Operating Systems Concepts

Threads

CS 4375, Fall *2025*
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Summery

- Introduction to xv6
  - What is xv6?
  - RISC-V
  - Hardware-software stack of xv6
  - xv6 system calls
  - Code-base overview
- Quiz 1

Quiz 1 Statistics

Grade Statistics	
Grade count	60
Minimum value	0
Maximum value	10
Range	10
Average	6.75
Median	7
Standard deviation	2.19
Variance	4.82

Grading Status	
Not started	2
In progress	0
Needs grading	0
Exempt	0

Grade Distribution (%)	
Greater than 100	0
90 - 100	12
80 - 89	9
70 - 79	18
60 - 69	10
50 - 59	4
40 - 49	3
30 - 39	1
20 - 29	0
10 - 19	0
0 - 9	3
Less than 0	0

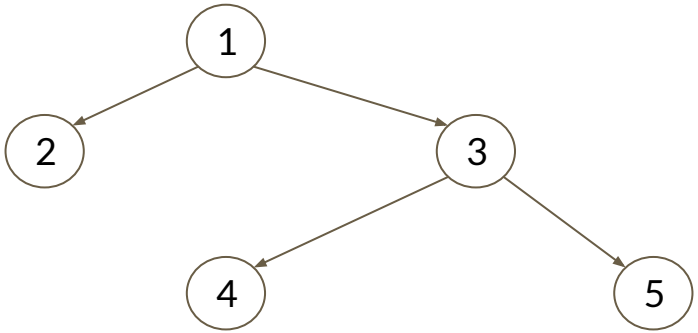
Agenda

- Threads
  - Concurrent programming
  - Why threads?
  - Threads vs Processes
  - Thread pools
  - Threading implementation & multithreading models
  - Threading issues
    - Semantics of fork() and exec()
    - Thread cancellation
    - Signal handling

Concurrent Programming

In certain cases, a single application may need to run several tasks at the same time.

Sequential

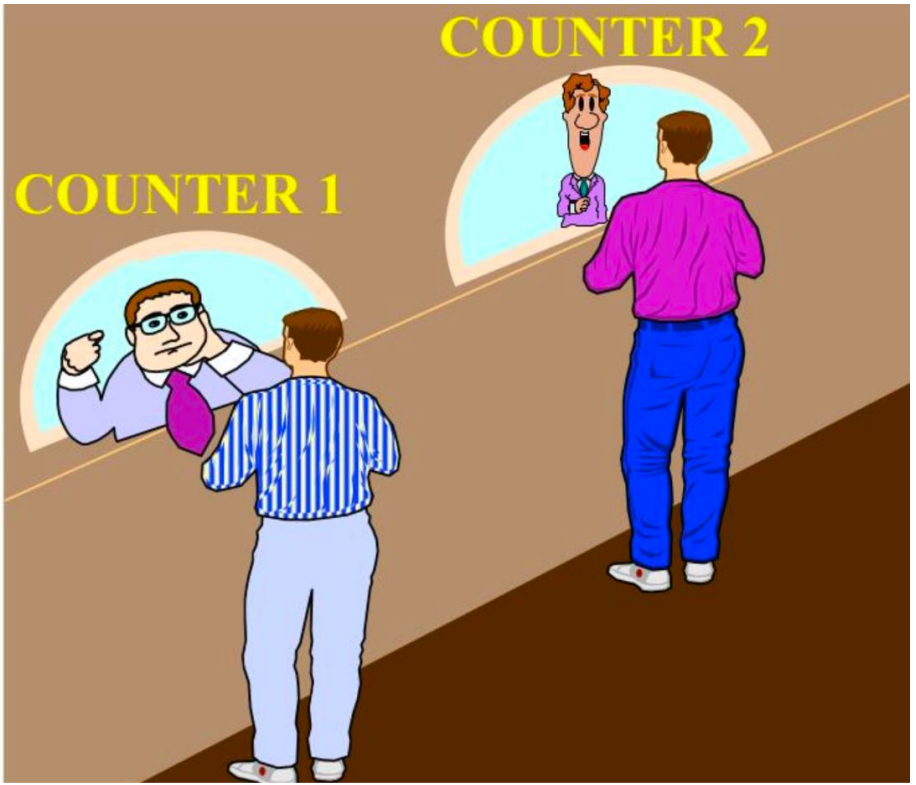


Concurrent

Motivation

- Increase the performance by running more than one task at a time
  - Divide the program to ***n*** smaller pieces, and run it ***n*** times faster using ***n*** processors
- To cope with independent physical devices
  - Do not wait for a blocked device, perform other operations in the background

Serial vs Parallel



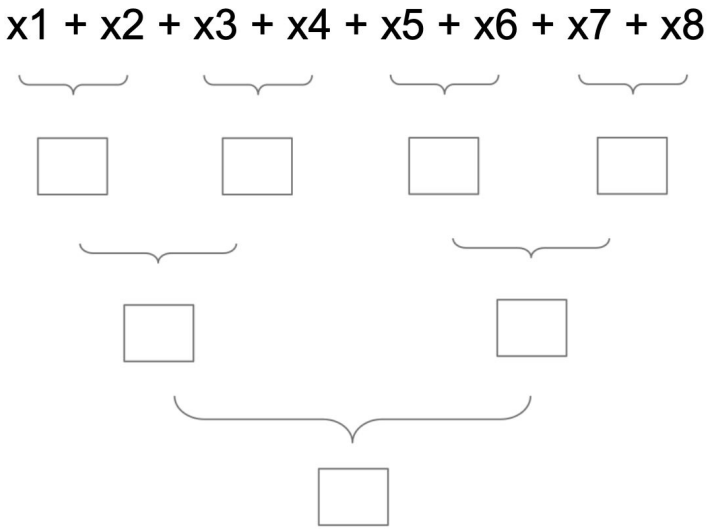
Divide and Compute

x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8

How many operations with sequential programming? 7

- **Step 1:** x1 + x2
- **Step 2:** x1 + x2 + x3
- **Step 3:** x1 + x2 + x3 + x4
- **Step 4:** x1 + x2 + x3 + x4 + x5
- **Step 5:** x1 + x2 + x3 + x4 + x5 + x6
- **Step 6:** x1 + x2 + x3 + x4 + x5 + x6 + x7
- **Step 7:** x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8

Divide and Compute



- **Step 1:** Parallelism = 4
- **Step 2:** Parallelism = 2
- **Step 3:** Parallelism = 1

Gain From Parallelism

- In theory:
  - Dividing a program into ***n*** smaller parts and running on ***n*** processors results in ***n*** time speedup
- In practice:
  - This is not true, due to
    - Communication costs
    - Dependencies between different program parts
      - The previous addition example can run only in ***log(n)*** time, and not ***1/n***

Concurrent Programming

- Implementation of concurrent tasks:
  - As separate programs
  - As a set of processes or threads created by a single program
- Execution of concurrent tasks:
  - On a single processor (can be multiple cores)
    - Multithreaded programming
  - On several processors in close proximity
    - Parallel computing
  - On several processors distributed across a network
    - Distributed computing

Why Threads?

In certain cases, a single application may need to run several tasks at the same time

- Creating a new process for each task is time and resource consuming
- Use a single process with multiple threads
  - Faster
  - Less overhead for creation, switching, and termination
  - Share the same address space

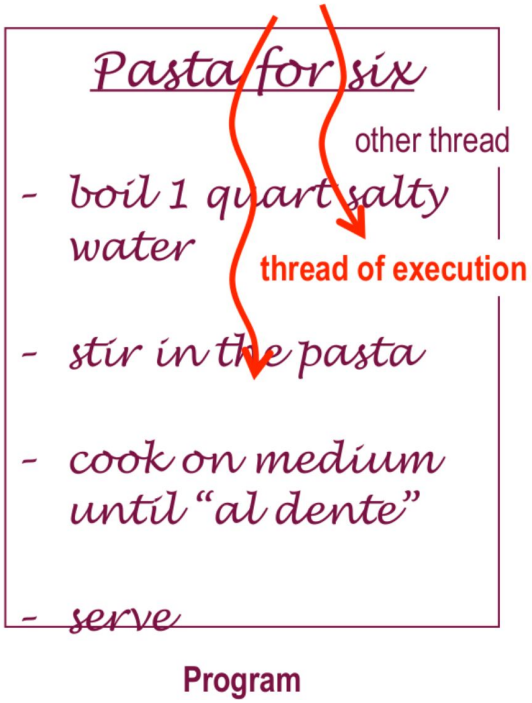
Threading Benefits

Patterns of multithreading usage across applications:

- Perform foreground and background work in parallel
  - Illusion of full-time interactivity toward the user while performing other tasks (same principle as time-sharing)
- Allow asynchronous processing
  - Separate and desynchronize the execution streams of independent tasks that don't need to communicate.
  - Handle external, surprise events such as client requests
- Increase speed of execution
  - "Stagger" and overlap CPU execution time and I/O wait time (same principle as multiprogramming)

Multithreading

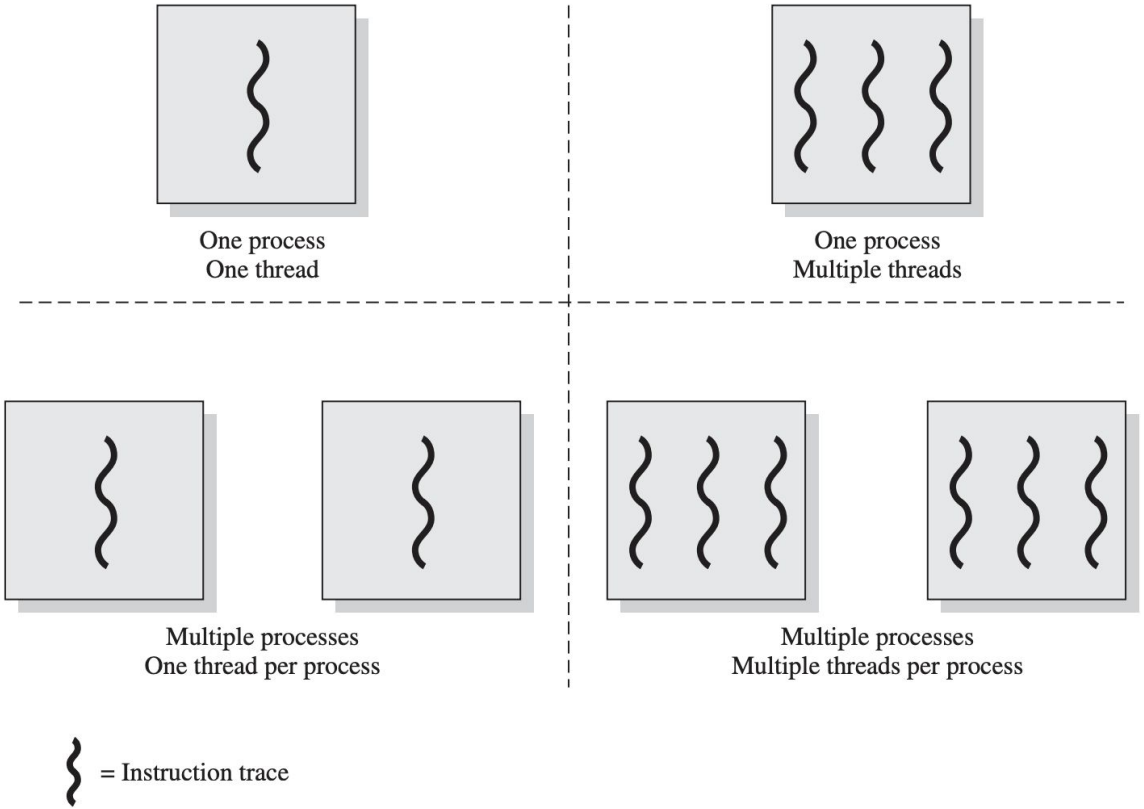
The execution part is a “thread” that can be multiplied



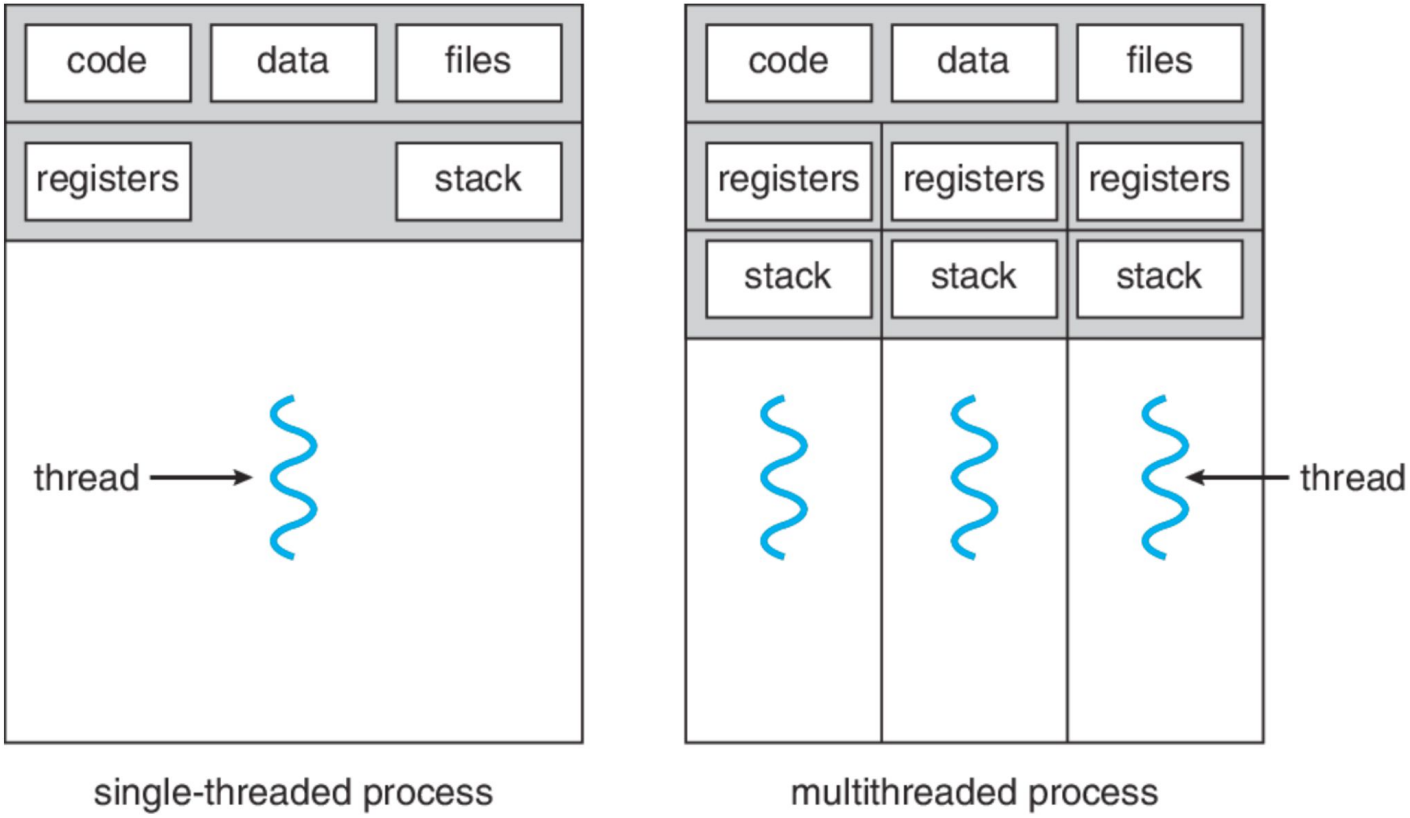
Program

Process

Multithreading



Single and Multithreaded Processes



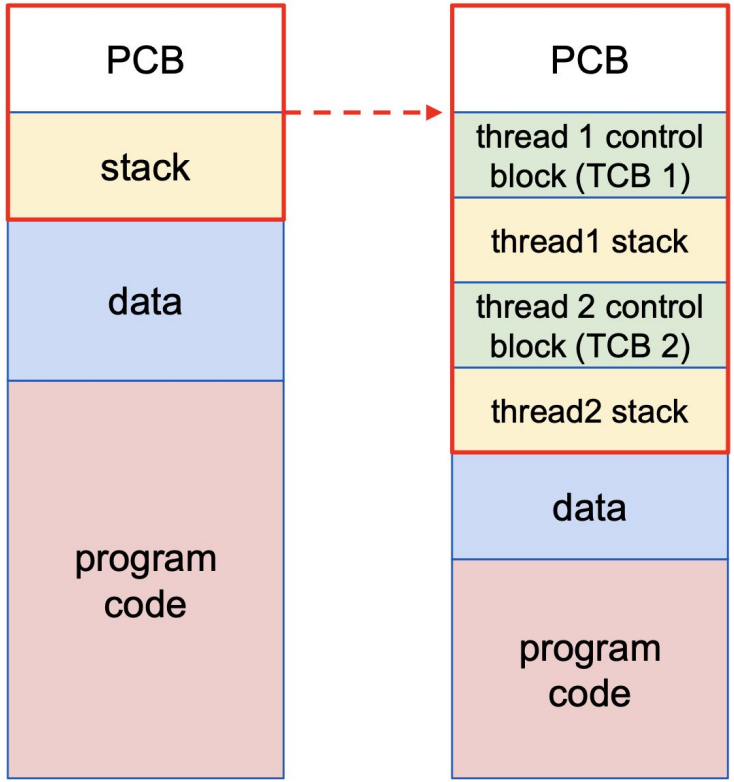
single-threaded process

multithreaded process

New Process Description Model

Multithreading requires changes in the process description model.

- Each thread of execution receives its own control block and stack.
  - Own execution state (“Running”, “Blocked”, etc.)
  - Own copy of CPU registers
  - Own execution history (stack)
- The process keeps a global control block listing resources currently used



Per-process vs Per-thread Items

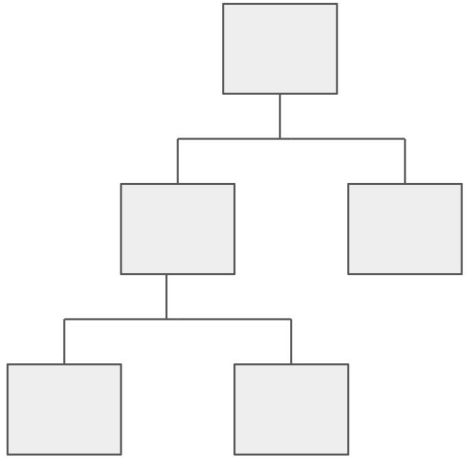
Per-process items and per-thread items in the control block structures:

- process identification data + thread identifiers
  - Numeric identifiers of the process, the parent process, the user, etc.
- CPU state information
  - User-visible, control & status registers
  - Stack pointers
- Process control information
  - Scheduling: state, priority, awaited event
  - Used memory and I/O, opened files, etc.
  - Pointer to next PCB

Multiprocessing Model

Process spawning

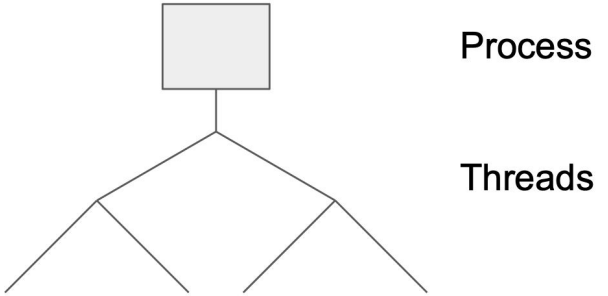
- Setting up the process control block
- Allocation of an address space
- Loading the program into the allocated address space
- Passing on the process control block to the scheduler



Multiprocessing Model

Thread spawning

- Threads are created *within* processes, and belonging to processes
- All the threads created within one process, share the resources of the process including the address space
- Scheduling is performed on per-thread basis
- Threads have a similar lifecycle as the processes and will be managed mainly in the same way



Threads vs Processes

- A common terminology:
  - Heavyweight Process = Process
  - **Lightweight Process = Thread**
- Advantages:
  - Much quicker to create a thread than a process
    - spawning a new thread only involves allocating a new stack and a new CPU state block
  - Much quicker to switch between threads than to switch between processes
  - Threads share data easily
- Disadvantages:
  - Processes are more flexible
    - They don't have to run on the same processor
  - No security between threads: One thread can stomp on another thread's data
  - For threads which are supported by user thread package instead of the kernel:
    - If one thread blocks all threads in task block

Example

Consider a process with two concurrent threads T1 and T2. The code being executed by T1 and T2 is as follows:

Shared Data:

X = 5;

Y = 10;

T1:	T2:
Y = X + 1;	U = Y - 1;
X = Y;	Y = U;
Print X;	Print Y;

Assume that each assignment statement on its own is executed as an ***atomic*** operation.

What are the possible outputs of this process?

Solution

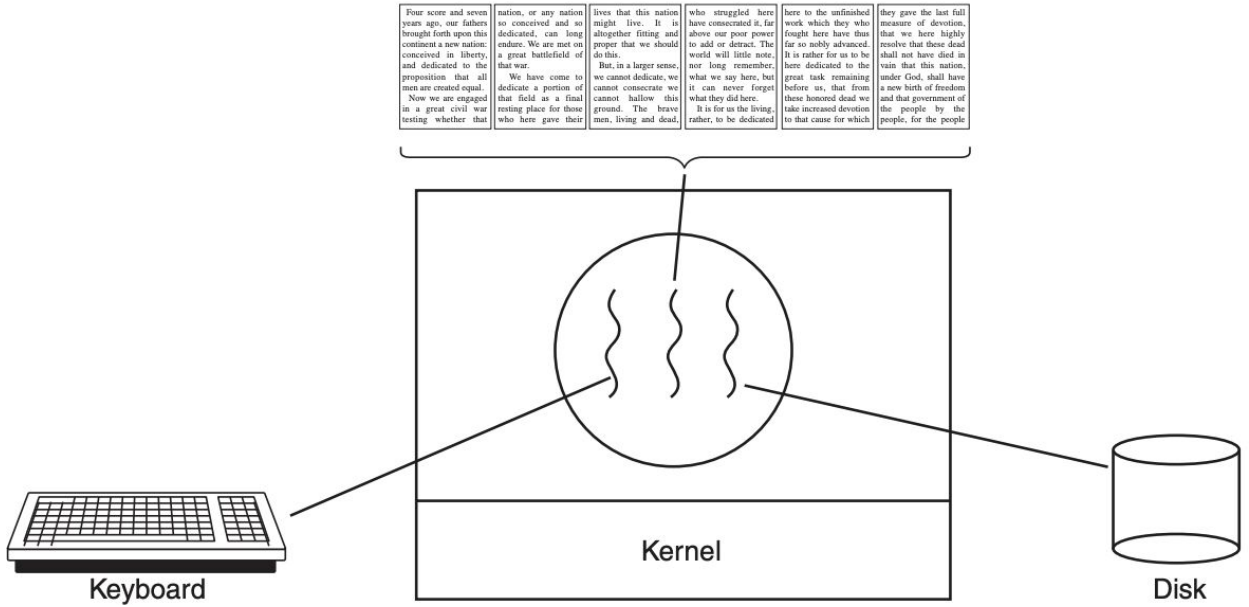
All six statements can be executed in any order!

Possible outputs are:

1. 65
2. 56
3. 55
4. 99
5. 66
6. 69
7. 96

Threading Examples

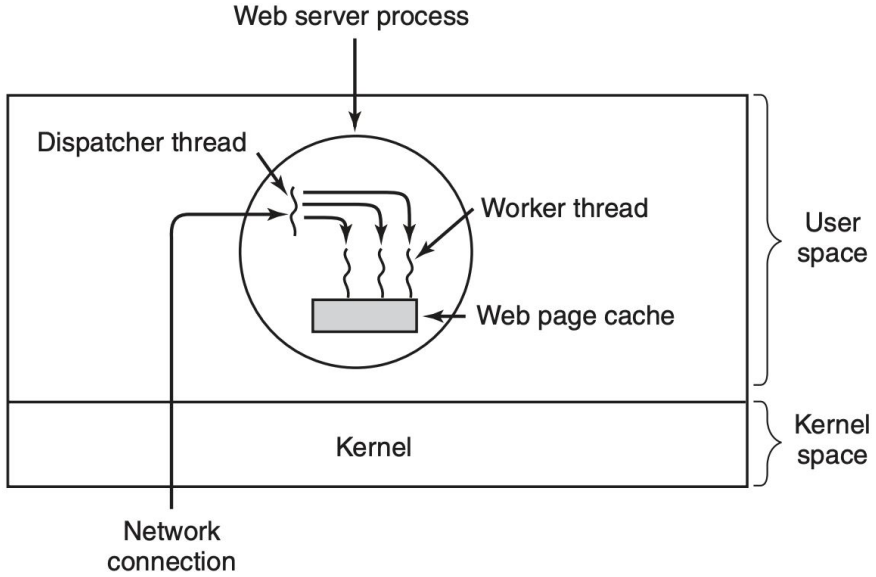
- Word processor:
  - One thread listens continuously to keyboard and mouse events to refresh the GUI; a second thread reformats the document (to prepare page 600); a third thread writes to disk periodically.



Tanenbaum, A. S. (2001)
Modern Operating Systems (2nd Edition).

Threading Examples

- Web server:
  - As each new request comes in, a “dispatcher thread” spawns a new “worker thread” to read the requested file (worker threads may be discarded or recycled in a “thread pool”)



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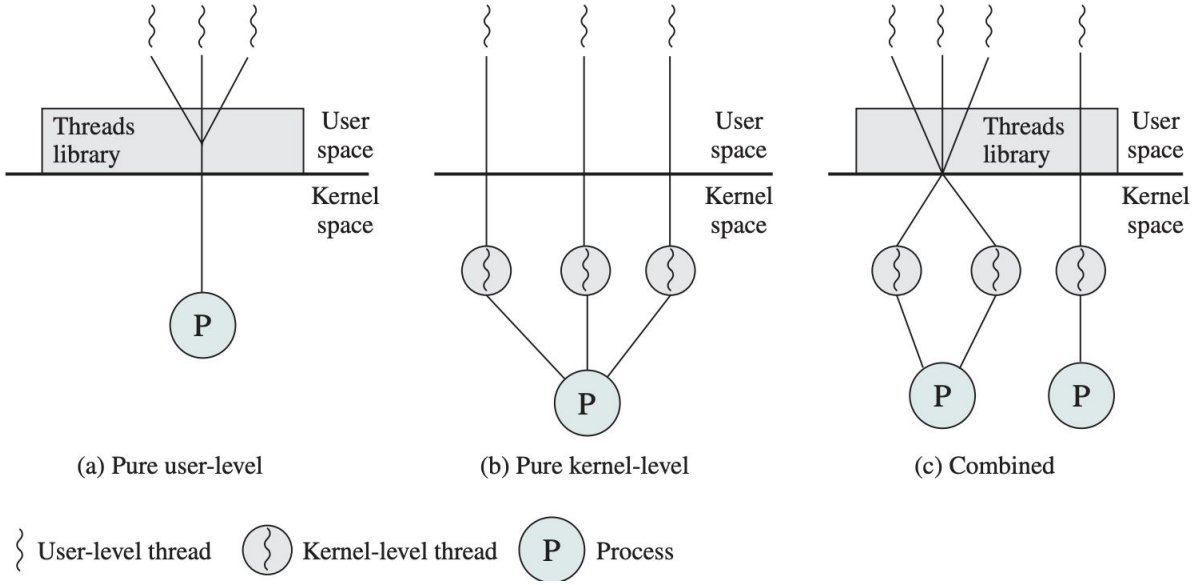
Thread Pools

- Threads come with some overhead as well
- Unlimited threads can exhaust system resources, such as CPU or memory
- Create a number of threads at process startup and put them in a pool, where they await work
- When a server receives a request, it awakens a thread from this pool
- Advantages:
  - Usually faster to service a request with an existing thread than create a new thread
  - Allows the number of threads in the application to be bound to the size of the pool
- Number of threads in the pool can be setup according to:
  - Number of CPUs, memory, expected number of concurrent requests

Thread Implementation

Two broad categories of thread implementation:

- User-Level Threads (ULTs)
- Kernel-Level Threads (KLTs)

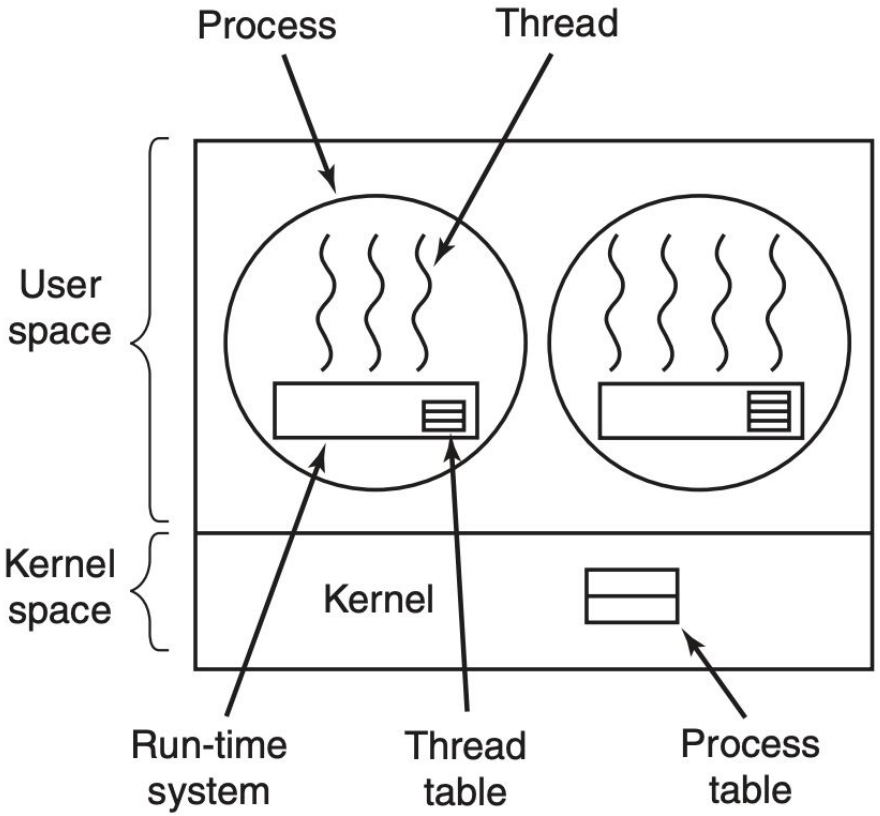


Thread Implementation - ULT

User-Level Threads (ULTs):

- The kernel is not aware of the existence of threads, it knows only processes with one thread of execution (one PC)
- Each user process manages its own private thread table
- Pros:
  - Light thread switching: Does not need kernel mode privileges
  - Cross-platform: ULTs can run on any underlying OS
- Cons:
  - If a thread blocks, the entire process is blocked, including all other threads in it

Thread Implementation - ULT



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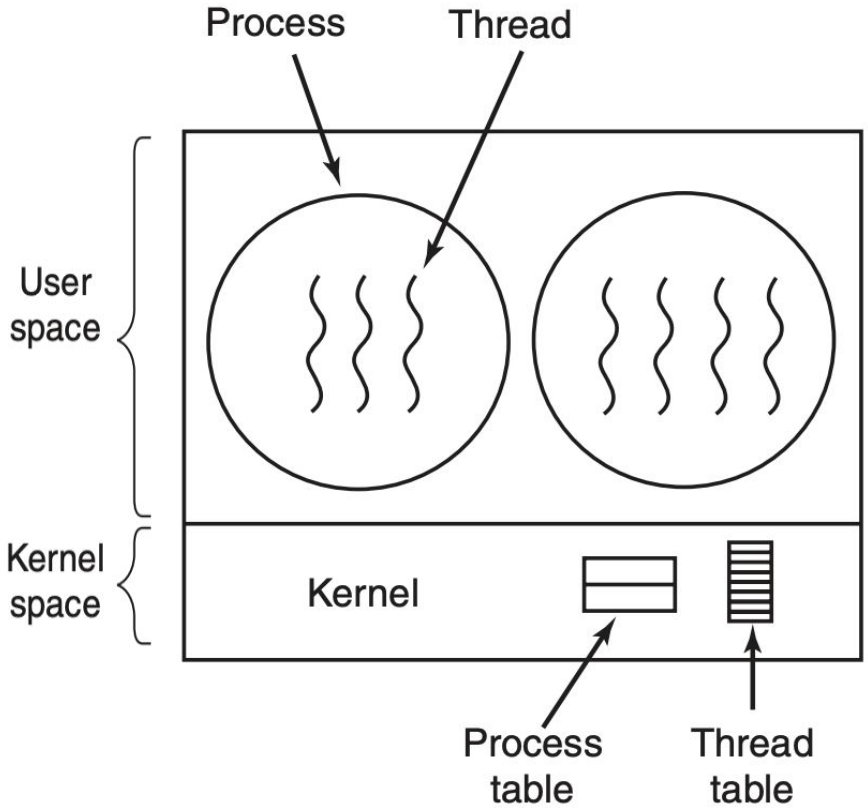
Thread Implementation - KLT

Kernel-Level Threads (KLTs):

- The kernel knows about and manages are system calls
- Supported by most operating systems (Linux, Windows, Mac OS X, Solaris, ...)
- Pros:
  - Fine-grain scheduling, done on a thread basis
  - If a thread blocks, another one can be scheduled without blocking the whole process
- Cons:
  - Heavy thread switching involving mode switch

Thread Implementation - KLT



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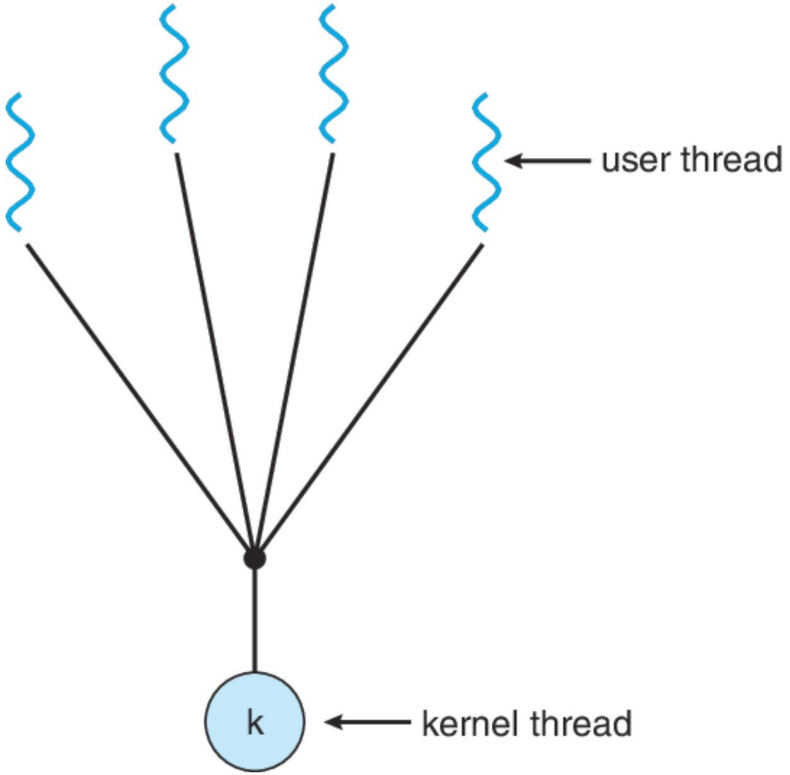
Different Multithreading Models

- Many-to-One
- One-to-One
- Many-to-Many
- Hybrid (Two-level)

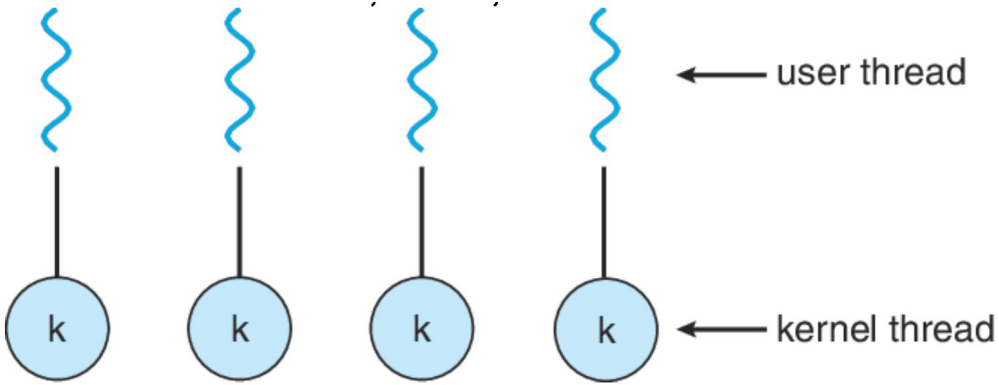
Different Multithreading Models

- Many-to-One
  - Several user-level threads mapped to single kernel thread
  - Thread management in user space
    - efficient
  - If a thread blocks, entire process blocks
  - One thread can access the kernel at a time
    - limits parallelism
  - Examples:
    - Solaris Green Threads
    - GNU Portable Threads



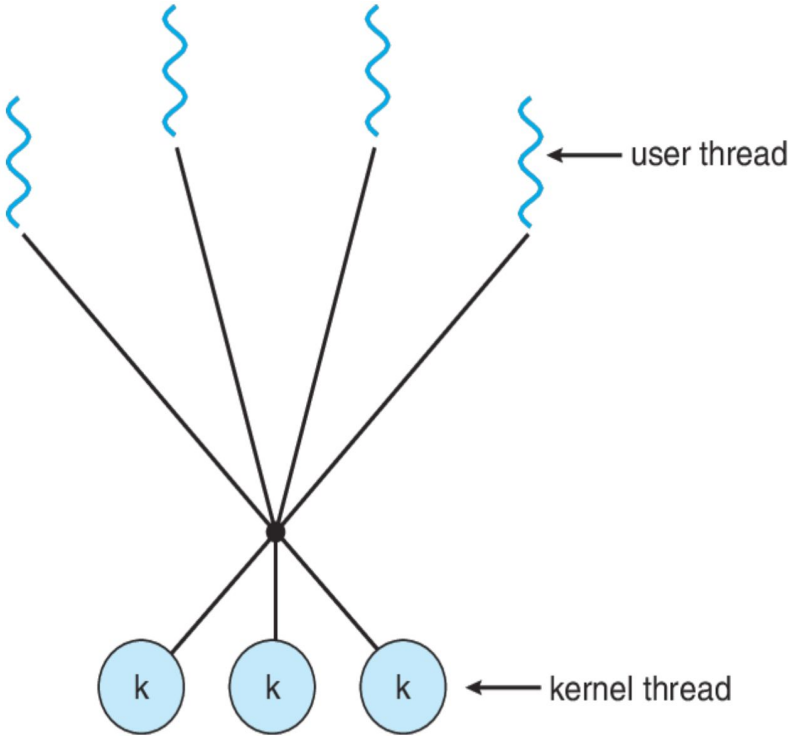
Different Multithreading Models

- One-to-One
  - Each user-level thread maps to a kernel thread
  - A blocking thread does not block other threads
  - Multiple threads can access kernel concurrently → increased parallelism
  - Drawback: Creating a user level thread requires creating a kernel level thread → increased overhead and limited number of threads
  - Examples: Windows NT/XP/2000, Linux, Solaris 9 and later



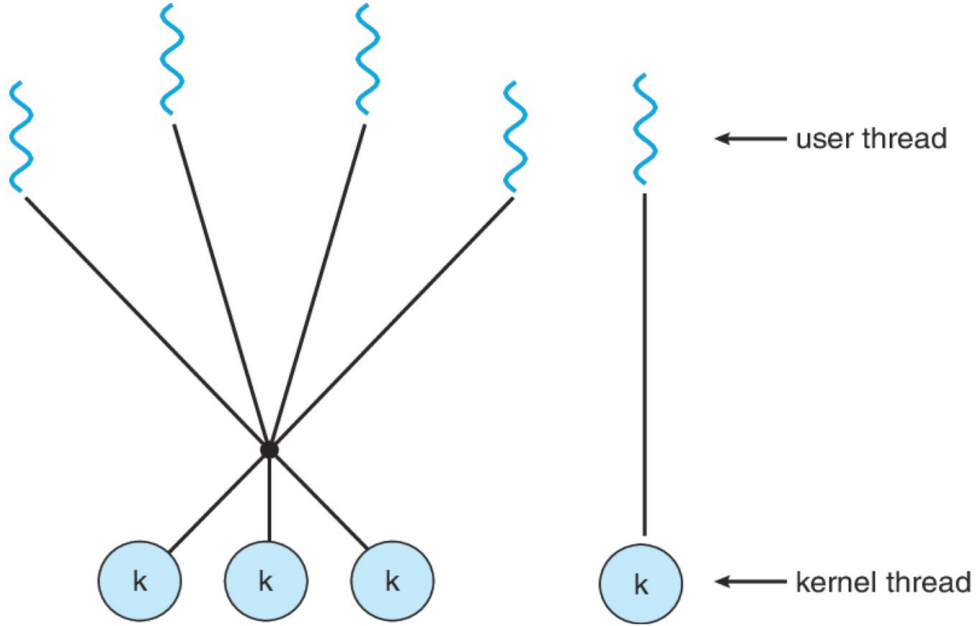
Different Multithreading Models

- Many-to-Many
  - Allows many user level threads to be mapped to a smaller number of kernel threads
  - Allows the operating system to create a sufficient number of kernel threads
  - Increased parallelism as well as efficiency
  - Solaris prior to version 9
  - Windows NT/2000 with the *ThreadFiber* package



Different Multithreading Models

- Hybrid (Two-level)
  - Similar to Many-to-Many, except that it allows a user thread to be bound to kernel thread.
  - Examples: IRIX, HP-UX, Tru64 UNIX, Solaris 8 and earlier



Threading Issues

- Semantics of fork() and execvp() system calls
- Thread cancellation
- Signal handling

Semantics of fork() and exec()

Semantics of ***fork()*** and ***exec()*** system calls change in a multithreaded program

- E.g. if one thread in a multithreaded program calls fork()
  - Should the new process duplicate all threads?
  - Or should it be single-threaded?
- Some UNIX systems implement two versions of fork()
- If a thread executes exec() system call
  - Entire process will be replaced, including all threads

Thread Cancellation

- Terminating a thread before it has finished
  - If one thread finishes searching a database, others may be terminated
  - If user presses a button on a web browser, web page can be stopped from loading further
- Two approaches to cancel the target thread
  - Asynchronous cancellation terminates the target thread immediately
  - Deferred cancellation allows the target thread to periodically check if it should be cancelled
    - More controlled and safe

Signal Handling

- Signals are used in UNIX systems to notify a process that a particular event has occurred
- All signals follow this pattern:
  - Signal is generated by particular event
  - Signal is delivered to a process
  - Once delivered, a signal must be handled
- In multithreaded systems, there are 4 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

Homework

- Submission
  - Code hosted on github (separate branches for each homework)
    - Your solution branch should private
    - Give access to the TA: ***danielmarin350@gmail.com***
  - Report modify the provided doc file
    - Provide your git repo link
    - Answer the question and put your code there
    - Submit PDF file to blackboard

Announcement

- Homework 1
  - **Get the installation done this week**
    - We will do a in class exercise next week
    - Bring your laptop

Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
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