CS 370: Operating Systems
[Threads]

Computer Science
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Topics covered in this lecture

- Classical thread model
- User- and kernel-level threads
- Thread Models

Classical Thread Model

The process model is based on two independent concepts

- Resource grouping
- Execution

A process can be thought of as a way to group related resources together

- **Address space** containing program text and data
- Other resources
  - Open files, child processes, pending alarms, signal handlers, etc.

A process also has a thread-of-execution

- Usually shortened to just **thread**
- The thread has
  1. Program counter
  2. Registers: Current working variables
  3. Stack: Contains execution history
     - One **frame** for each procedure **called, but not returned from**

Although a thread must execute in some process

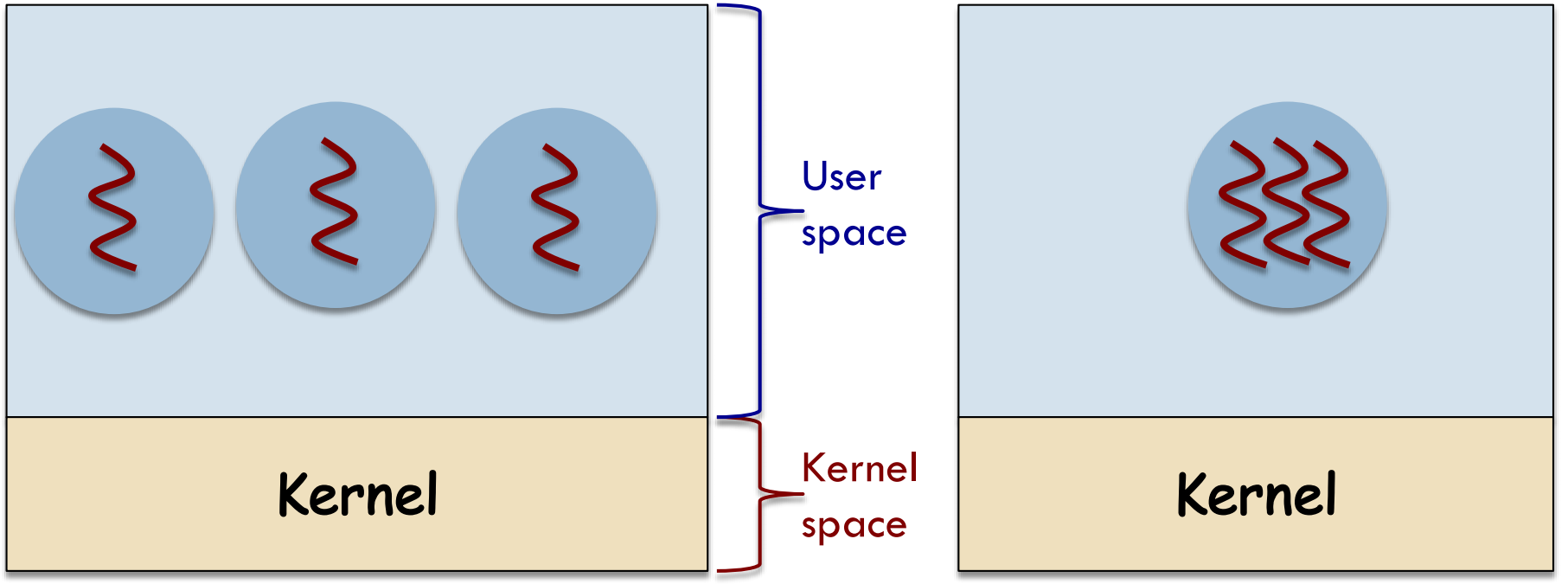
- The process and thread are *different* concepts
  - Can be treated separately
- Processes are used to group resources together
- Threads are entities scheduled for execution on the CPU

Threads & Processes

- Threads extend the process model by allowing *multiple executions* in the **same process**

- Multiple threads in parallel in one process?
  - Analogous to multiple processes running in parallel on one computer

Threads and Processes



Three processes, each with one thread

One process with three threads

Different threads in a process are NOT AS INDEPENDENT as different processes

- All threads within a process have the **same address space**
  - Share the same global variables
- Every thread can access **every** memory address within the process' address space
  - Read
  - Write
  - Wipe out another thread's stack

There is no protection between threads, because …

① It is "**impossible" (part of the same process)**

② It *should not* be necessary

Unlike processes which may be from different users

- A process is always owned by a single user
- User created threads so that they can cooperate … not fight

Contrasting items unique & shared across threads

Per process items {Shared by threads within a process}	Per thread items {Items unique to a thread}
Address space	Program Counter
Global variables	Registers
Open files	Stack
Child Processes	State
Pending alarms	
Signals and signal handlers	
Accounting Information	

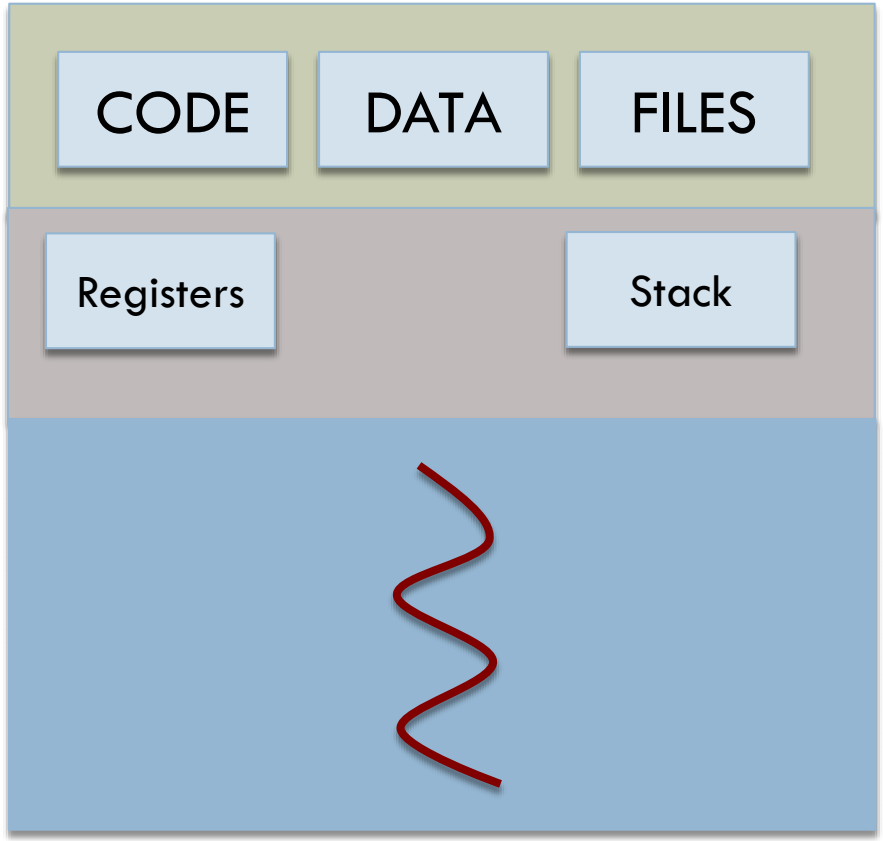
A thread is a basic unit of CPU utilization

- Thread ID
- Program Counter
- Register Set
- Stack
- State

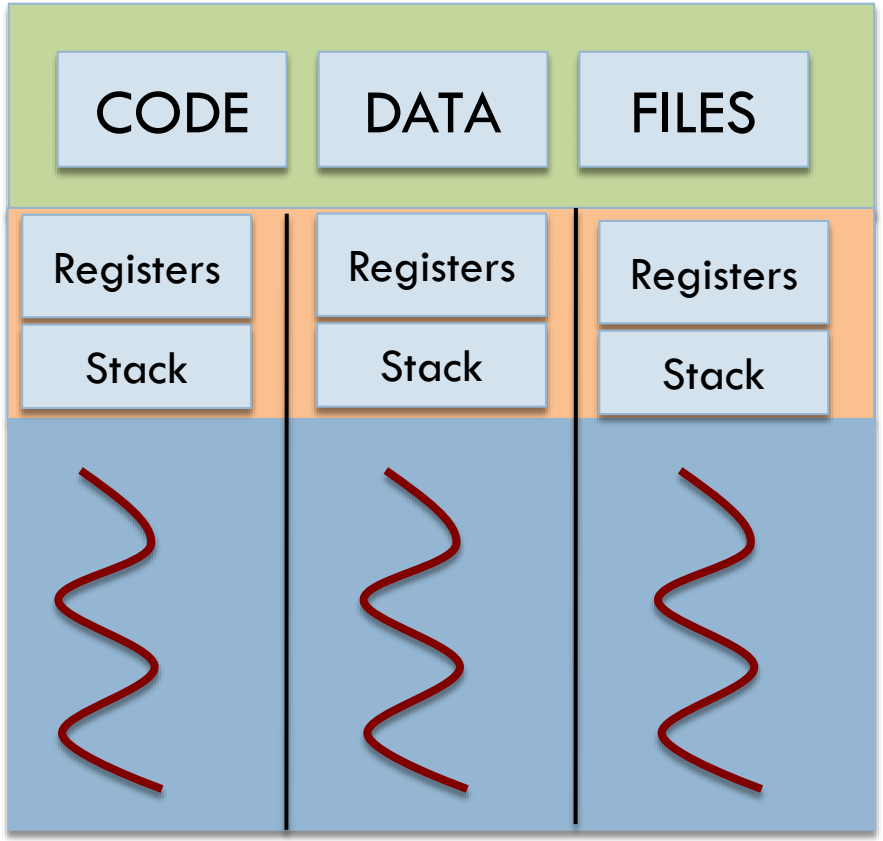
Sharing among threads belonging to a given process

- Code section
- Data section
- OS resources
  - Open files
  - Signals

A process with multiple threads of control can perform more than 1 task at a time



Traditional Heavy weight process



Process with multiple threads

Why each thread needs its own stack (1)

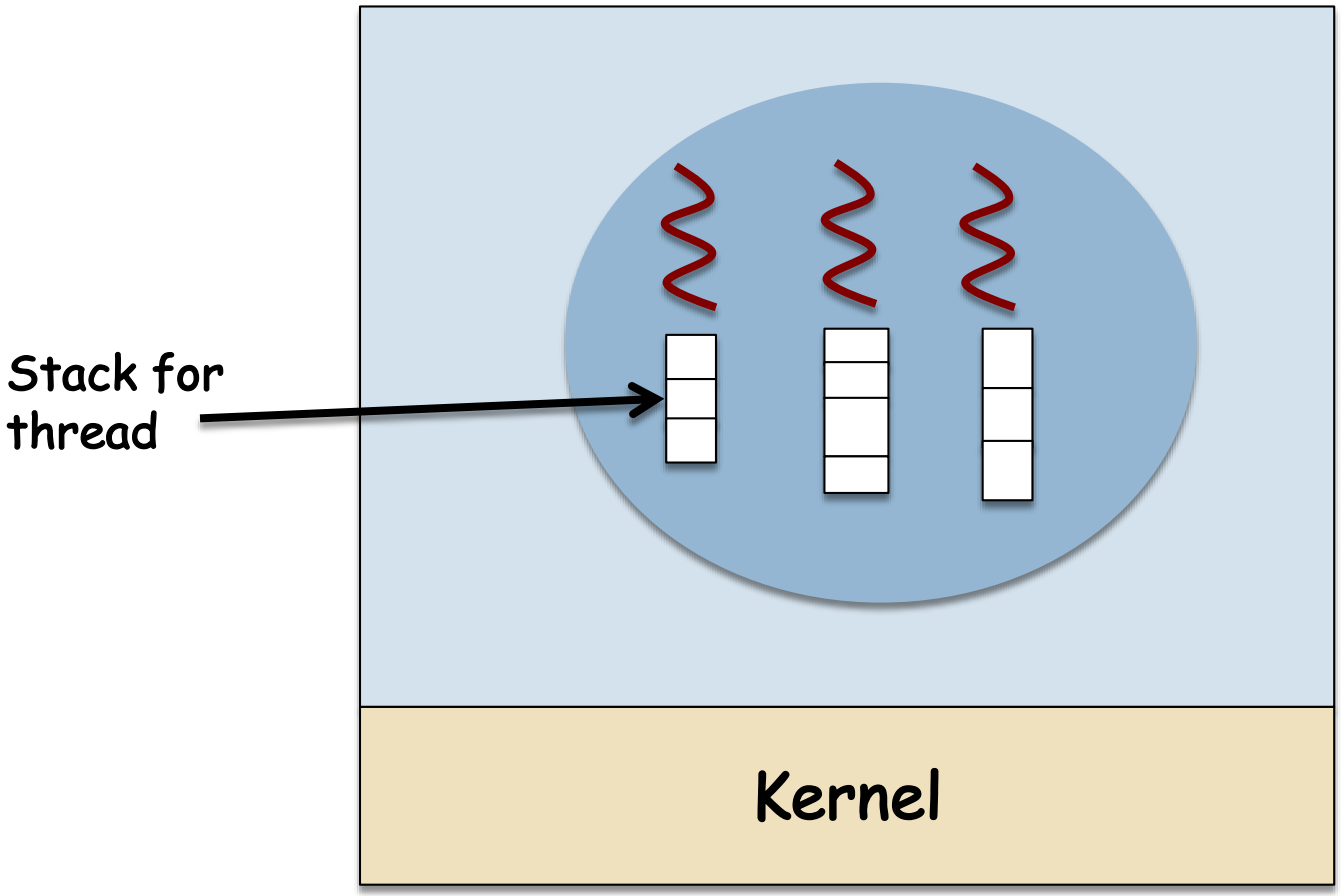
- Stack contains one **frame** for each procedure *called but not returned from*
- Frame contains
  - Local variables
  - Procedure's return address

Why each thread needs its own stack (2)

- Procedure **X** calls procedure **Y**, **Y** then calls **Z**
  - When **Z** *is executing*?
    - Frames for **X**, **Y** and **Z** will be on the stack

- Each thread calls *different* procedures
  - So has a *different execution* history

Each thread has its own stack



Thread states are similar to processes

- Running
- Blocked
- Ready
- Terminated

Benefits of Multithreaded Programming

The rationale for threads

- Process creation is
  - Time consuming
  - Resource intensive
- If new process performs same tasks as existing process
  - Why incur this overhead?
- Much more efficient to use multiple threads in the process

Threads have made inroads into the OS itself

- Most OS kernels are now multithreaded
  - Perform specific tasks
  - Interrupt handling
  - Device management
- Solaris OS
  - Multiple threads in the kernel for interrupt handling
- Linux
  - Kernel thread manages system's free memory

Benefits of multithreaded programming

1. Responsiveness
2. Resource Sharing
3. Economy
4. Scalability

Multithreaded programming: Benefit #1 Responsiveness

- Interactive multithreaded application
  - **Parts** of program may be blocked or slow
  - **Remainder** of program may still chug along
  - E.g., Web browser
    - You may read text, while high-resolution image is being downloaded

Multithreaded programming: Benefit #2 Resource Sharing

- Programmer **arranges sharing** between processes
  - Shared memory & message passing
- Threads within a process **share** its resources
  - Memory, code, and data
  - Allows several different threads of activity within the same process

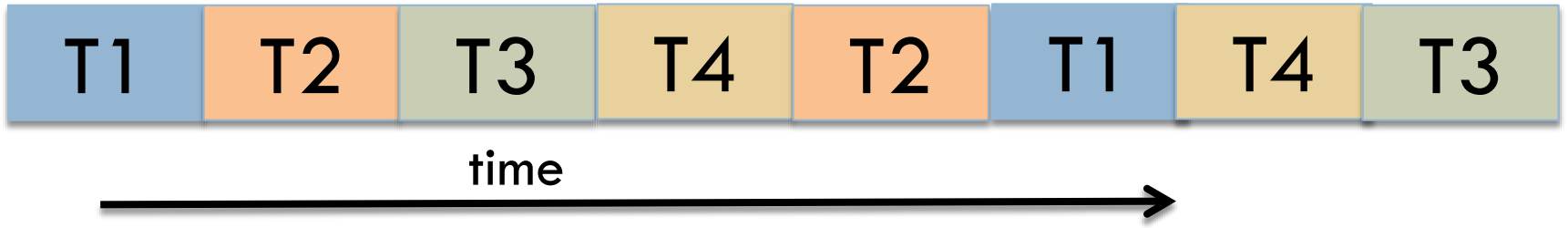
Multithreaded programming: Benefit #3 Economy

- Process creation is memory and resource intensive
- Threads share process' resources
  - Economical to **create** and **context-switch** threads
- Solaris: Process vs. Threads
  - Process creation is 30 times slower
  - Process context switching is 5 times slower

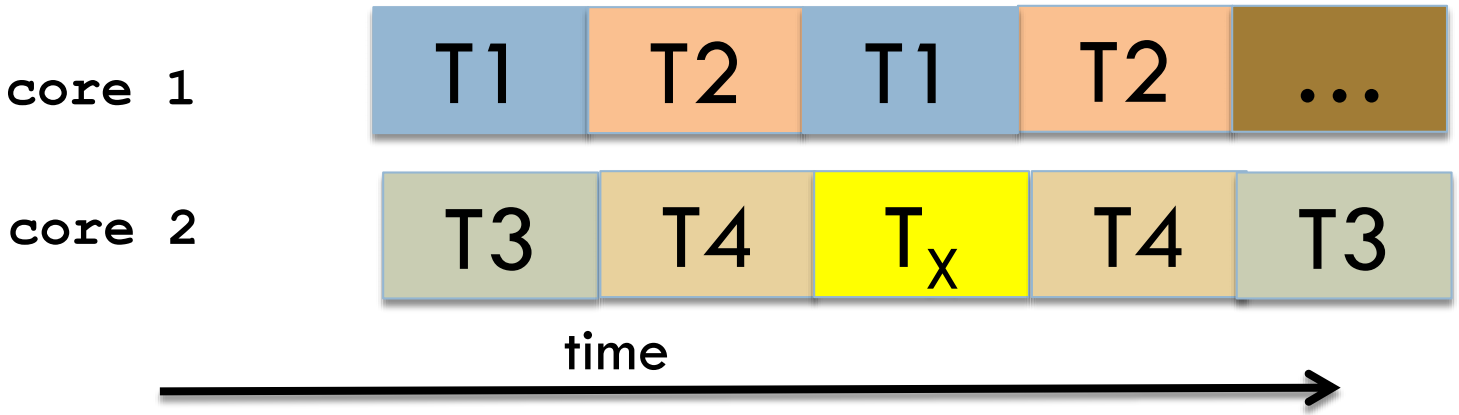
Multithreaded programming: Benefit #4 Scalability

- A single threaded process can ONLY run on 1 processor
  - Regardless of how many are available
  - Underutilization of compute resource

Comparing thread executions on single core and dual core systems



Single core: Thread executions are interleaved on a single core



True concurrency: Threads execute in parallel on different cores

Demand pulls of multicore systems

- OS designers
  - Scheduling algorithms to harness multiple cores
- Application Programmers
  - Modify existing non-threaded programs
    - Daunting!
  - Design multithreaded programs

Going about writing multithreaded programs (1)

- **Subdivide** functionality into multiple separate & concurrent tasks
- Ensure tasks perform equal work of equal value

Going about writing multithreaded programs (2)

- Managing **data** manipulated by tasks
  - Split to run on separate cores. BUT
    - Examine data dependencies between the tasks
- Threaded programs on many core systems have many different **execution paths**
  - Which may or may not reveal **bugs**
  - Testing and debugging is inherently harder

COMPLICATIONS INTRODUCED BY THREADS

Semantics of `fork()` and `exec()` with a multithreaded program

- If one thread calls `fork()`
  - Does new thread duplicate all threads?
  - Is the new process single-threaded?
- Depends on when/if `exec()` is called
  - If immediate: Duplicating all threads unnecessary
  - If NOT: Separate process should duplicate all threads

If the child process gets as many threads as the parent

- What happens if a thread in the parent was blocked on a `read` system call?
  - Say from the keyboard
- Are there two threads blocked on the keyboard?
  - When a line is typed, do both threads get a copy?
- Same issue with open network connections

Problems relating to sharing data structures

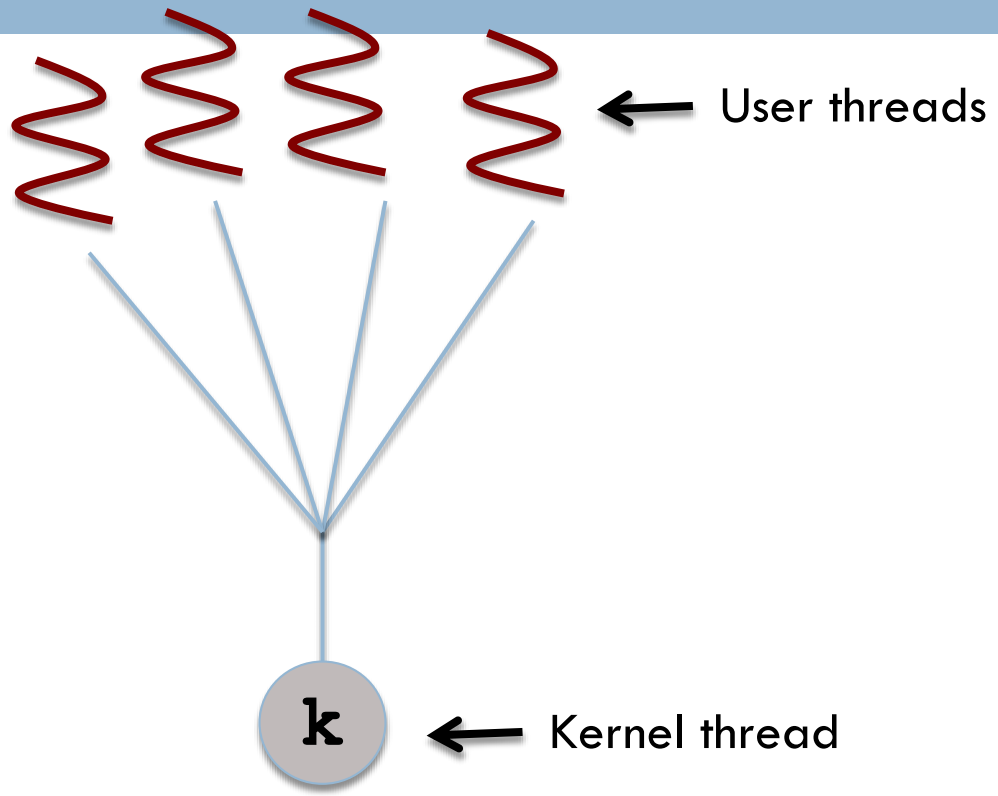
- What if one thread closes a file …
  - When another thread is reading from it?
- A thread notices that there is little memory
  - Starts allocating more memory
  - Midway in the allocation, a thread-switch occurs
  - New thread notices there is too little memory
    - Starts allocating more memory
  - Memory gets allocated twice!

Support for Threads

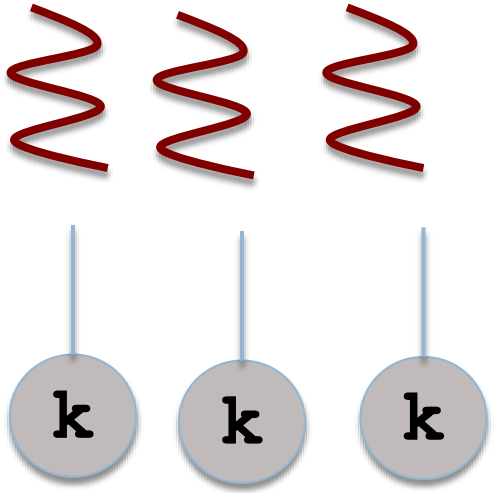
Support for threads

- Kernel threads
  - Supported & managed by the OS
- User threads
  - User level
  - Above the kernel
- A **relationship must exist** between user threads and kernel threads

Summarizing threading models

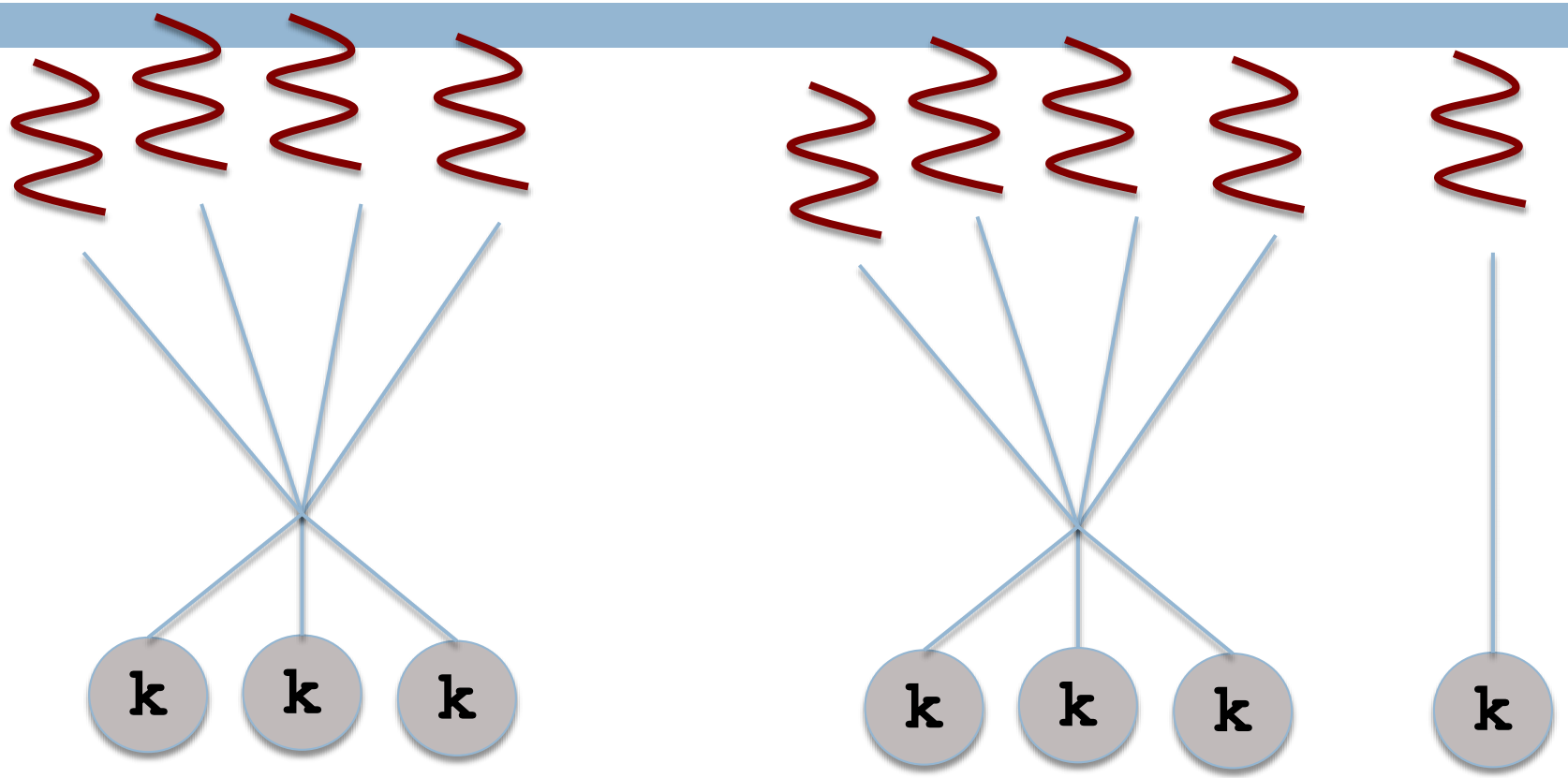


Many-to-One



One-to-one

Summarizing threading models

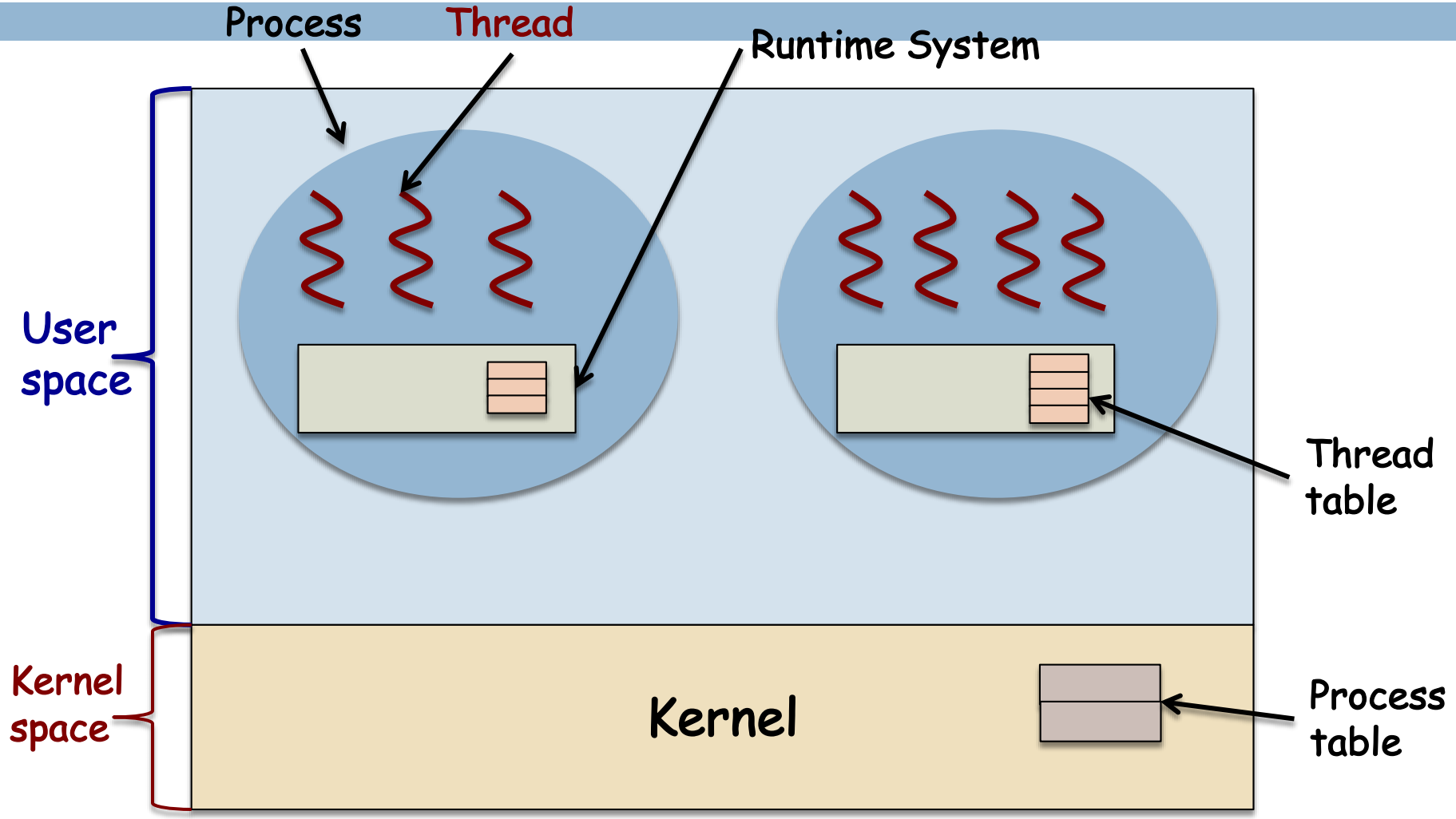


Many-to-Many

Two-level

User-level Threads

User-level threads: Overview



User threads are invisible to the kernel and have low overhead

- **Compete among themselves** for resources allocated to their encapsulating process
- Scheduled by a *thread runtime* system that is **part** of the process code
- Programs link to a special library
  - Each function is enclosed by a **jacket**
  - Jacket function calls thread runtime to do thread management
    - Before (and possibly after) calling jacketed library function.

User level thread libraries: Managing blocking calls

- **Replace** potentially blocking calls with non-blocking ones
- If a call does not block, the runtime invokes it
- If the call *may block*
  1. Place thread on a list of *waiting* threads
  2. Add call to list of actions to *try later*
  3. Pick another thread to run
- ALL control is **invisible** to user and OS

Disadvantages of the user level threads model (1)

- Assumes that the runtime will **eventually regain** control, this is thwarted by:
  - CPU bound threads
  - Thread that *rarely* perform library calls …
    - Runtime can't regain control to schedule other threads
- Programmer must avoid **lockout** situations
  - Force CPU-bound thread to *yield* control

Disadvantages of the user level threads model (2)

- Can only share processor resources allocated to encapsulating process
  - **Limits** available parallelism

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 4]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2].
- *Kay Robbins & Steve Robbins. Unix Systems Programming, 2nd edition, Prentice Hall ISBN-13: 978-0-13-042411-2.* [Chapter 12]