Processes and Threads

What is a program?

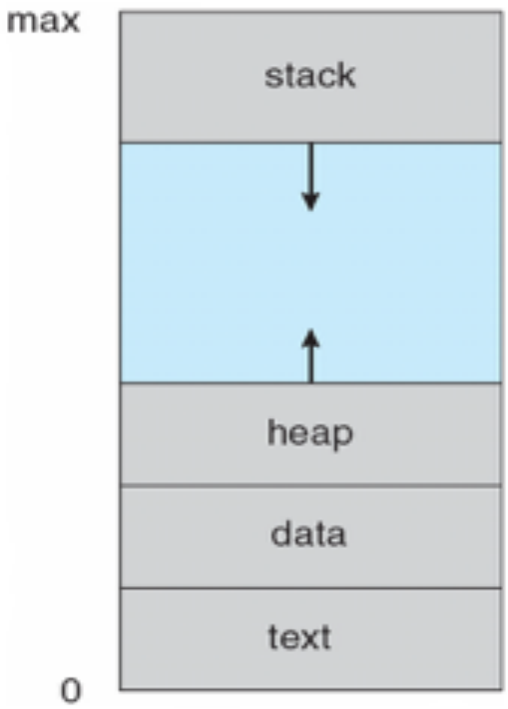
- A Program is an **executable file** that contains:
  - Code: Machine Instructions
  - Data: Variables Stored And Manipulated In Memory
    - initialized variables (globals)
    - dynamically allocated variables (malloc, new)
    - stack variables (C automatic variables, function arguments)
- Process != Program
- Example:
  - We can run 2 instances of *Mozilla Firefox*:
    - Same program
    - Separate processes

An analogy
Baking a Cake

- Need a cake recipe and a kitchen well stocked with all the input: flour, eggs, sugar ….
- the recipe is the program (i.e., an algorithm expressed in some suitable notation),
- the baker is the processor (CPU),
- and the cake ingredients are the input data.
- The process is the *activity* consisting of the baker reading the recipe, fetching the ingredients, and baking the cake.

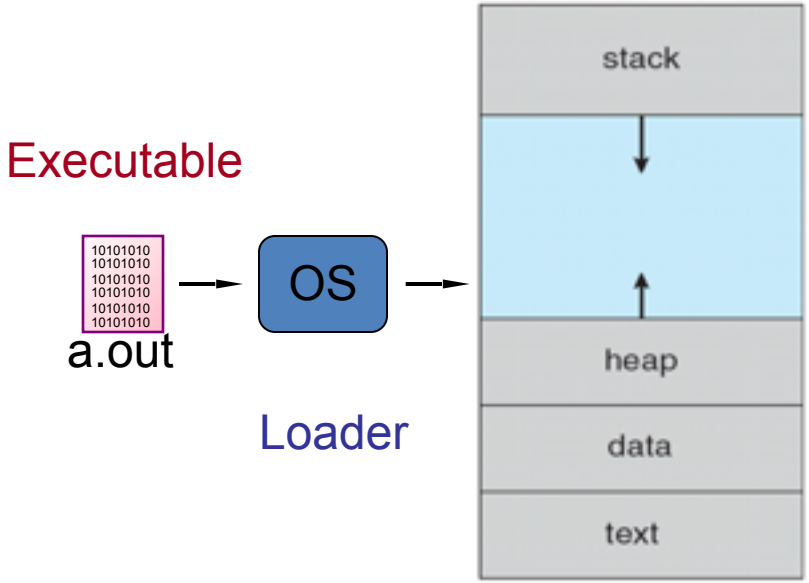
Process in Memory

- Program becomes process when executable file loaded into memory
- Process address space
  - set of all memory addresses accessible by a process



How Program Becomes Process

- When a program is launched
  - OS loads executable file of a program into memory
  - Creates kernel data structure for the process
  - Initializes data
  - Starts from an entry point (e.g., main())



Processes

- Multiple Parts
  - The Program Code, Also Called **Text Section**
  - Current Activity Including the current values of **PC**, Registers
  - **Stack** Containing Temporary Data
    - Function Parameters, Return Addresses, Local Variables
  - **Data Section** Containing Global Variables
  - **Heap** Containing Memory Dynamically Allocated During Run Time

Process Data Structures

- OS represents a process using a Process Control Block (*PCB*)
  - Has all the details of a process
  - Context of the process
  - Also called **process table entry**

Process Control Block (PCB)

Process management	Memory management	File management
Registers	Pointer to text segment	Root directory
Program counter	Pointer to data segment	Working directory
Program status word	Pointer to stack segment	File descriptors
Stack pointer		User ID
Process state		Group ID
Priority		
Scheduling parameters		
Process ID		
Parent process		
Process group		
Signals		
Time when process started		
CPU time used		
Children's CPU time		
Time of next alarm		

Figure: Fields of a PCB

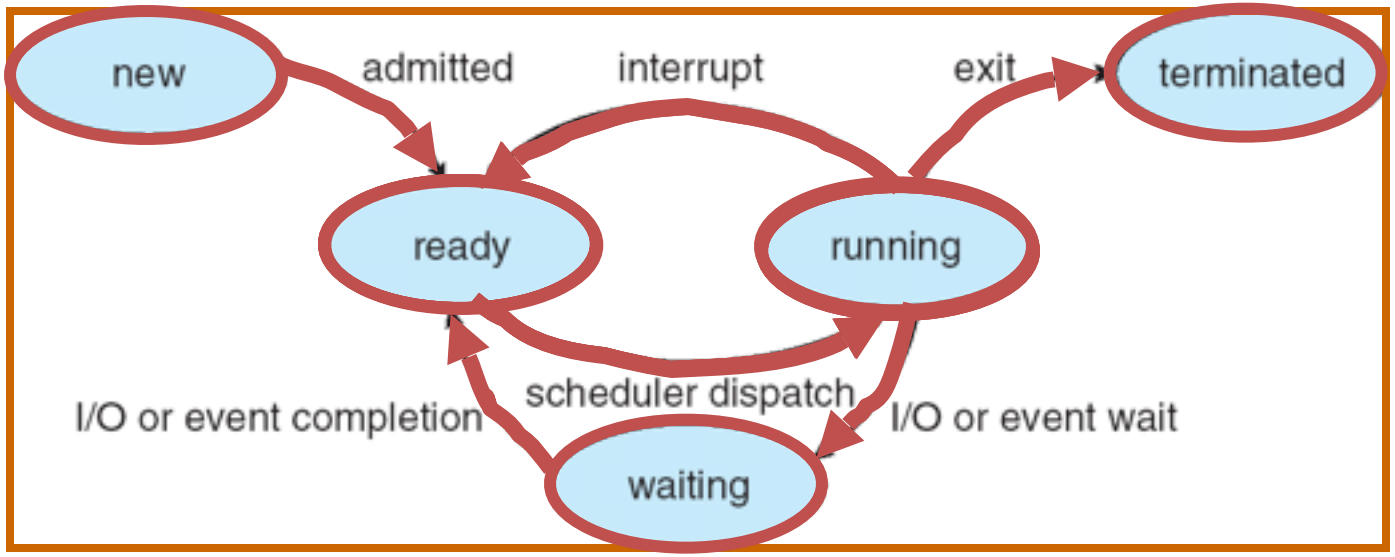
Process Creation

- Four principal events for process creation:
  - System initialization.
  - Execution of process creation system call by a running process.
  - A user can request to create a new process (typing a command or double clicking an icon).
  - Initiation of a batch job (possibly remotely).

Process Termination

- Nothing lasts forever, not even processes ☺️
- A process terminates usually due to
  - Normal exit (voluntary)
  - Error exit (voluntary)
  - Fatal error (involuntary)
  - Killed by another process (involuntary)

Lifecycle of a Process



- As a process executes, it changes *state*
  - new: The process is being created
  - ready: The process is waiting to run
  - running: Instructions are being executed
  - waiting (or, blocked): Process waiting for some event to occur
  - terminated: The process has finished execution

The Process Model

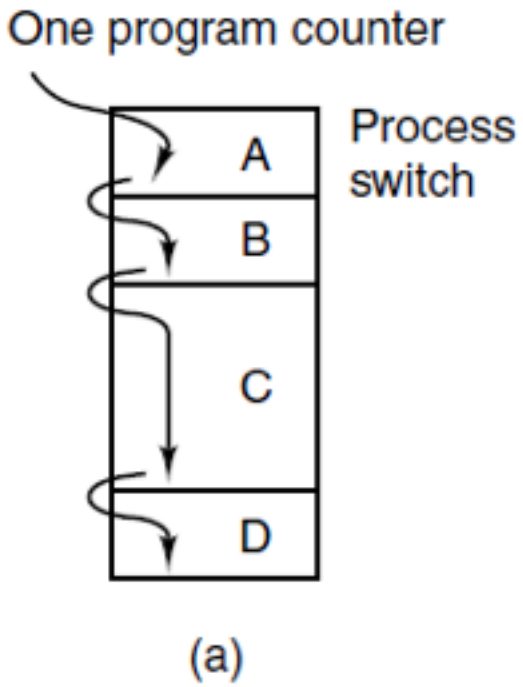


Figure 2-1. (a) Multiprogramming of four programs in memory. Only one physical program counter.

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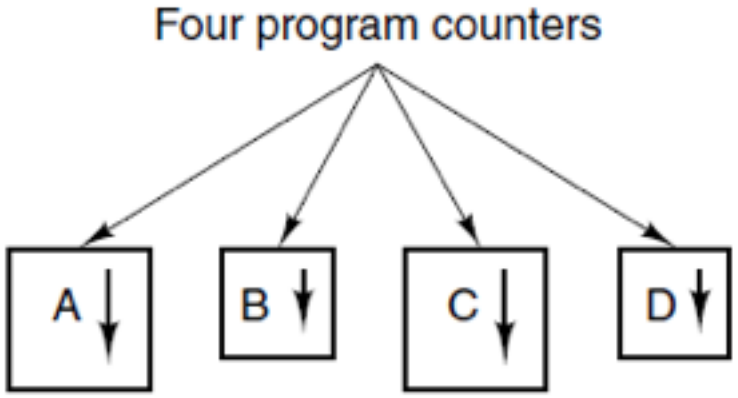
The Process Model



(b)

Figure 2-1. (b) Conceptual model of four independent, sequential processes. There exist only one physical program counter, but four different logical counters. When a program runs, its logical counter is loaded into the physical program counter

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The Process Model

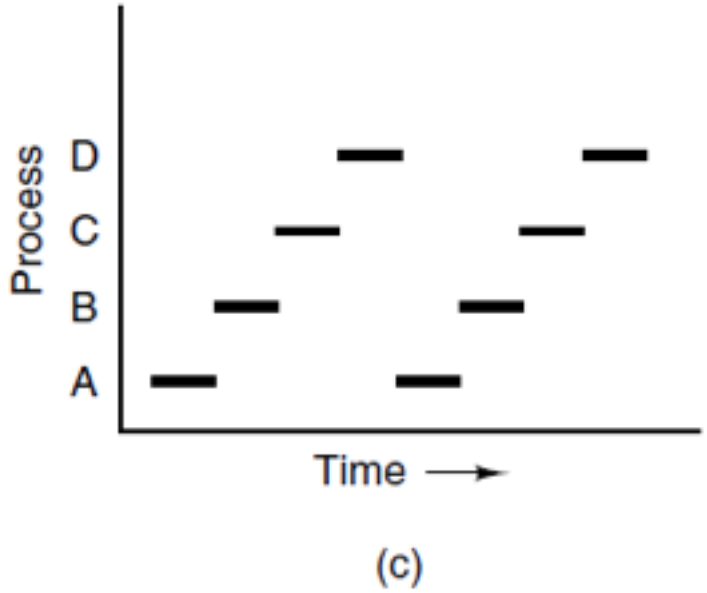

Figure 2-1. (c) Only one program is active at once. All processes have made progress, but at any given instant only one process is actually running.

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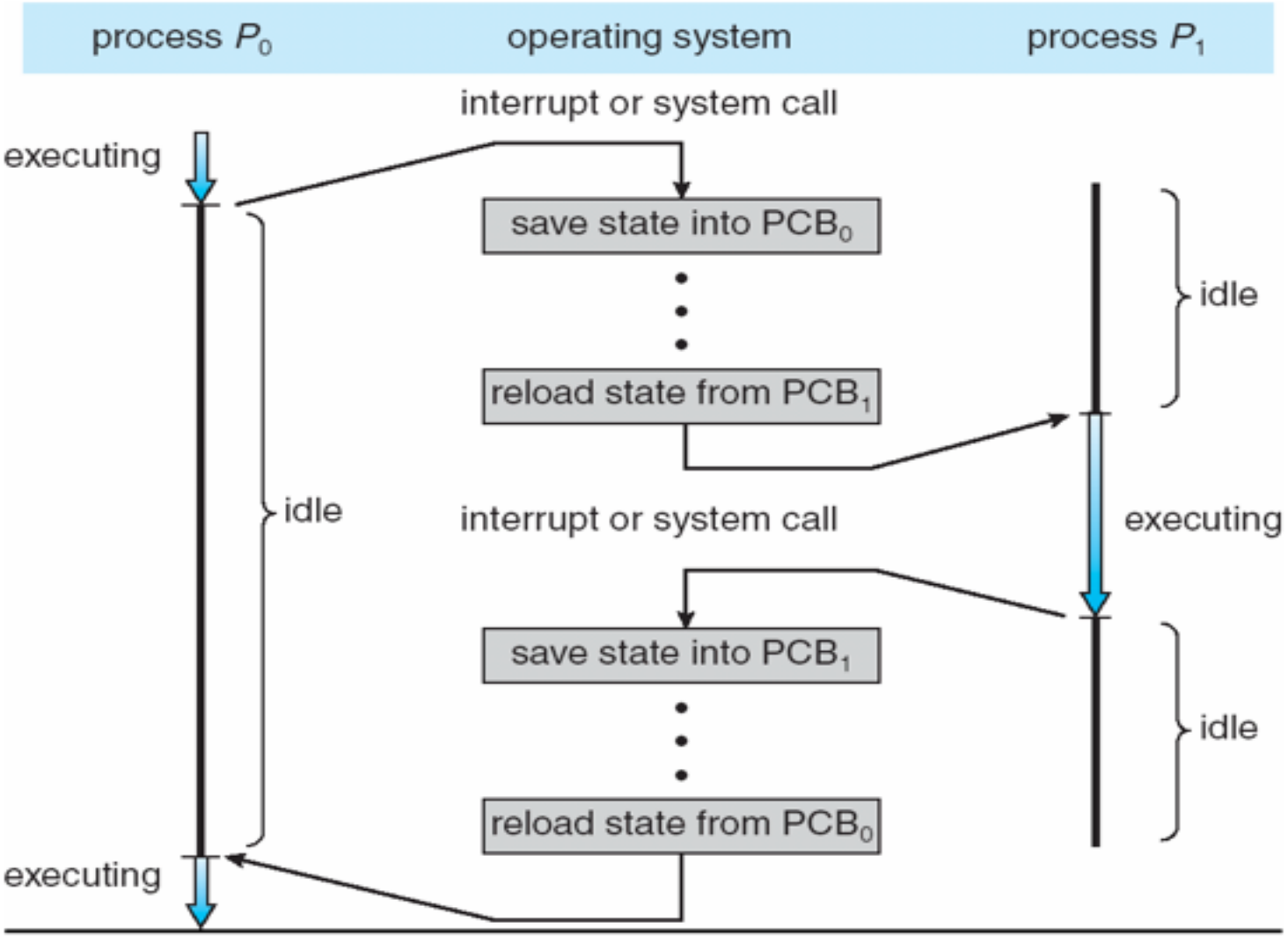
Multiprogramming

- Rapidly switching back and forth from process to process is called multiprogramming.
- When each process runs, its logical program counter is loaded into the real program counter.
- When it is finished (for the time being), the physical program counter is saved in the process' stored logical program counter in memory.
- From now on, we assume that there is only one CPU.

CPU Switch From Process to Process



Context Switch

- For a running process
  - All registers are loaded in CPU and modified
    - E.g. Program Counter, Stack Pointer, General Purpose Registers
- When process relinquishes the CPU, the OS
  - Saves register values to the PCB of that process
- To execute another process, the OS
  - Loads register values from PCB of that process

⇒Context Switch

- Process of switching CPU from one process to another
- Very machine dependent for types of registers

What does it take to create a process?

- Must construct new PCB
  - Inexpensive
- Must set up new address space
  - More expensive

- Creating a new process is costly
- Context switching is costly

Need something more lightweight!

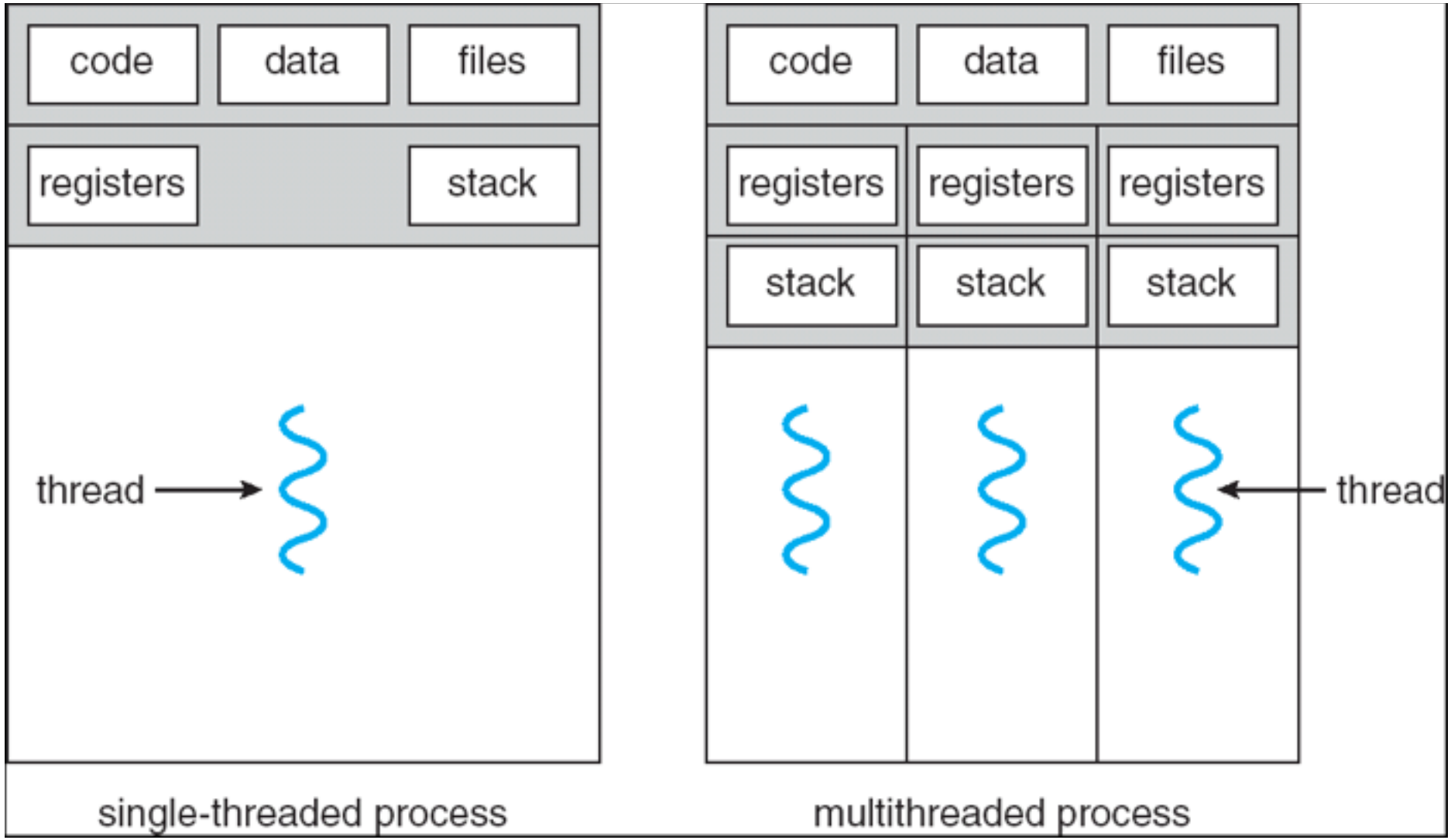
Threads and Processes

- Most operating systems therefore support two entities:
  - the process,
    - which defines the address space and general process attributes
  - the thread,
    - which defines a **sequential** execution stream within a process
    - Like a miniprocess within a process
- A thread is bound to a single process.
  - For each process, however, there may be many threads.
- Threads are the unit of scheduling
- Processes are *containers* in which threads execute

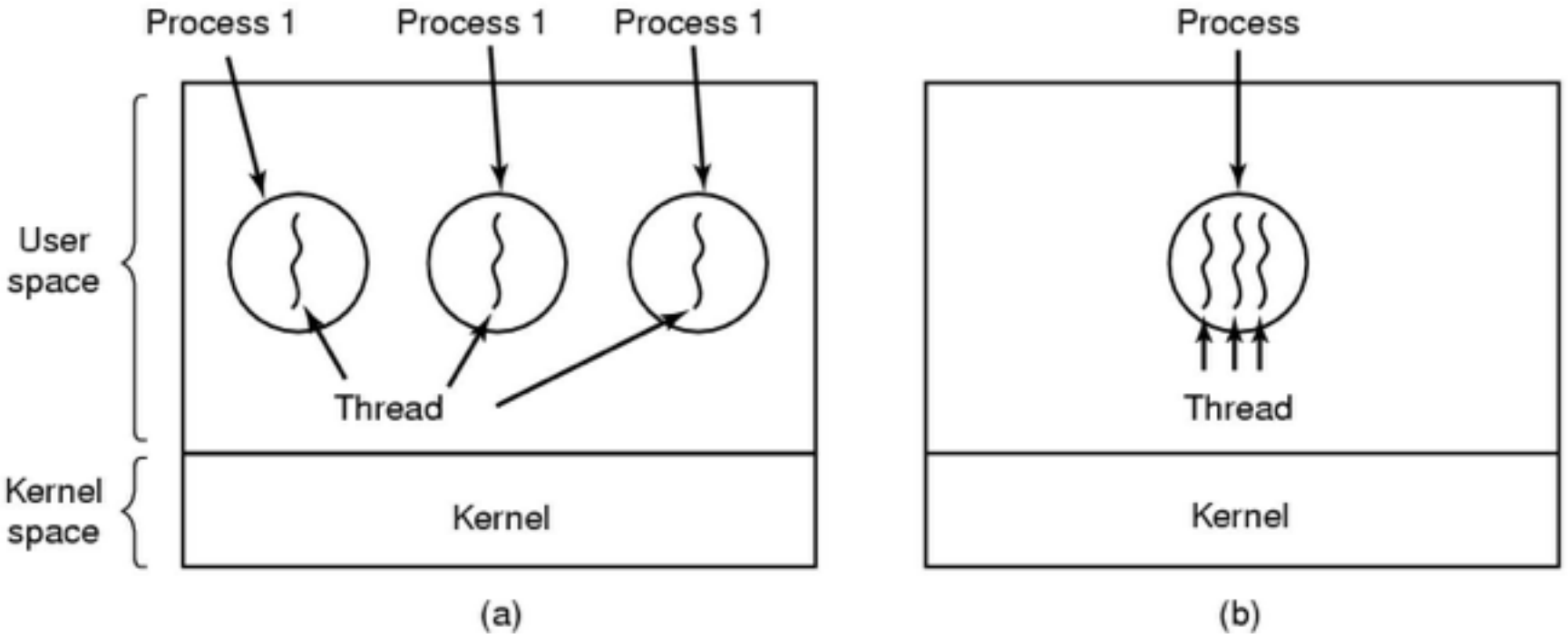
Threads and Processes

- Thread within the same process needs a new ability:
  - Share an address space and all of it's data among themselves.
- Remember, processes does not share their address spaces.

Multithreaded Processes



The Classical Thread Model

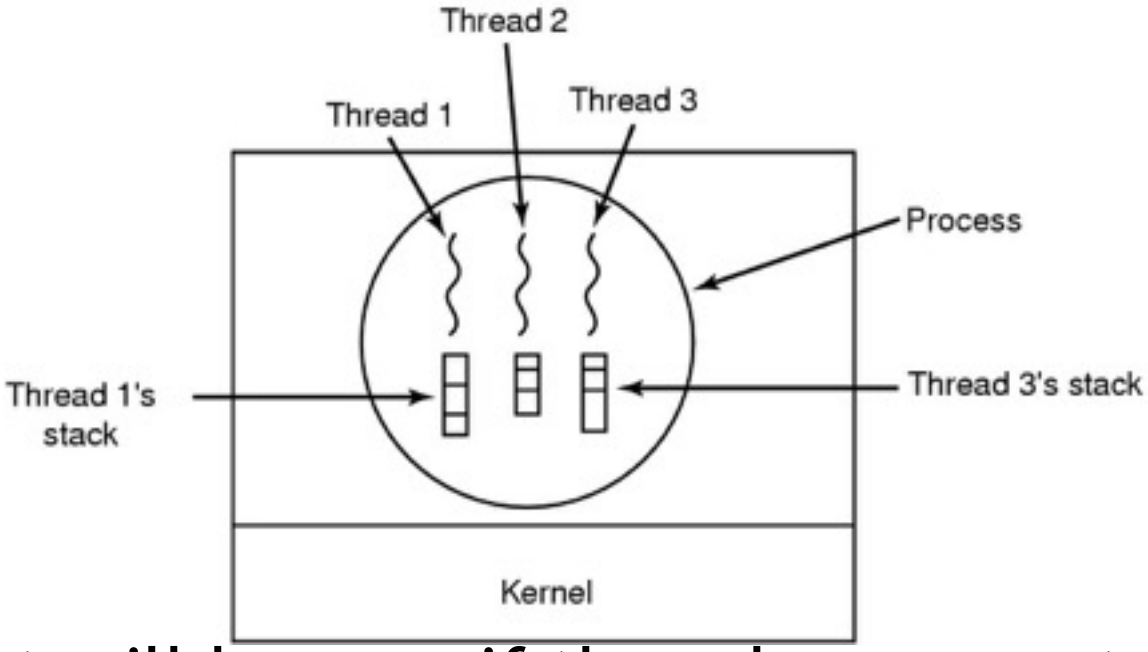


(a) Three processes each with one thread
(b) One process with three threads

The Classical Thread Model

- Shared information
  - Address space: text, data structures, etc.
  - I/O and file: comm. ports, directories and file descriptors, etc.
  - Global variables and child processes.
  - Accounting info: stats
- Private state
  - State (ready, running and blocked)
  - Registers
  - Program counter
  - Execution stack
- Each thread execute separately

Why each thread has its own stack?

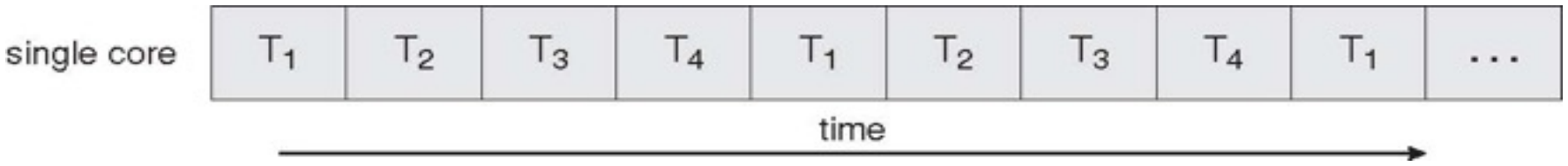


- What will happen if they share one stack?
  - Each thread call different procedures and each has a different execution history.

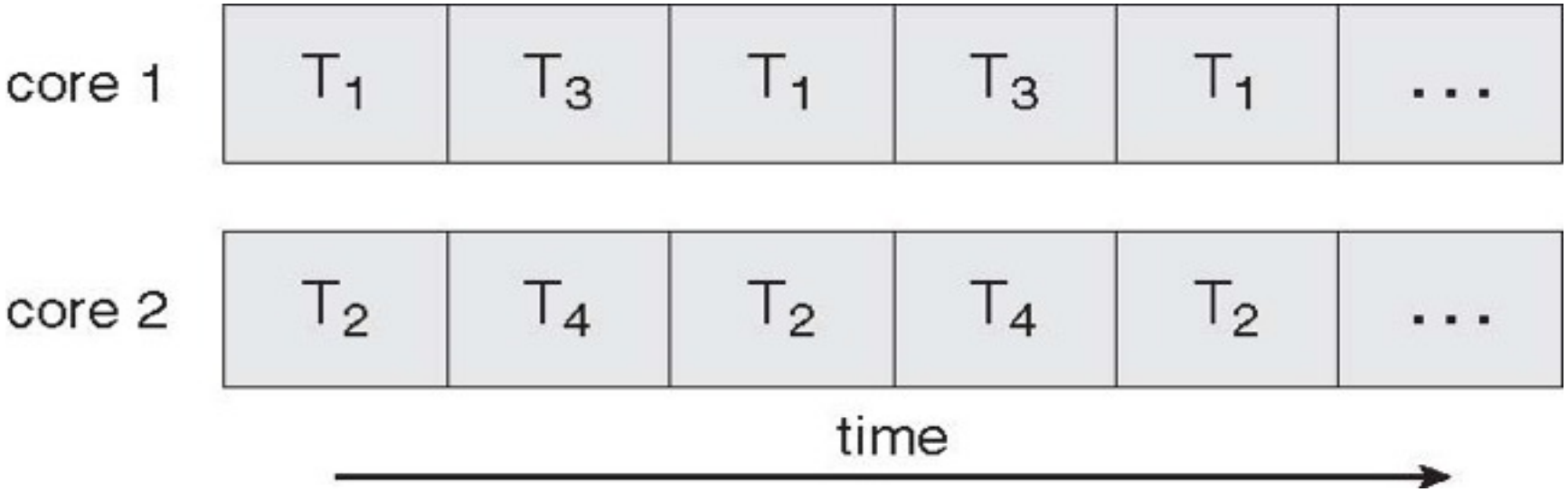
Thread Context Switch

- Multiplex multiple threads on single CPU
- Similar to process context switch, but less expensive
  - Still needs to switch register set
  - But no memory management related work!!!

Concurrent Execution on a Single-core System



Parallel Execution on a Multicore System



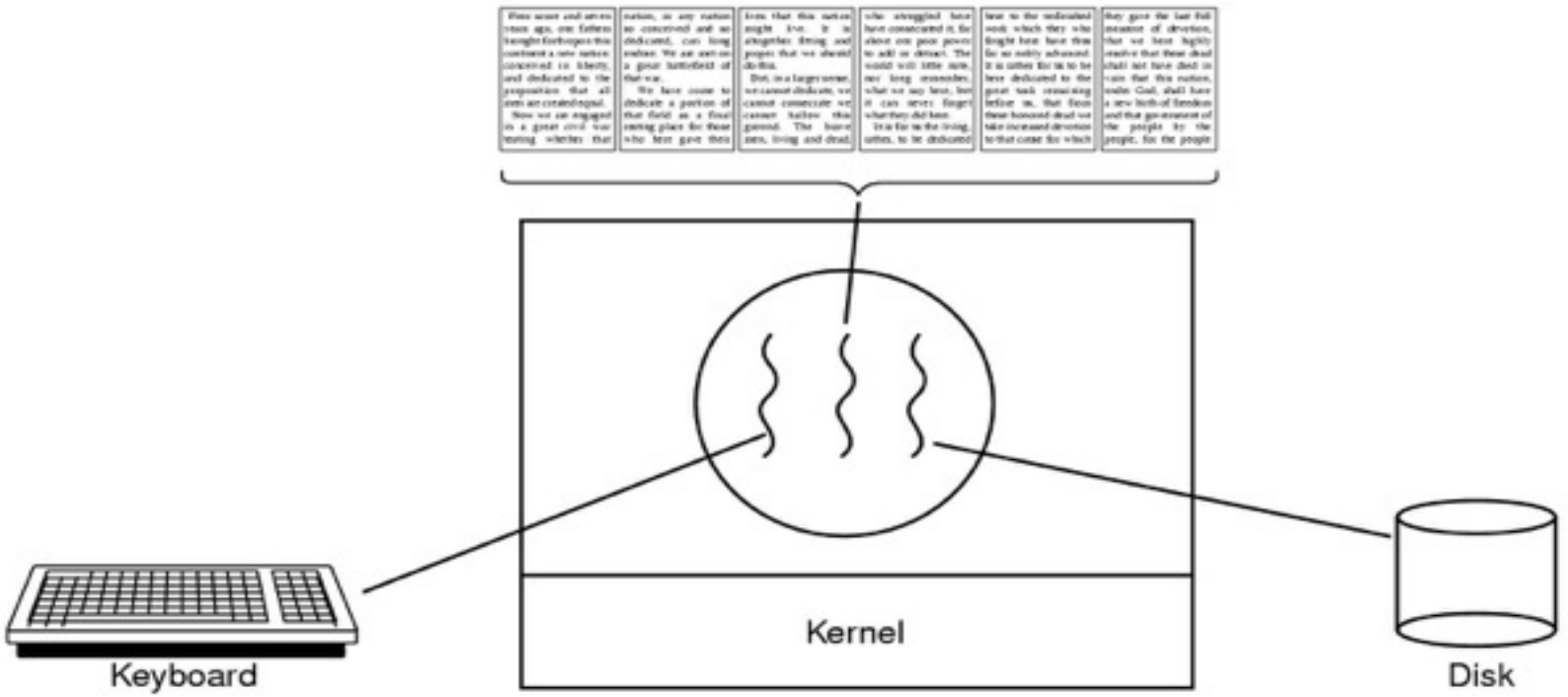
Thread Dynamics

- Threads are dynamically created/terminated
- Thread is the unit of scheduling.
  Multiple threads need to be scheduled
  - Ready
  - Blocked
  - Running
  - Terminated
- Threads share CPU and on single processor machine only one thread can run at a time

Thread Usage

- Why need threads?
  - Simplify coding
  - Concurrent activities within a process
    - Better CPU utilization
    - Better responsiveness
  - Less costly to create & switch
  - Utilizing parallelism of multi-processor systems

Thread Usage: word processor



- A thread can wait for I/O, while the others can still be running.
- What if it is single-threaded?

Thread Implementation

- In user space
  - Kernel unaware of multiple threads
  - User level runtime system does scheduling
- In kernel space
  - Kernel supports threads (lightweight process)

User-Level Threads

- The thread scheduler is part of a *user-level library*
- Each thread is represented simply by:
  - PC
  - Registers
  - Stack
  - Small control block
- All thread operations are at the user-level:
  - Creating a new thread
  - switching between threads
  - synchronizing between threads

User-Level vs. Kernel Threads

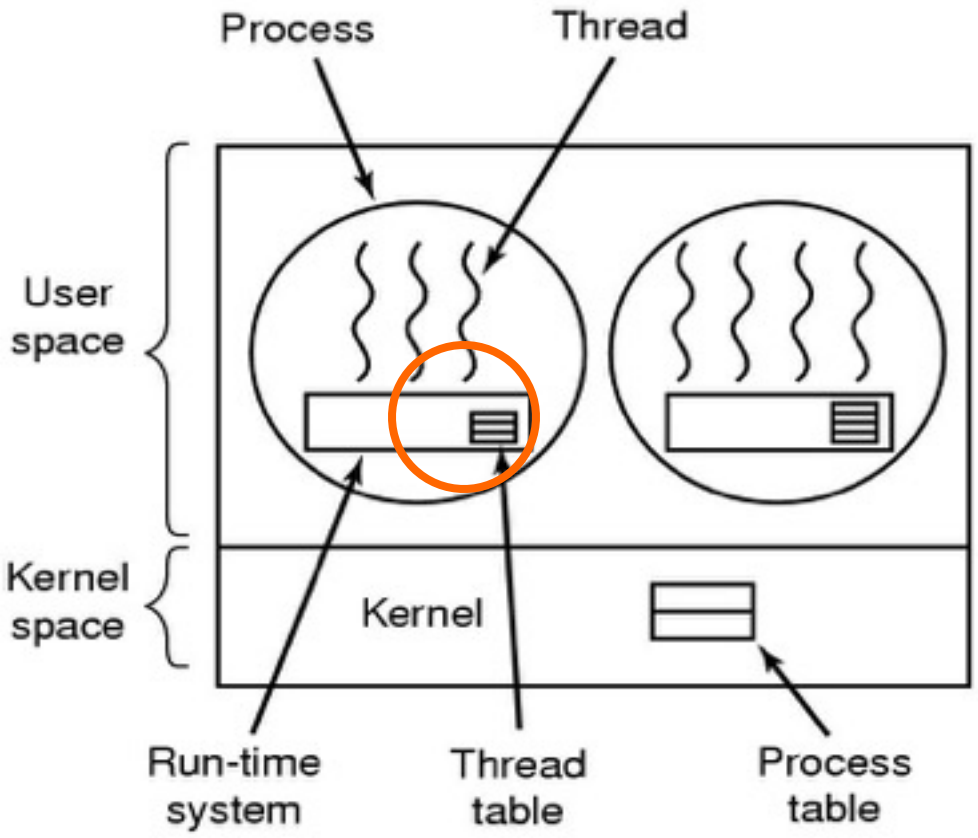
User-Level

- Managed by application
- Kernel not aware of thread
- Context switching cheap
- Create as many as needed
- Must be used with care

Kernel-Level

- Managed by kernel
- Consumes kernel resources
- Context switching expensive
- Number limited by kernel resources
- Simpler to use

Implementing Threads in User Space



A user-level threads package

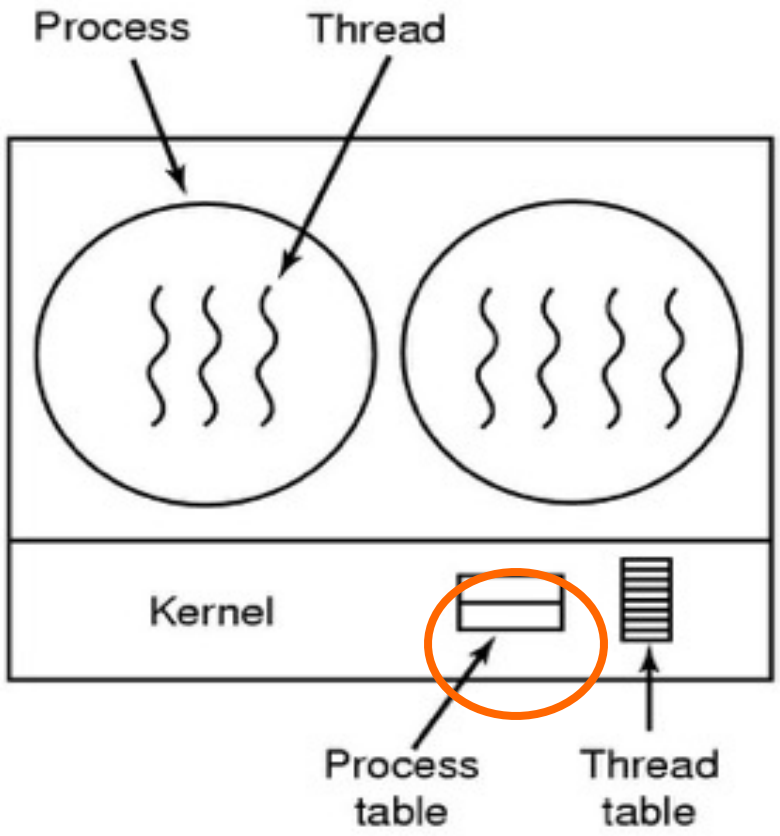
User-level Threads

- Advantages
  - Fast Context Switching:
    - Switching entirely in user mode – local procedures.
    - No need to trap to kernel, no memory flush;
  - Customized Scheduling
- Disadvantages
  - Blocking
    - Any user-level thread can block the entire task executing a single system call (page fault is similar case).
  - No protection, threads are expected to be polite to share CPU.
    - Uncooperative/buggy threads may monopolize CPU.

Kernel Threads

- Kernel threads may not be as heavy weight as processes, but they still suffer from performance problems:
  - Any thread operation still requires a system call.
  - The kernel doesn't trust the user
    - there must be lots of checking on kernel calls

Implementing Threads in the Kernel

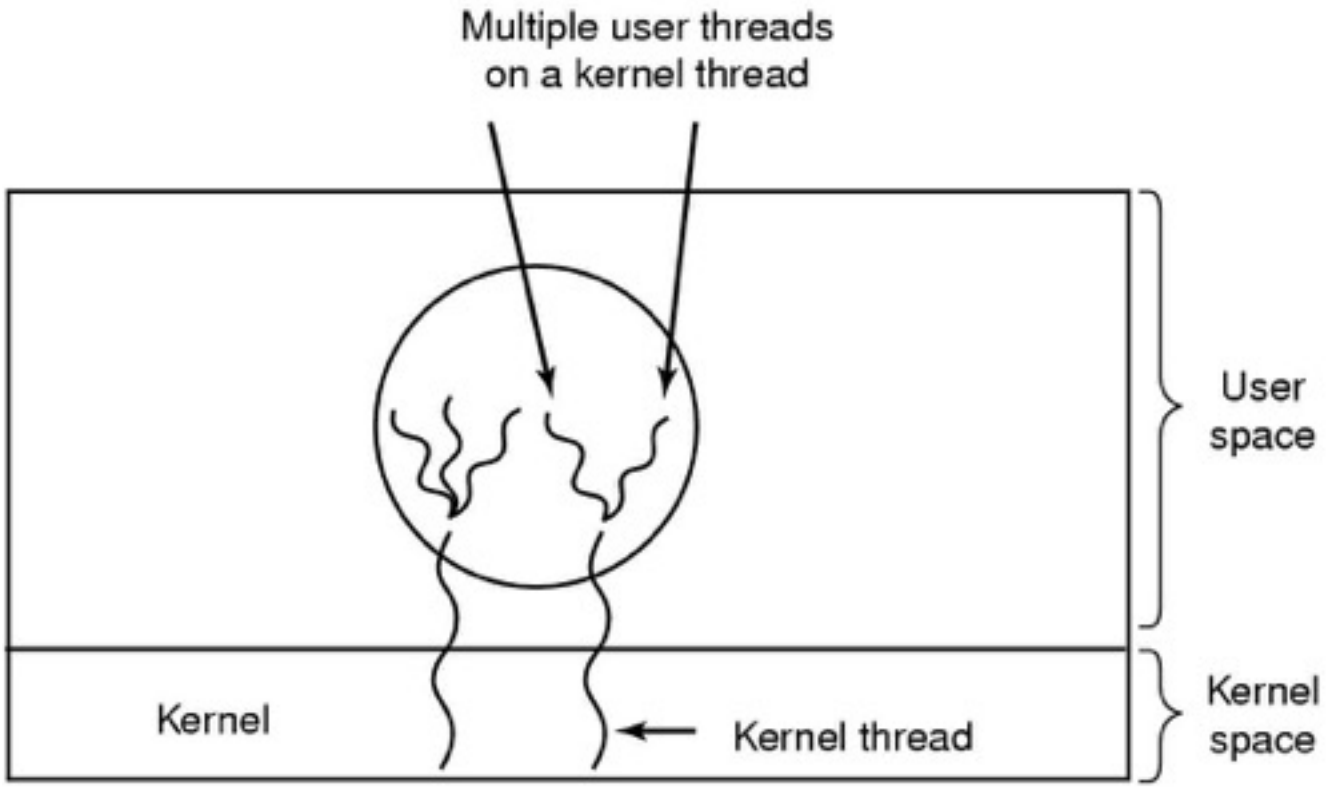


A thread package managed by the kernel

Kernel-Level Threads

- Advantages:
  - Kernel aware of threads, if one thread blocks, can schedule another thread in the process.
- Disadvantages:
  - Context switch is more expensive.

Hybrid Implementations



Multiplexing user-level threads onto kernel- level threads

Hybrid Implementations

- Combining the advantages of the 2 methods
- the kernel is aware of only the kernel-level threads and schedules those.
- ,each kernel-level thread has some set of user-level threads that take turns using it.
- These user-level threads are created, destroyed, and scheduled just like user-level threads in a process

Thanks ☺️