# COS 318: Operating Systems

# Processes and Threads

# Next Few Lectures

- Processing: Concurrency and Sharing
  - Concurrency, Processes, Threads
  - Synchronization
  - CPU scheduling
  - Deadlock

# Today's Topics

- Concurrency
- Processes
- Threads

# Concurrency, Processes and Threads

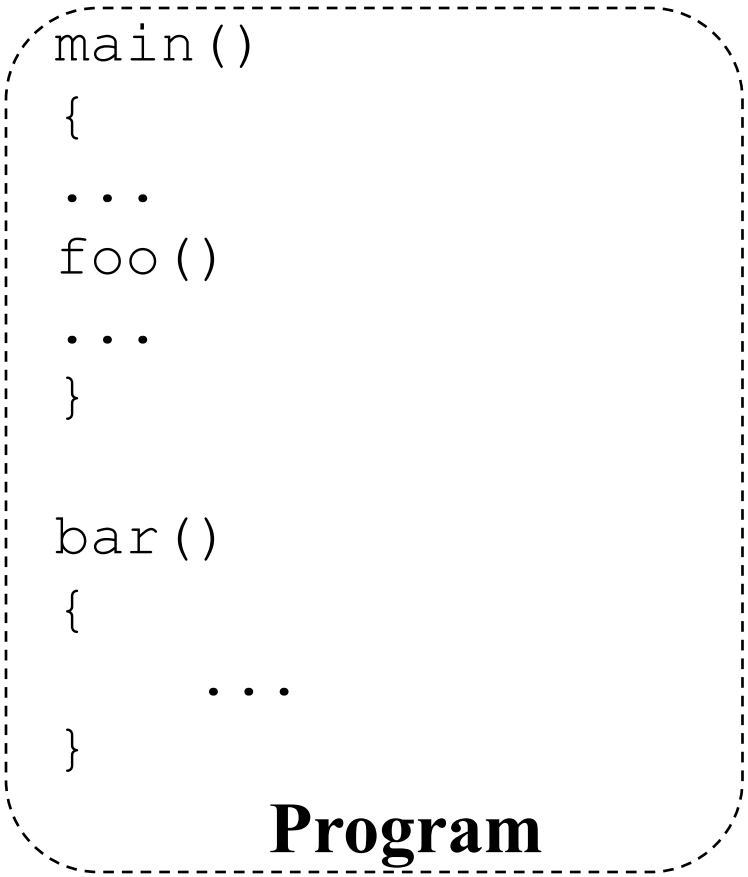
- Concurrency
  - Many things going on in an operating system
    - Application process execution, interrupts, background tasks, maintenance
  - CPU is shared, as are I/O devices
  - Human beings are not good at keep track and programming monolithically
  - Processes (and threads) are abstractions to bridge this gap

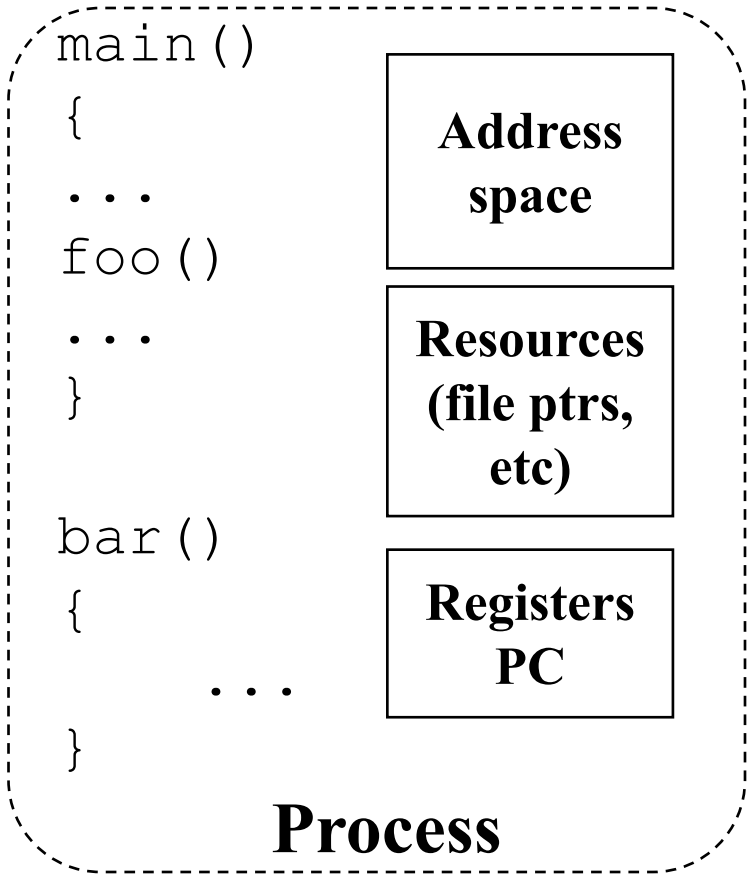
- Concurrency via Processes
  - Decompose complex problems into simple ones
  - Make each simple one a process
  - Processes run ‘concurrently’ but each process feels like it has its own CPU

- Q: What programs, and what processes are launched when you type “gcc –pipe –v”

# Process

- An instance of a program in execution
  - Program code, execution context, one or more threads




# Process vs. Program

- Process > program
  - Program is just the code; just part of process state

- Process < program
  - A program can invoke more than one process
  - Example: Fork off processes
  - Many processes can be running the same program

# Simplest Process

- Sequential execution
  - One thread per process
  - No concurrency inside a process
  - Everything happens sequentially
  - Some coordination may be required

- Process state
  - Registers
  - Main memory
  - I/O devices
    - File system
    - Communication ports
  - …

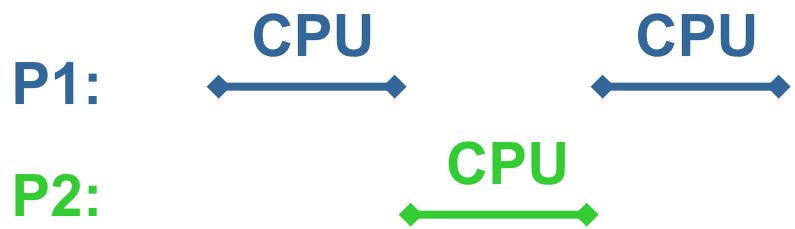
# Threads

- A process has an address space and resources
- Thread: a locus of execution
  - A sequential execution stream within a process (sometimes called lightweight process)
  - Separately schedulable: OS/runtime can run/suspend
  - A process can have one or more threads
  - Threads in a process share the same address space

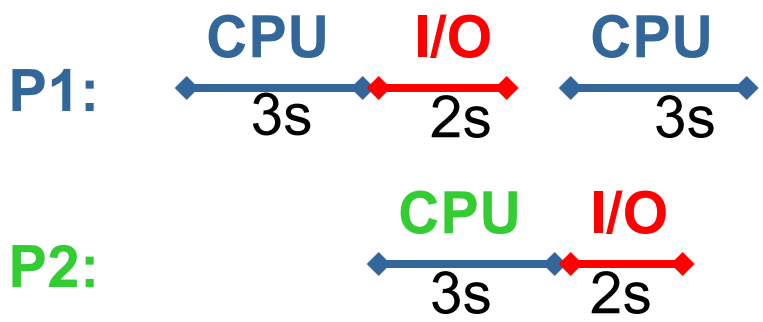

- Can have concurrency across processes, and/or across threads within a process
  - We will initially assume one thread per process

# Process Concurrency

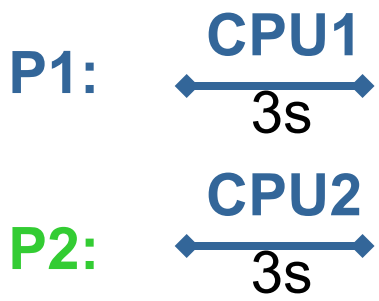
- CPU Interleaving
  - Processes interleaved on CPU




- I/O concurrency
  - P1 doing I/O overlapped with P2 running on CPU
  - Each may run almost as fast as if it has its own computer
  - Reduce total completion time




- CPU parallelism
  - Multiple CPUs (such as SMP)
  - Processes running in parallel
  - Speedup



# Parallelism

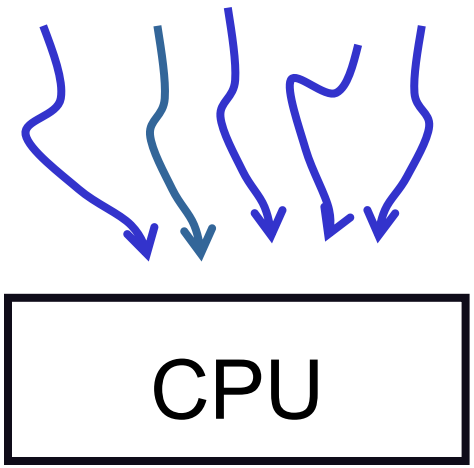
- Parallelism is common in real life
  - A single salesperson sells $1M annually
  - Hire 100 salespeople to generate $100M revenue
- Speedup
  - Linear speedup is factor of N for N parallel entities
- Q:
  - By what factor can you speed up completing your assignment by working with a partner or two?
  - By what factor when working with 20 partners?
  - Can you get super-linear (more than a factor of N) speedup? Can a program (by using N processors)?

# Concurrency in Computing

- Parallel programs
  - To achieve better performance
- Servers (expressing logically concurrent tasks)
  - Multiple connections handled simultaneously
- Programs with user interfaces
  - To achieve user responsiveness while doing computation
- Network and disk bound programs
  - To hide network/disk latency

# The Processing Illusion

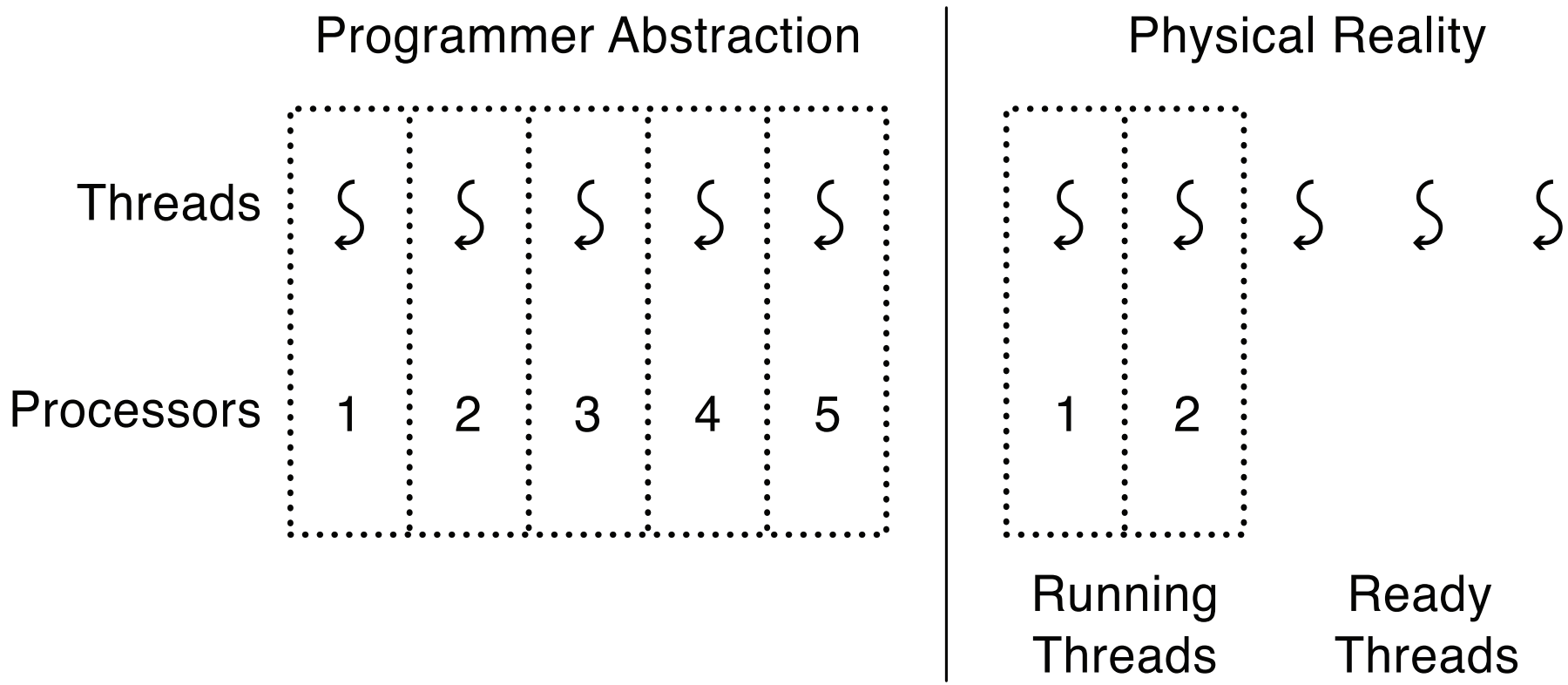
- Every process thinks it owns the CPU
  - Yet on a uniprocessor all processes share the same physical CPU
  - How does this work?
  - Processes are interleaved on the CPU
    - (and further, their threads are, but for now we assume one thread per process)




- Four key pieces:
  - Timer interrupt
  - PCB --- process control block, one per process, holds execution state
  - Dispatch loop
  - Scheduling algorithm

# The Abstraction

- Every process (thread) runs on a dedicated virtual processor, with unpredictable/variable speed
  - Programs must work with any schedule

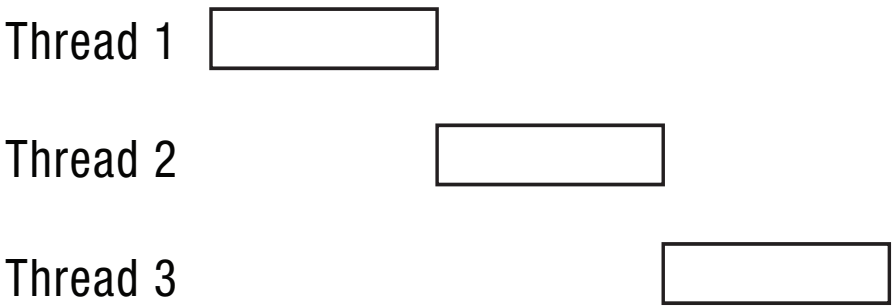



# Programmer vs. Processor View

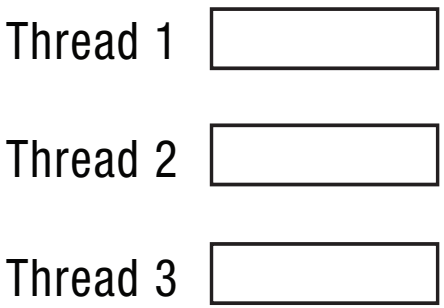
| Programmer's View | Possible Execution #1 | Possible Execution #2 | Possible Execution #3 |
|---|---|---|---|
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| x = x + 1; | x = x + 1; | x = x + 1; | x = x + 1; |
| y = y + x; | y = y + x; | ..... | y = y + x; |
| z = x + 5y; | z = x + 5y; | Thread is suspended. | ..... |
| . | . | Other thread(s) run. | Thread is suspended. |
| . | . | Thread is resumed. | Other thread(s) run. |
| . | . | ..... | Thread is resumed. |
| | | y = y + x; | ..... |
| | | z = x + 5y; | z = x + 5y; |

# Possible executions

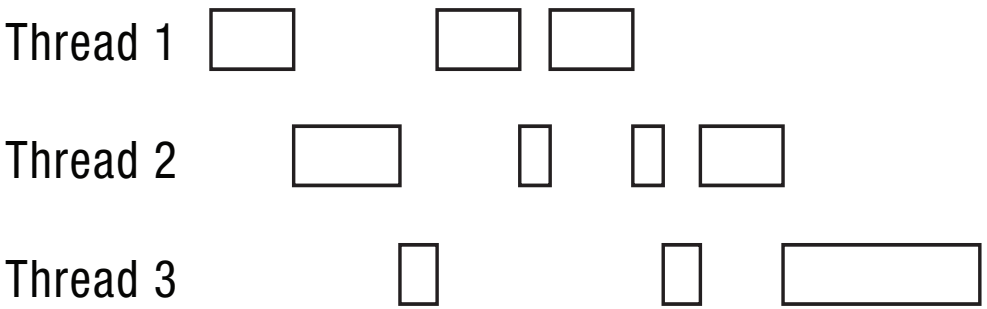
## One Execution (1 core)




## Another Execution (3 cores)




## Another Execution (1 core)

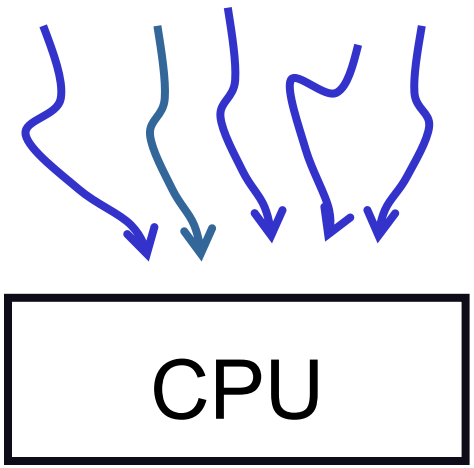



Q: Why might a running thread be de-scheduled from the CPU?

# Context Switching Processes

- Scheduler Dispatch Loop

```
while(1){
   interrupt
   save state
   get next process
   load state, jump to it}
```




- But processes have state, some of which resides in resources that the new running process may use

# Process State

- Process management info
  - Identification
  - State
    Ready: ready to run.
    Running: currently running.
    Blocked: waiting for resources
  - Registers, EFLAGS, EIP, and other CPU state
  - Stack, code and data segment
  - Parents, etc
- Memory management info
  - Segments, page table, stats, etc
- I/O and file management
  - Communication ports, directories, file descriptors, etc.
- Resource allocation and accounting information

# Managing Execution: Process Control Block

PCB holds state and resource information associated with a process

| **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 | | |

Possible fields of a PCB

# API for Process Management

- Creation and termination
  - Exec, Fork, Wait, Kill
- Operations
  - Block, Yield
- Signals
  - Default action, Handler, Ways to send
- Synchronization
  - We will talk about this a lot more later

# Create a Process

- Creation
  - Load code and data into memory
  - Create an empty call stack
  - Initialize state
  - Make the process ready to run

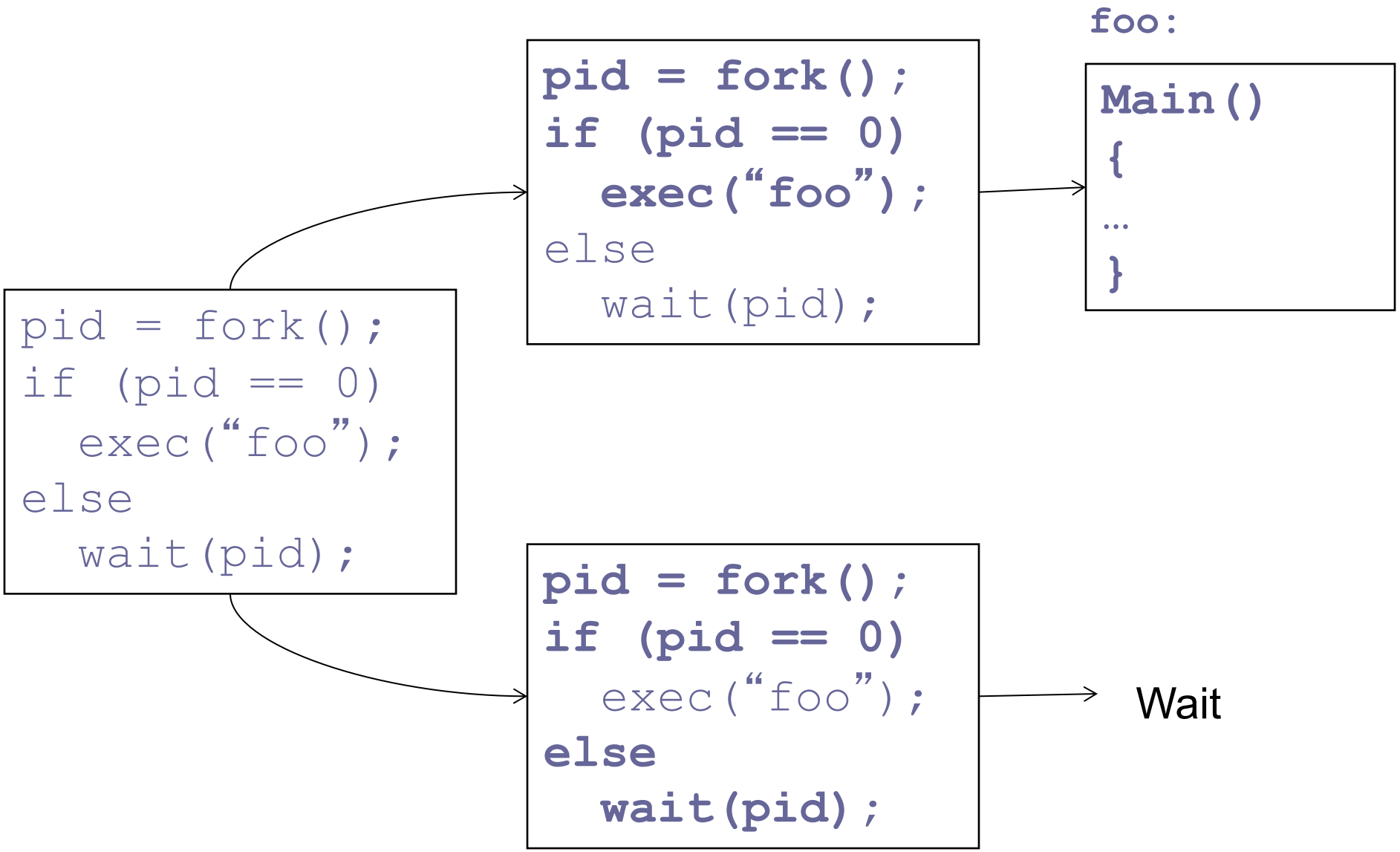
- Cloning a process
  - Save state of current process
  - Make copy of current code, data, stack and OS state
  - Make the process ready to run

# Unix Example

- Methods to create and run processes:
  - fork clones a process
  - exec overlays the current process

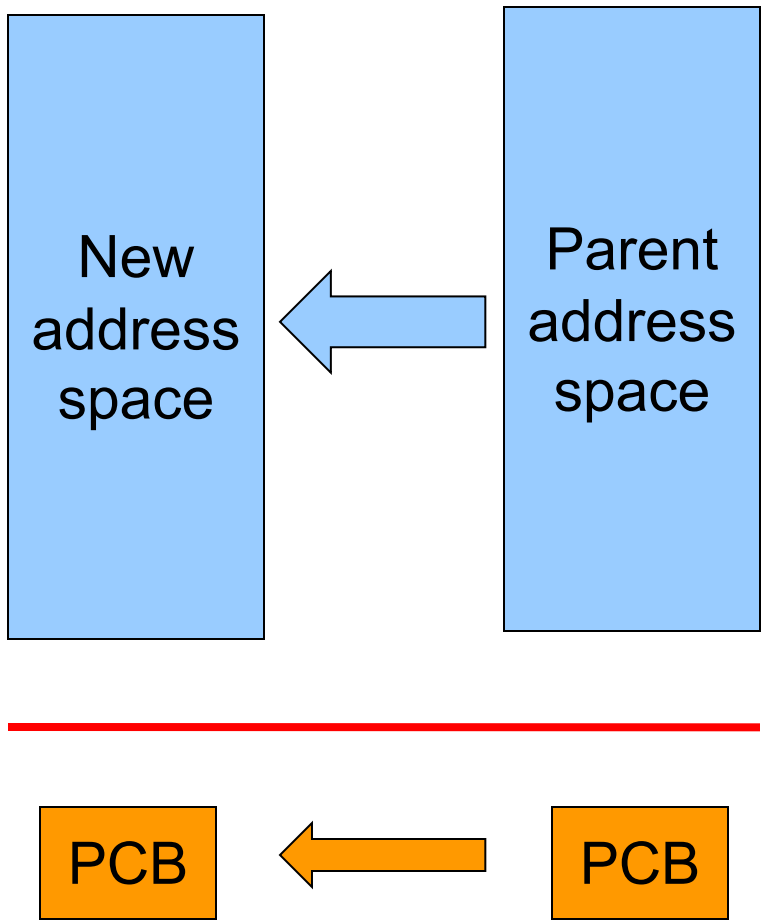
```
pid = fork();
if (pid == 0)    /* child process */
  exec("foo");   /* does not return */
else             /* parent */
  wait(pid);     /* wait for child to die */
```

# Fork and Exec in Unix



# More on Fork

- Create and initialize PCB
- Create an address space
- Copy the content of the parent address space to the new address space
- Child inherits the execution context of the parent (e.g. open files)
- Inform scheduler that new process is ready

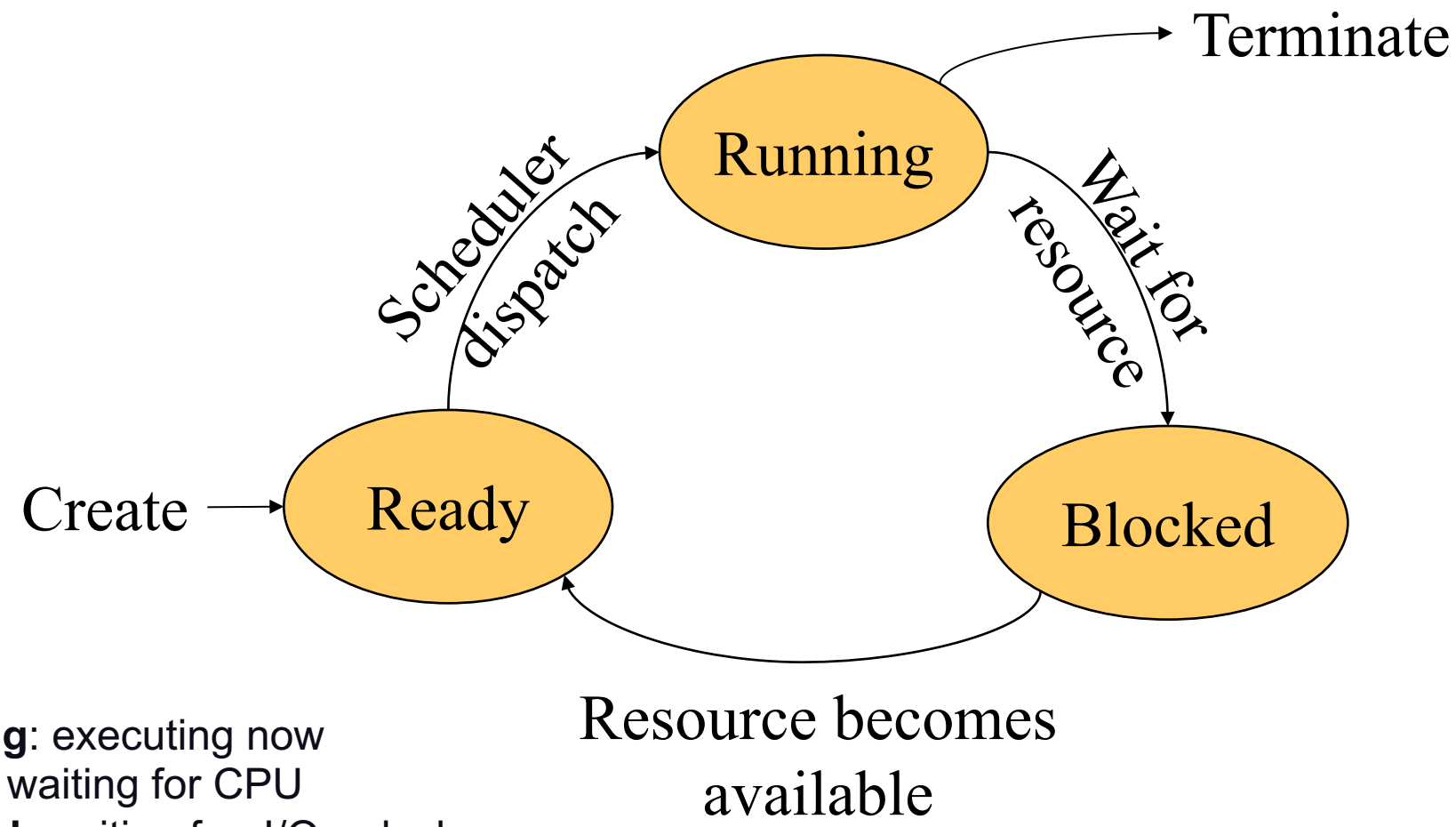



# Process Context Switch

- Save a context (everything that a process may damage)
  - All registers (general purpose and floating point)
  - All co-processor state
  - Save all memory to disk?
  - What about cache and TLB?
- Start a context
  - Does the reverse
- Challenge
  - OS code must save state without changing any state
  - E.g. how should OS run without touching any registers?
    - CISC machines have a special instruction to save and restore all registers on stack
    - RISC: reserve registers for kernel or have way to carefully save one and then continue

# Process State Transition

Non-preemptive case: e.g. no timer interrupts



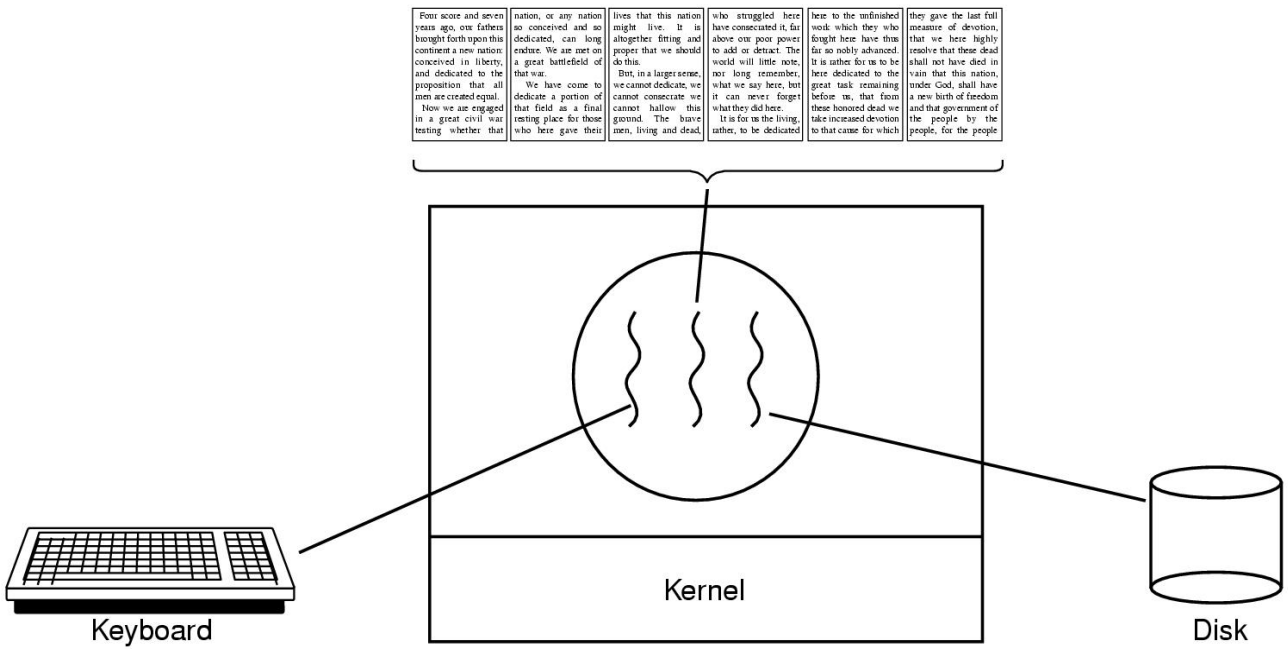

**Running**: executing now
**Ready**: waiting for CPU
**Blocked**: waiting for I/O or lock

# Threads

- Thread
  - A sequential execution stream within a process (also called lightweight process)
  - Separately schedulable: OS or runtime can run or suspend at any time
  - A process may have one or more threads (loci of execution)
  - Threads in a process share the same address space
  - Process is more about code and resources; thread about instruction execution paths – every process has at least one
- Why do we need multiple threads per process?

# Thread Concurrency

- Easier to program overlapping I/O and CPU with threads than with signals
- A server (e.g. file server) serves requests with different threads
- Multiple CPUs sharing the same memory

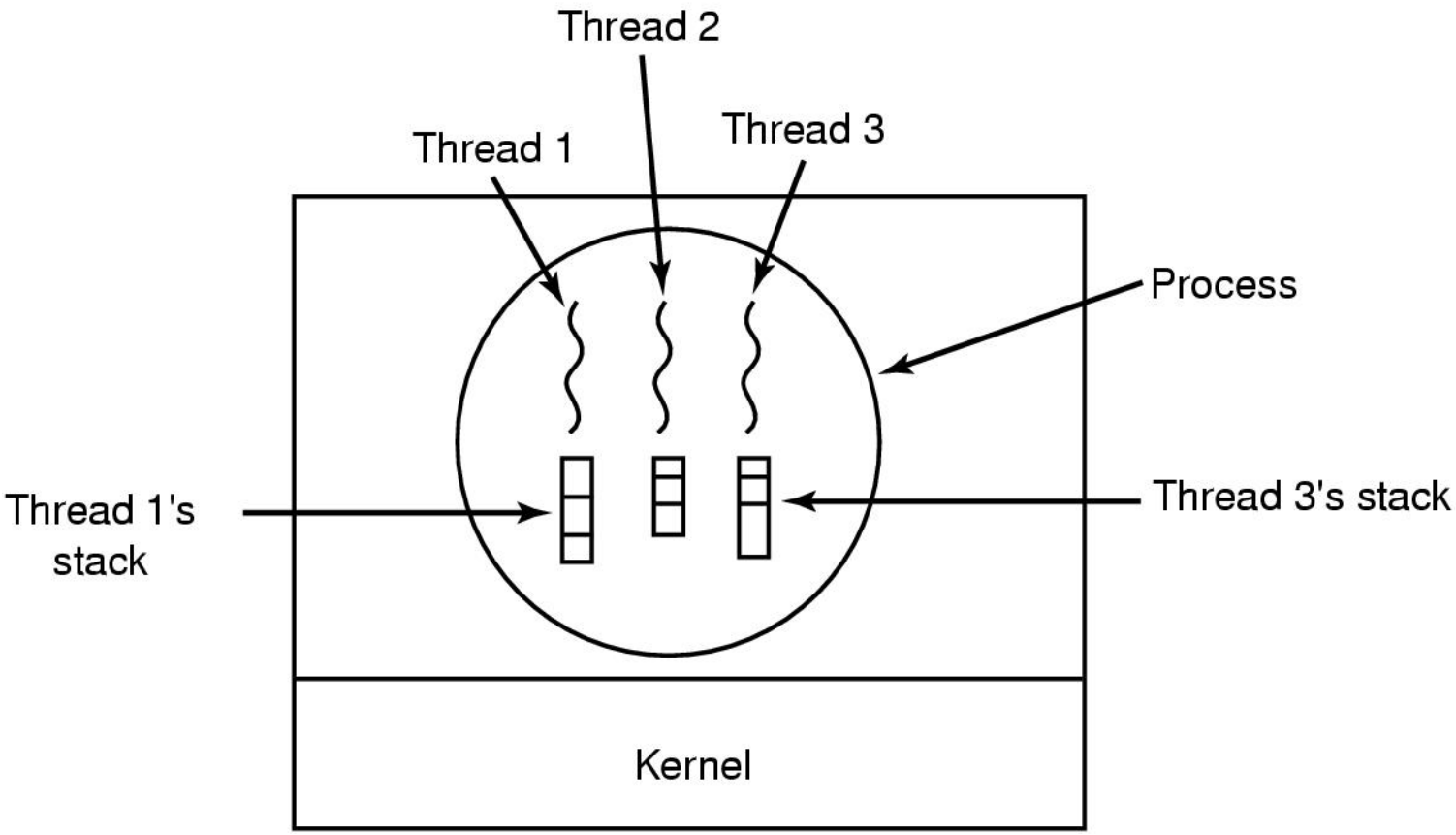



A word processor with three threads

# Typical Thread API

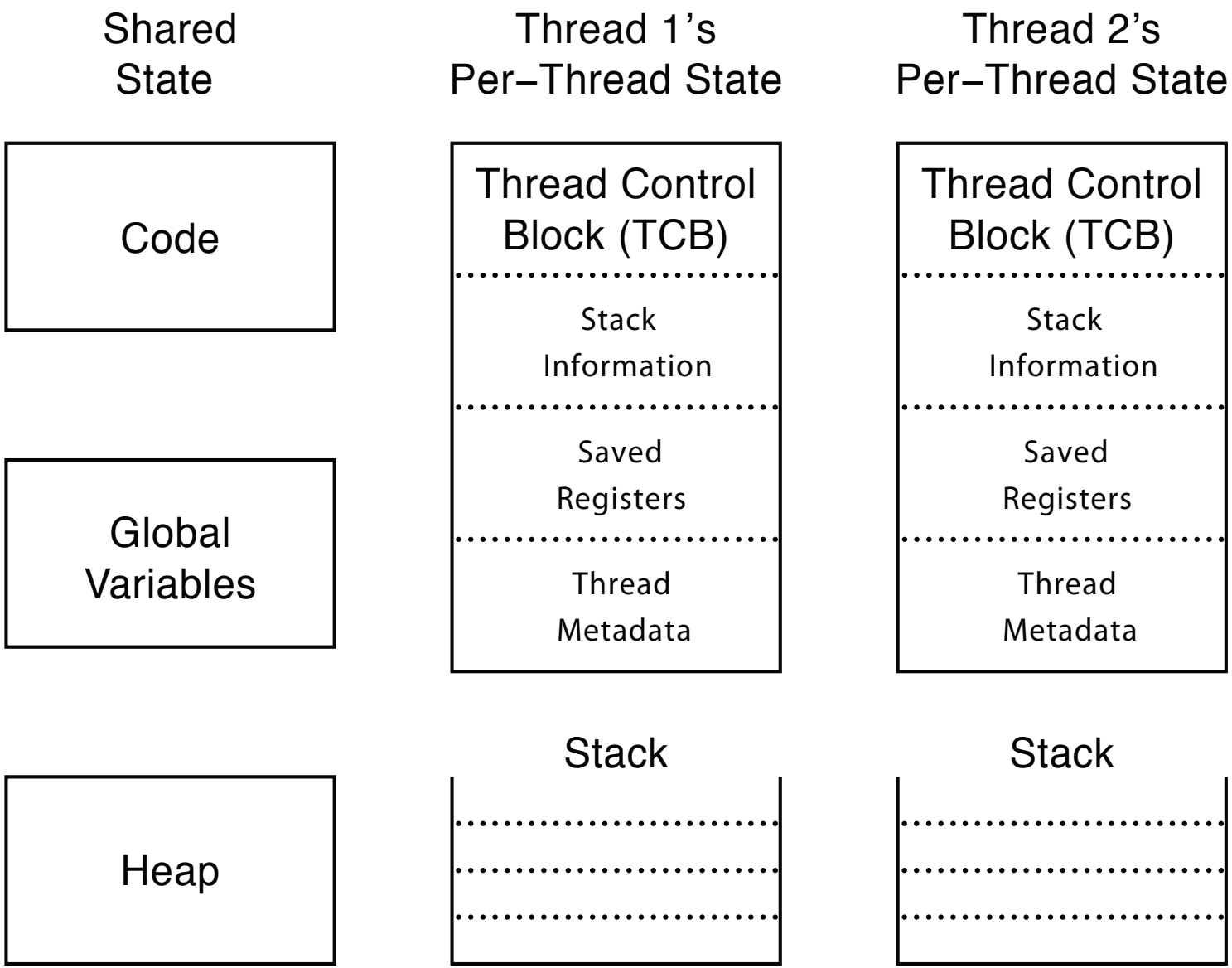
- Creation
  - Fork, Join
- Mutual exclusion
  - Acquire (lock), Release (unlock)
- Condition variables
  - Wait, Signal, Broadcast
- Alert
  - Alert, AlertWait, TestAlert

# Threads (cont'd)




Every thread has its own stack

# Thread Data Structures




# Thread Control Block (TCB)

- Current execution state that thread is in
  - Ready: ready to run
  - Running: currently running
  - Blocked: waiting for resources
- Registers
- Status (EFLAGS)
- Program counter (EIP)
- Stack information
- Code information

# Thread and Process State

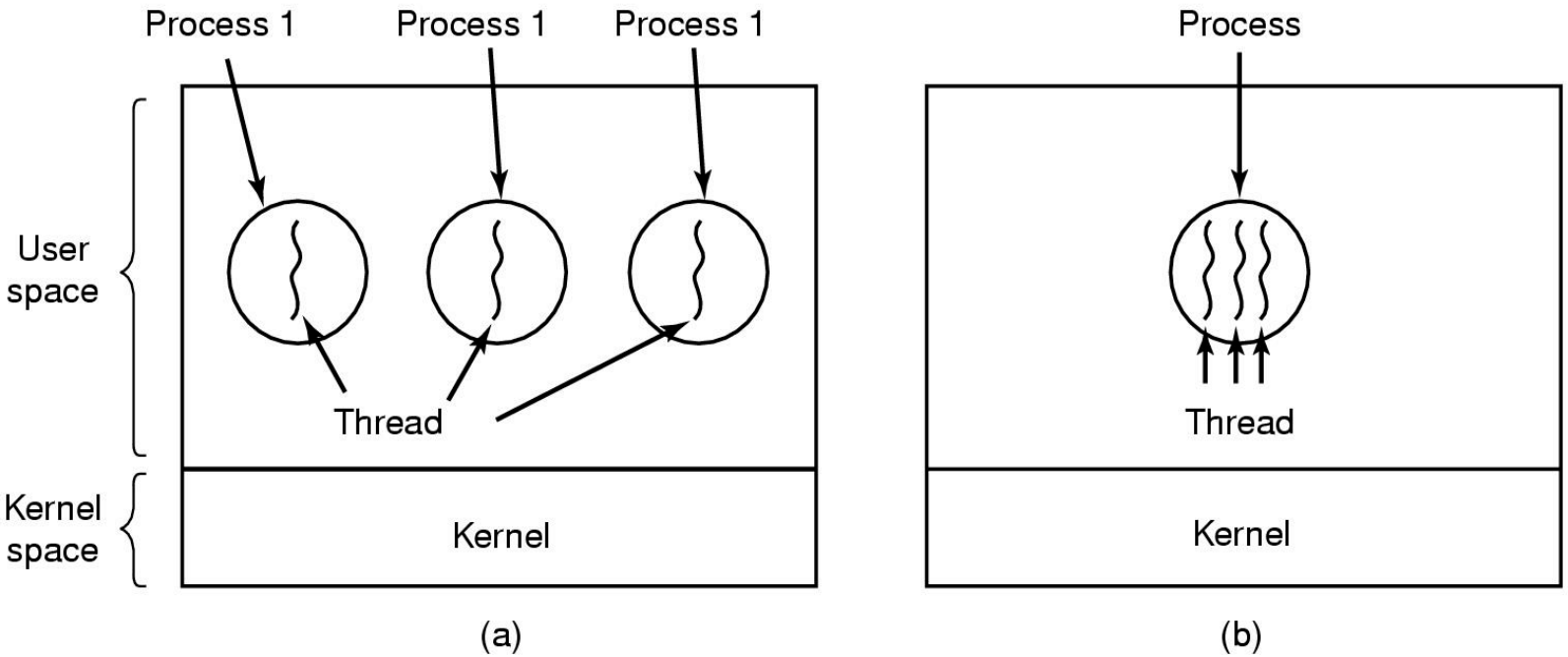
| Per process items | Per thread items |
| --- | --- |
| Address space | Program counter |
| Global variables | Registers |
| Open files | Stack |
| Child processes | State |
| Pending alarms | |
| Signals and signal handlers | |
| Accounting information | |

- Per process: Items shared by all threads in a process
- Per thread: Items private to each thread

# Thread Context Switch

- Save a context (everything that a thread may damage)
  - All registers (general purpose and floating point)
  - All co-processor state
  - Q; Need to save the stack on a thread context switch?
  - Q: What about cache and TLB contents?
- Start a context
  - Does the reverse
- May trigger a process context switch

# Threads and Processes




(a) Three processes each with one thread

(b) One process with three threads

- Process = thread + address space + OS env (open files, etc.)
- Thread provides concurrency; process provides protection

# Process vs Thread Execution Model

- Address space
  - Processes do not usually share memory (address space)
  - Process context switch switches page table and other memory mechanisms
  - Threads in a process share the entire address space
- Privileges
  - Processes have their own privileges (e.g. file access)
  - Threads in a process share all privileges
- Threads are about concurrency, across or within processes; processes are about protection and resource sharing

# Real Operating Systems

- One or many address spaces
- One or many threads per address space

| | 1 address space | Many address spaces |
|---|---|---|
| 1 thread per address space | MSDOS<br>Macintosh | Traditional Unix |
| Many threads per address space | Embedded OS, Pilot | VMS, Mach (OS-X), OS/2, Windows NT/XP/Vista/7, Solaris, HP-UX, Linux |

# Summary

- Concurrency
  - CPU and I/O
  - Among applications
  - Within an application
- Processes
  - Abstraction for concurrency across or within applications
  - Include protection as a key aspect
- Threads
  - Abstraction for concurrency within an application
  - Just about concurrency