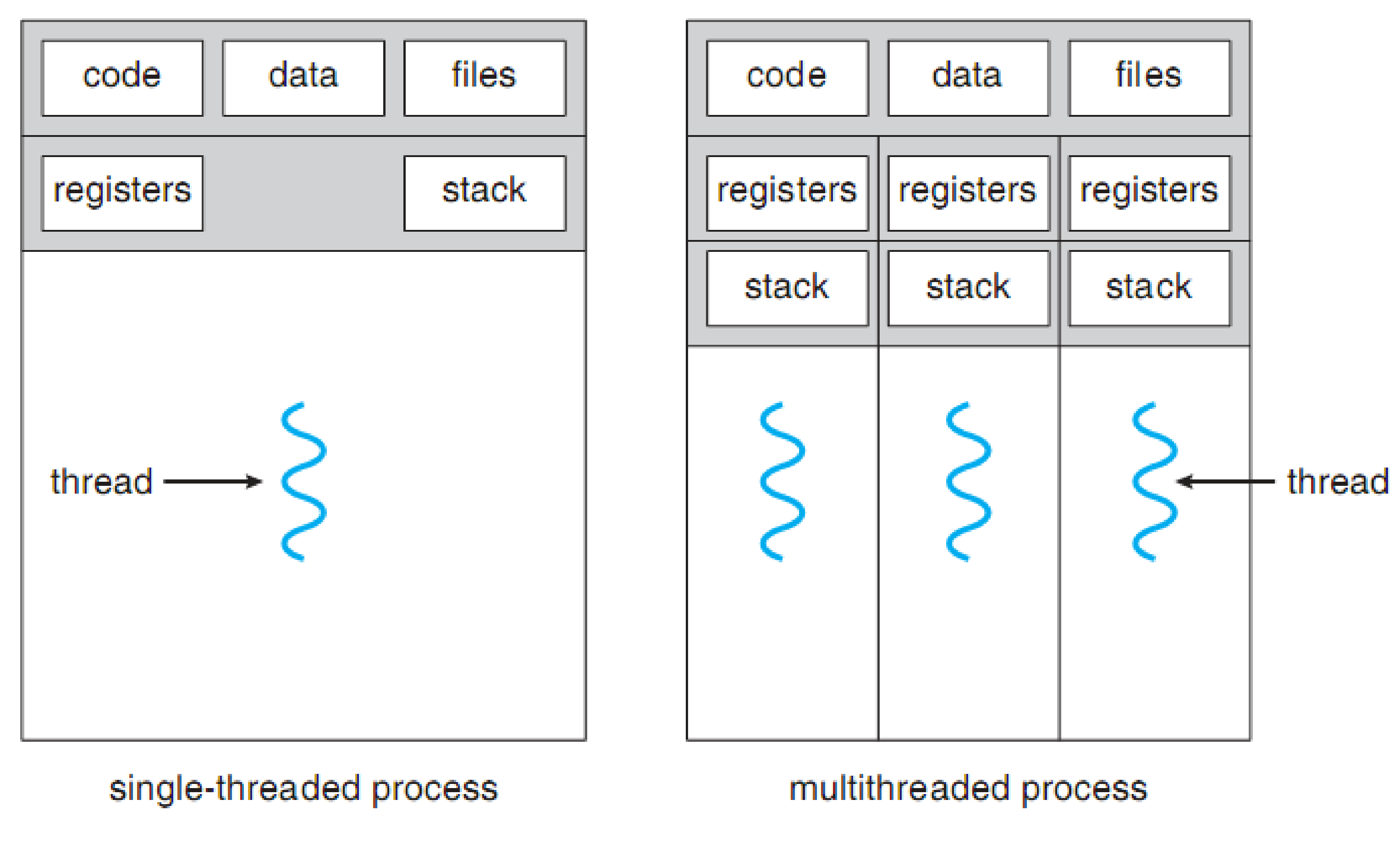
Definition

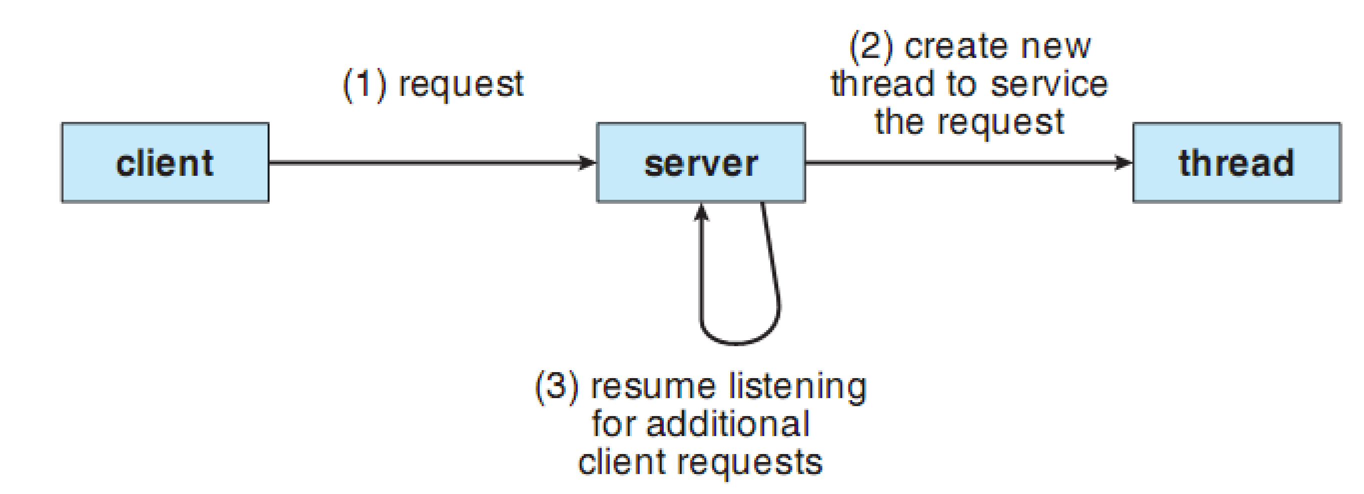
- What’s the difference between a thread and a process?
- Heavyweight process: A single thread process
- What a thread has for itself?
  - Thread-Specific Data
    - Thread ID
    - Program Counter
    - A register set
    - A stack

Single-threaded and Multithreaded Processes



Examples

- A Web server
- A RPC server
- Since the requests from these servers are similar, it is better to avoid creating new processes that may be much more costly



The Benefits of Multithreaded Programming

- Responsiveness
  - If a thread is blocked, other threads can continue
  - E.g., showing an image while getting text from the user in a web page
- Resource sharing
  - Threads share the memory and resources of the respective process (shared code and data)
- Economy
  - Allocating memory and resource to processes and their respective context-switch is more costly with respect to threads
  - Solaris: speed of process creation=1/30 speed of thread creation
  - Solaris: speed of process CS=1/5 speed of thread CS
- Utilization of multiprocessor architectures
  - No speed-up with a heavyweight process on a multiprocessor system
  - Concurrency with multithreaded processes on multiprocessor systems

Multicore Programming

- Amdahl's Law
  - S: The portion of the application that must be performed serially
  - N: the number of processing cores
    - Suppose that N goes to infinity!

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

Challenges in Programming for Multicore Systems

- **Identifying tasks**: Finding areas that can be divided into separate, concurrent tasks.
- **Balance**: Programmers must ensure that the tasks perform equal work of equal value to assign a core for which.
- **Data splitting**: The data accessed and manipulated by the tasks must also be divided to run on separate cores.
- **Data dependency**: When one task depends on data from another, programmers must ensure that the execution of the tasks is synchronized to accommodate the data dependency.
- **Testing and debugging**: When a program is running in parallel on multiple cores, many different execution paths are possible. Testing and debugging such concurrent programs is inherently more difficult.

Types of Parallelism

- **Data Parallelism**: Distributing subsets of the same data across multiple computing cores and performing the same operation on each core.
  - Example: Summing the contents of an array of size N.
- **Task Parallelism**: Distributing not data but tasks (threads) across multiple computing cores. Each thread is performing a unique operation.

In most instances, applications use a hybrid of these two strategies.

Multithreading Models

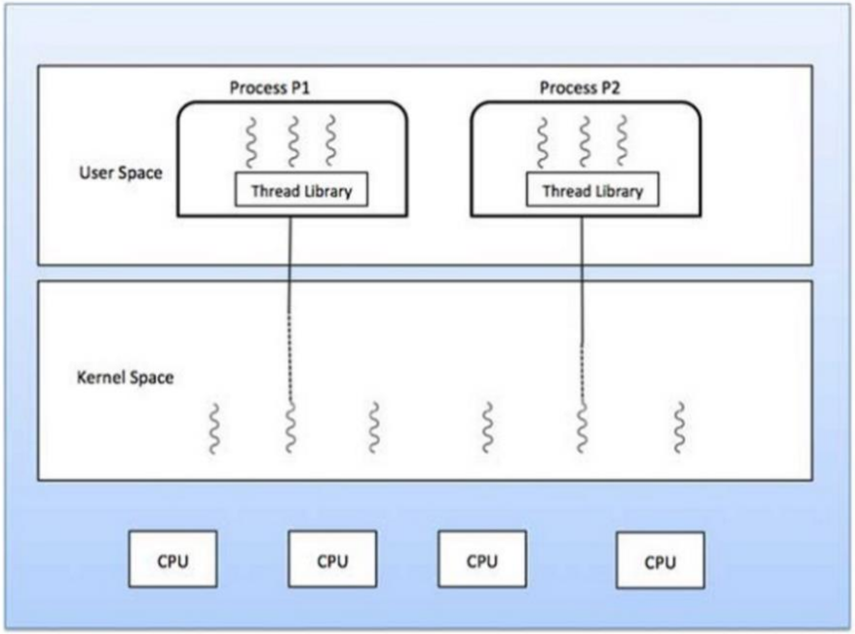
- *User threads* are supported above the kernel
- *Kernel threads* are supported and managed by the OS

Thread Libraries

- Pthreads (Book::P.173)
- Win32 threads
- Java threads

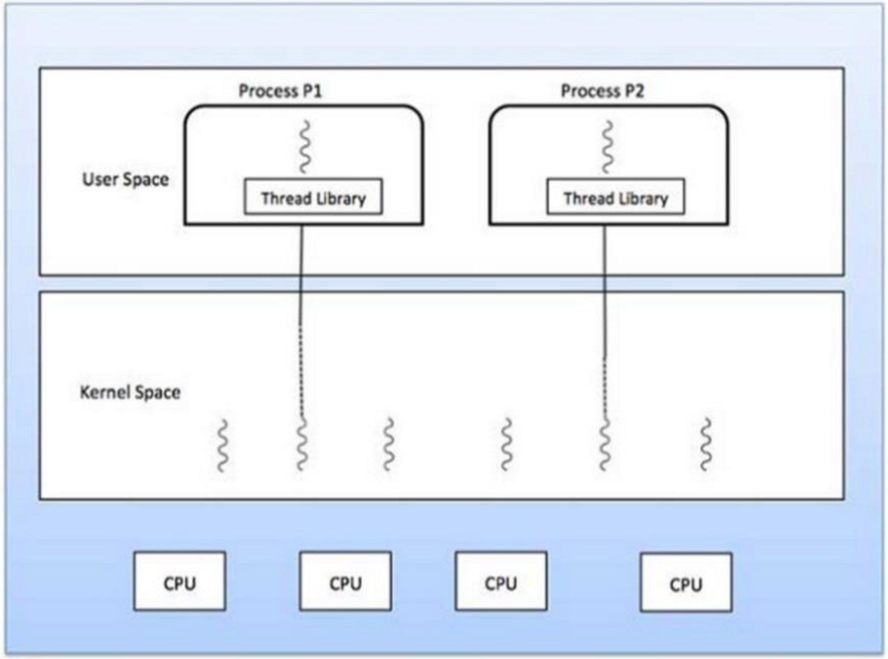
Many-to-One Model

- Benefit
  - Since thread management is in user space, it is efficient
- Disadvantage
  - A blocking system call will block the entire process
  - No benefit of using a multiprocessor system
- Examples
  - Green threads in Solaris
  - GNU Portable threads



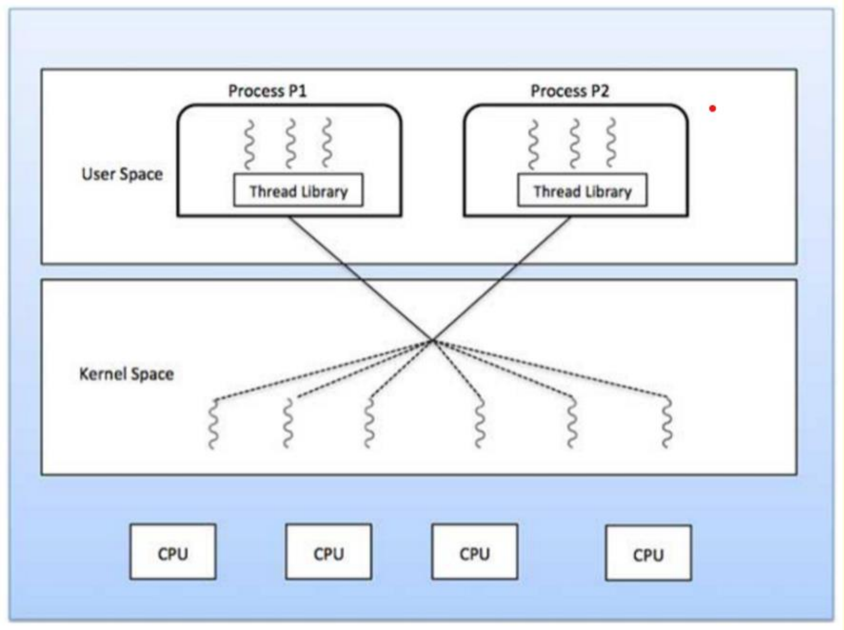
One-to-One Model

- Benefits
  - A blocking system call will not block the entire process
  - Multiple threads can run concurrently on a MP system
- Disadvantage
  - Creating a user thread requires creating a corresponding kernel thread which is costly and usually restricts the number of threads supported by the system
- Examples
  - Linux and the family of Windows

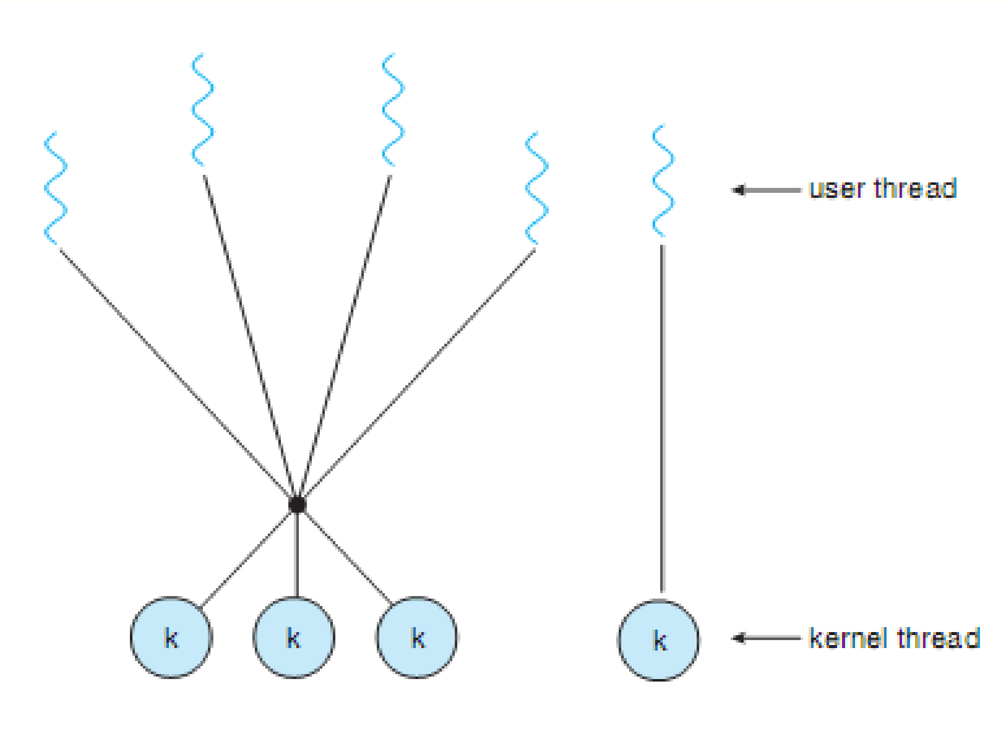


Many-to-Many Model

- Multiplexing (Tru64 UNIX)
  - No. of kernel threads ≤ no. of user threads
- Properties
  - As many user threads as necessary can be created
  - The corresponding kernel threads can run in parallel on a multiprocessor
  - When a thread performs a blocking system call, the kernel can schedule another thread



Two-Level Model



Differences Between User-Level and Kernel-Level Threads

S.N.	User-Level Threads	Kernel-Level Thread
1	User-level threads are faster to create and manage.	Kernel-level threads are slower to create and manage.
2	Implementation is by a thread library at the user level.	Operating system supports creation of Kernel threads.
3	User-level thread is generic and can run on any operating system.	Kernel-level thread is specific to the operating system.
4	Multi-threaded applications cannot take advantage of multiprocessing.	Kernel routines themselves can be multithreaded.

Implicit Threading

- To transfer the creation and management of threading from application developers to compilers and run-time libraries.
- Thread Pools
- OpenMP
- GCD: Grand Central Dispatch
- …

Threading Issues

- The fork() and exec() system calls
  - After calling fork(), does the new process duplicates all threads, or is the new process single-threaded?
    - Two variation
  - What about exec()?
  - Which variation should be used if exec() is called immediately after forking?
    - Duplicating is not necessary!

Thread Cancellation

- Asynchronous cancellation
  - One thread immediately cancels the target thread
  - *Problem*: if resources have been allocated to a cancelled thread or is updating some shared data
- Deferred cancellation
  - The target thread periodically checks whether it should terminate
  - Safe cancellation in *cancellation points*

Signal Handling

- Synchronous signal
  - Delivered to the same process that performed the operation that caused the signal (division by 0)
- Asynchronous signal
  - Generated by an external event (e.g., a timer expiration)
- Signal handlers
  - *Default signal handler* is run by the kernel
  - *User-defined signal handler* overrides default handler

Options for Delivering a Signal

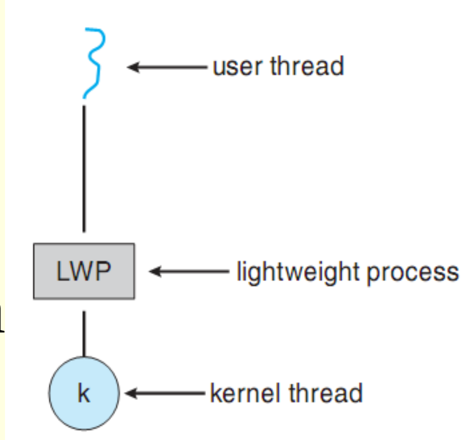
- To the thread to which the signal applies
- To every thread in the process
- To certain threads in the process
- Assign a specific thread to receive all signals to the process

Thread Pools

- Creating a number of threads at process startup and place them into a pool
- Benefits
  - Faster than waiting for creating a thread
  - Limiting the number of threads of each process

Scheduler Activation

- For communication between the kernel and the thread library
  - Many-to-many and two-level models
- LWP: Lightweight Process
  - An intermediate data structure between the user and kernel threads



  - Similar to a virtual processor for the user-thread library
  - Each LWP is attached to a kernel-level thread
  - If the kernel thread blocks, the LWP blocks as well

Number of LWPs

- Assume a CPU-bound application running on a single processor
  - Only one thread can run at once, so one LWP is sufficient
- Assume an IO-bound application
  - One LWP is required for each concurrent blocking system call

How Scheduler Activation Works?

- Kernel informs an application about certain events through *upcalls*
- Upcalls are handled by the thread library with the respective *upcall handler* which is run on a virtual processor
- When a thread is about to block, the kernel makes an upcall and allocates a new virtual processor to the application
- The application runs an upcall handler on this new virtual processor that saves the state of the blocking thread
- The upcall handler schedules another thread on the new virtual processor