# COS 318: Operating Systems

# Processes and Threads

Kai Li and Andy Bavier
Computer Science Department
Princeton University

http://www.cs.princeton.edu/courses/archive/fall13/cos318

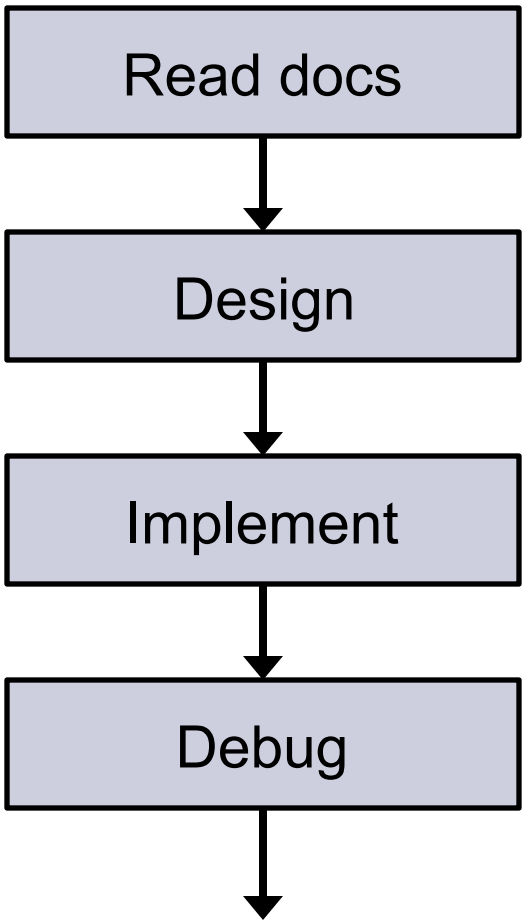
# Today's Topics

- Concurrency
- Processes
- Threads

- Reminder:
  - Hope you're all busy implementing Project 1

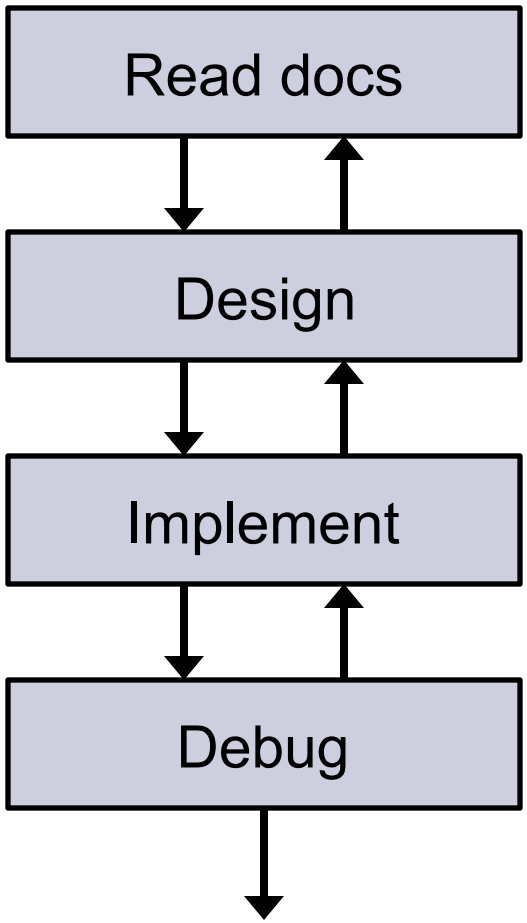
# Development Models

Linear




Vs.

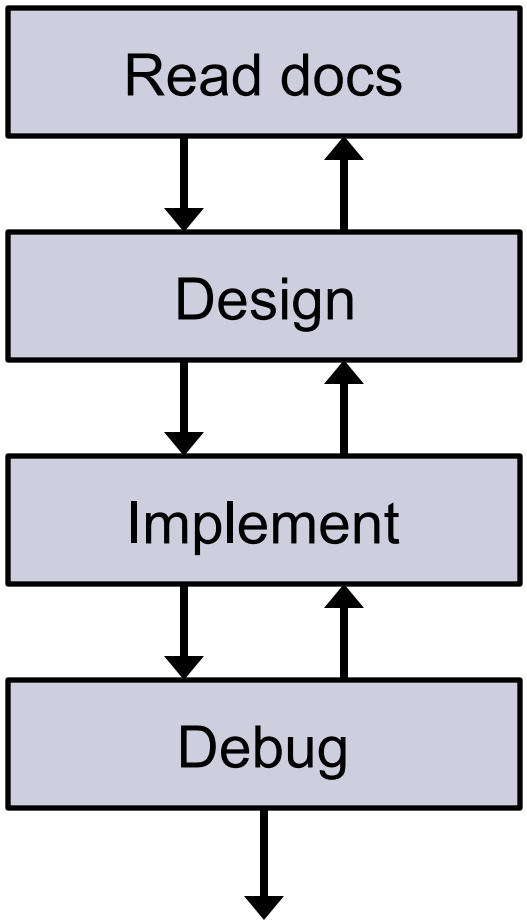
Iterative




# Development Models


"Mr. Osborne, may I be excused? My brain is full."

## Iterative

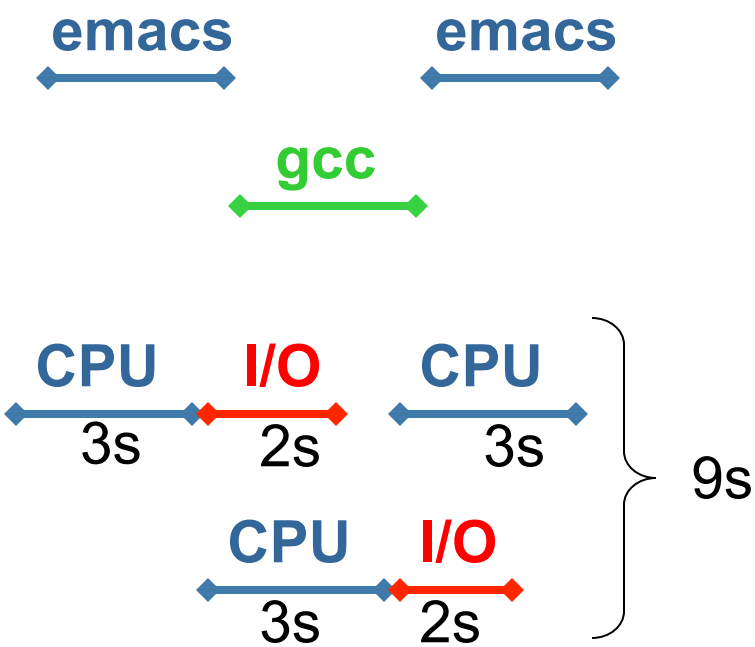


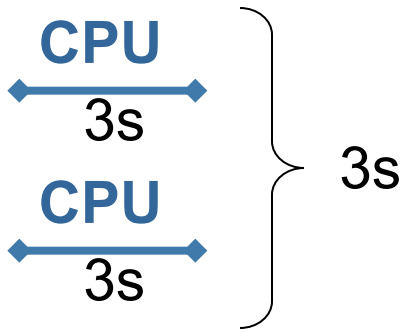
# Concurrency and Process

- Concurrency
  - Hundreds of jobs going on in a system
  - CPU is shared, as are I/O devices
  - Each job would like to have its own computer
- Process concurrency
  - Decompose complex problems into simple ones
  - Make each simple one a process
  - Deal with one at a time
  - Each process feels like having its own computer
- Example: gcc (via “gcc –pipe –v”) launches
  - /usr/libexec/cpp | /usr/libexec/cc1 | /usr/libexec/as | /usr/libexec/elf/ld
  - Each instance is a process

# Process Parallelism

- Virtualization
  - Each process run for a while
  - Make a CPU into many
  - Each virtually has its own CPU
- I/O parallelism
  - CPU job overlaps with I/O
  - Each runs 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



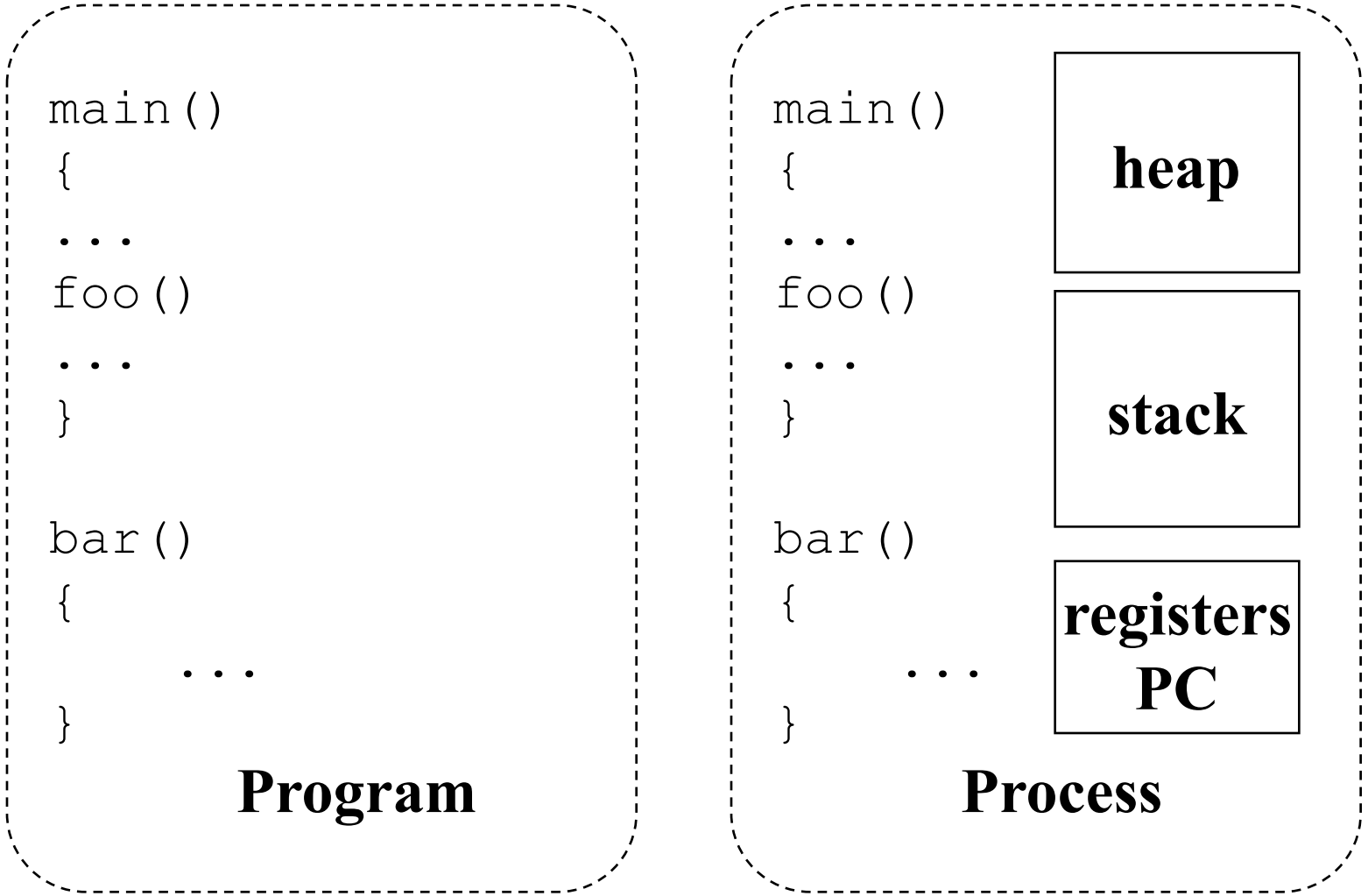
# More on Process Parallelism

- Process parallelism is common in real life
  - Each sales person sell $1M annually
  - Hire 100 sales people to generate $100M revenue
- Speedup
  - Ideal speedup is factor of N
  - Reality: bottlenecks + coordination overhead
- Question
  - Can you speedup by working with a partner?
  - Can you speedup by working with 20 partners?
  - Can you get super-linear (more than a factor of N) speedup?

# Simplest Process

- Sequential execution
  - 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
  - …

# Program and Process



# Process vs. Program

- Process > program
  - Program is just part of process state
  - Example: many users can run the same program
    - Each process has its own address space, i.e., even though program has single set of variable names, each process will have different values
- Process < program
  - A program can invoke more than one process
  - Example: Fork off processes

# Process Control Block (PCB)

- Process management info
  - State
    - Ready: ready to run
    - Running: currently running
    - Blocked: waiting for resources
  - Registers, EFLAGS, 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.
- How OS takes care of processes
  - Resource allocation and process state transition

# Primitives of Processes

- Creation and termination
  - Exec, Fork, Wait, Kill
- Signals
  - Action, Return, Handler
- Operations
  - Block, Yield
- Synchronization
  - We will talk about this later

# Make A Process

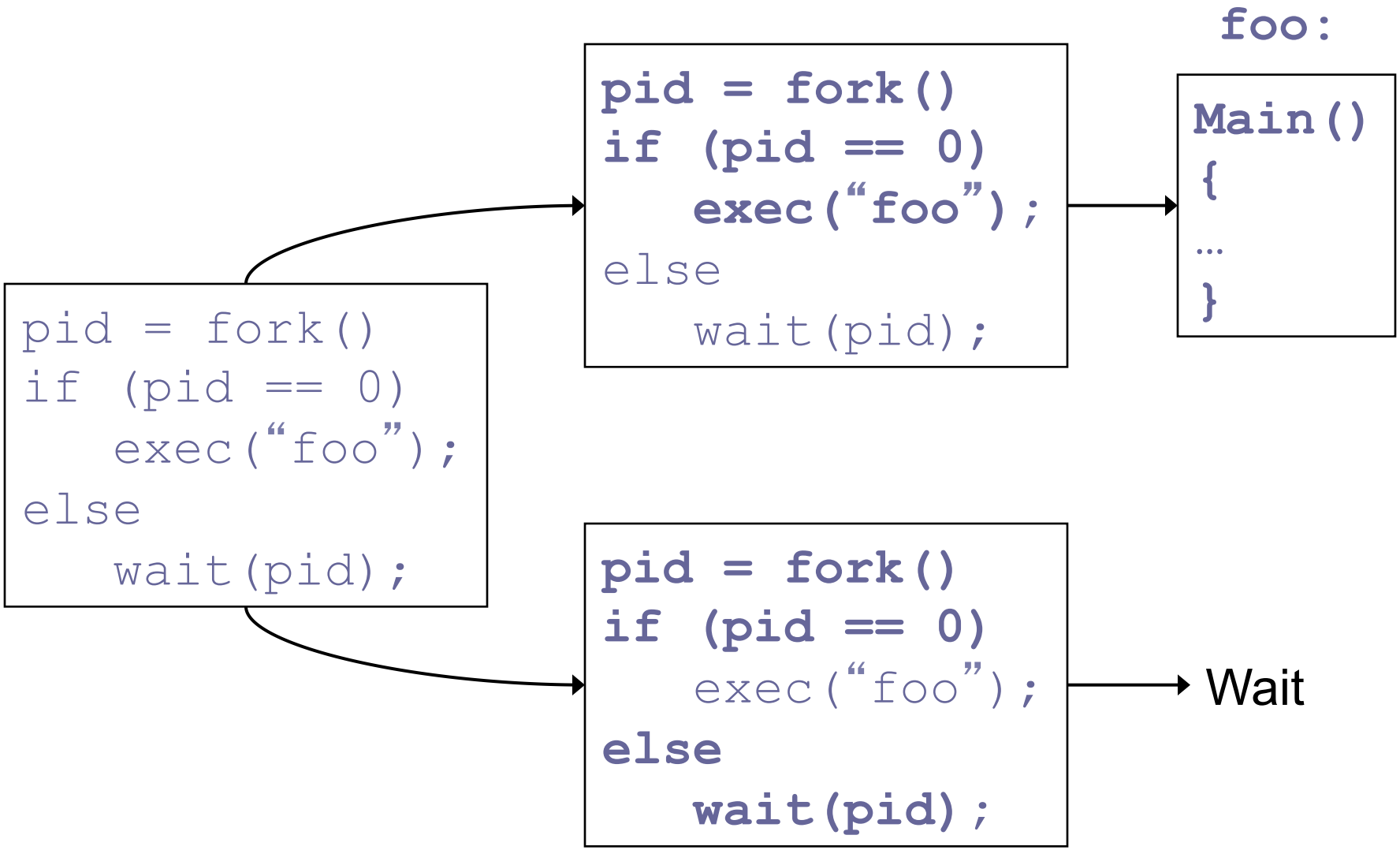
- Creation
  - Load code and data into memory
  - Create an empty call stack
  - Initialize state to same as after a process switch
  - Make the process ready to run
- Clone
  - Stop current process and save state
  - Make copy of current code, data, stack and OS state
  - Make the process ready to run

# Example: Unix

- How to make processes:
  - fork clones a process
  - exec overlays the current process

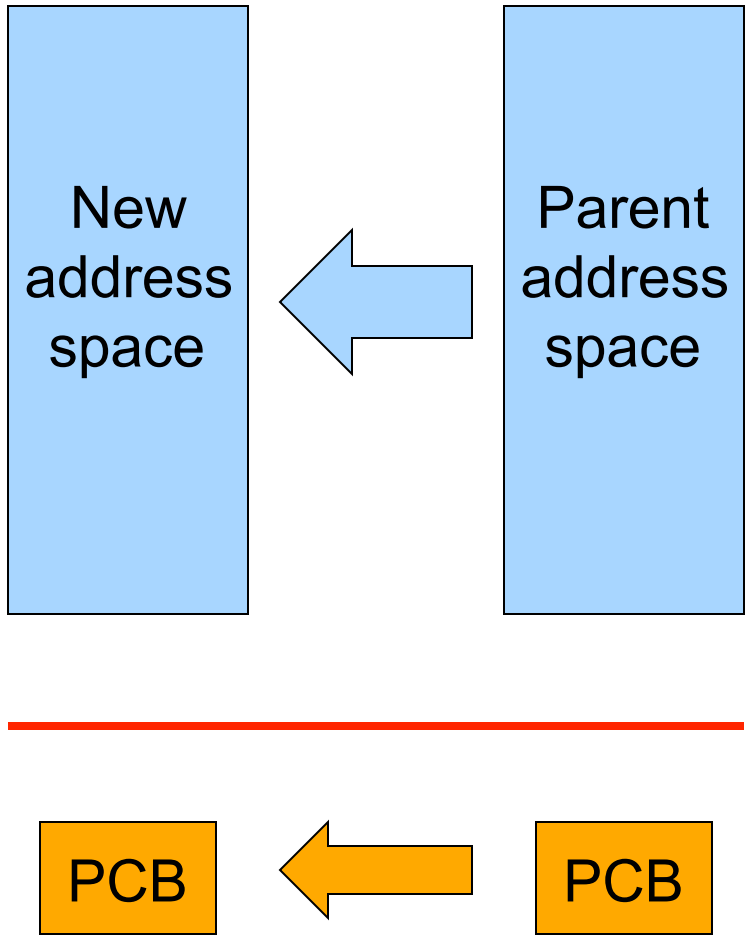
```
pid = fork()
if (pid == 0) {
        /* child process */
       exec("foo");  /* does not return */
} else {
       /* parent */
       wait(pid);     /* wait for child to die */
}
```

# Fork and Exec in Unix



# More on Fork

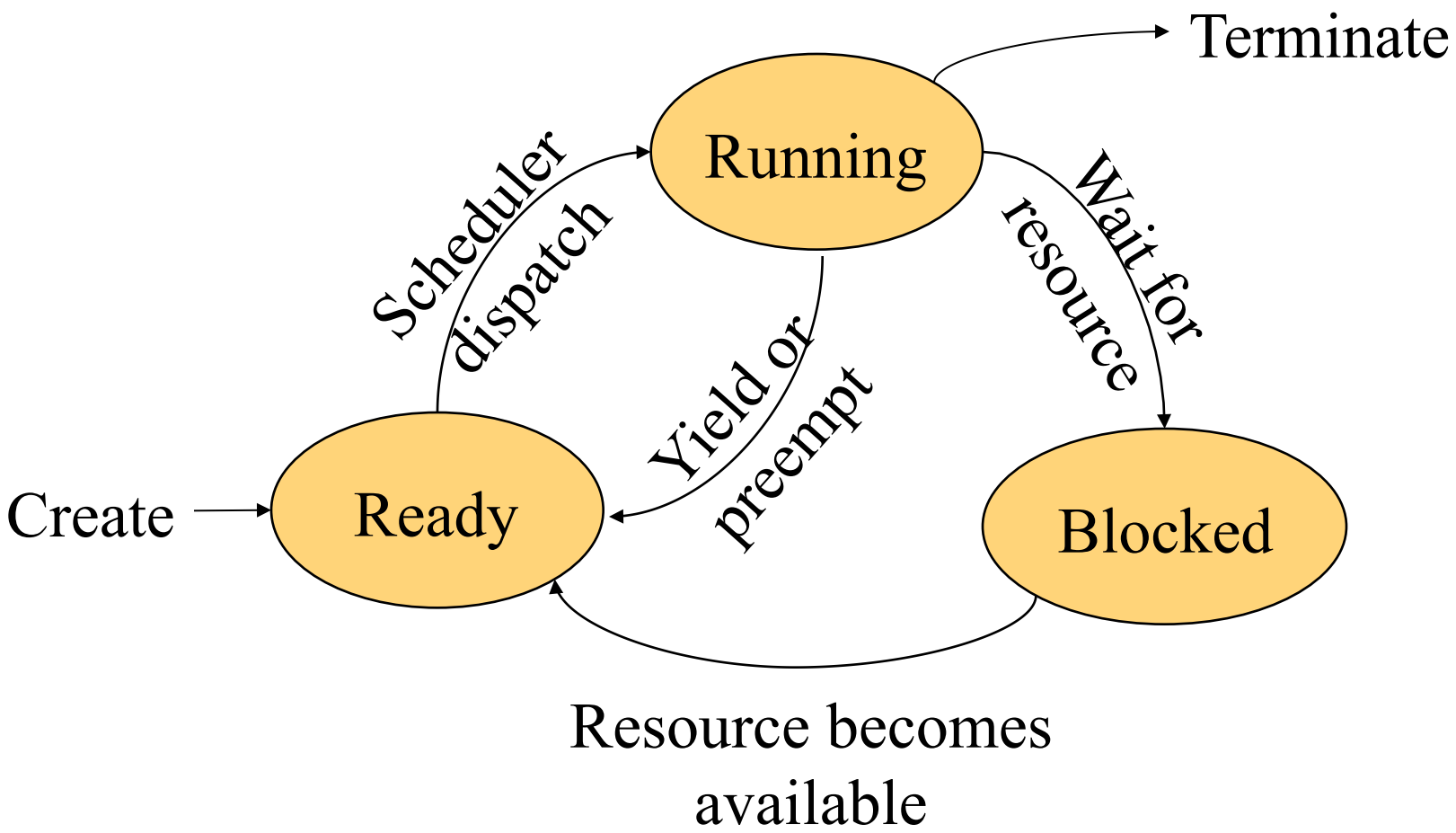
- Parent process has a PCB and an address space
- Create and initialize PCB
- Create an address space
- Copy the contents of the parent address space to the new address space
- Inherit the execution context of the parent
- New process is ready




# 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 stuff?
- Start a context
  - Does the reverse
- Challenge
  - OS code must save state without changing any state
  - How to 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



# Today's Topics

- Concurrency
- Processes
- Threads

# Interlude

*I think there is a profound and enduring beauty in simplicity, in clarity, in efficiency. True simplicity is derived from so much more than just the absence of clutter and ornamentation. It's about bringing order to complexity.*

-- Sir Jony Ive

# From Last Time…

- Q: It says on the slide that Mac OS X is a microkernel, and microkernels are supposed to be more robust, so why does my Mac OS X crash?
- Microkernels can still crash
  - Bugs in the kernel
  - Cannot recover from a critical OS service crashing
- Mac OS X uses XNU "hybrid" kernel: Mach + BSD
  - Many claim it's not a true microkernel

# Threads

- Thread
  - A sequential execution stream within a process (also called lightweight process)
  - Threads in a process share the same address space
- Thread concurrency
  - Easier to program I/O overlapping with threads than signals
  - Responsive user interface
  - Run some program activities “in the background”
  - Multiple CPUs sharing the same memory

# Thread Control Block (TCB)

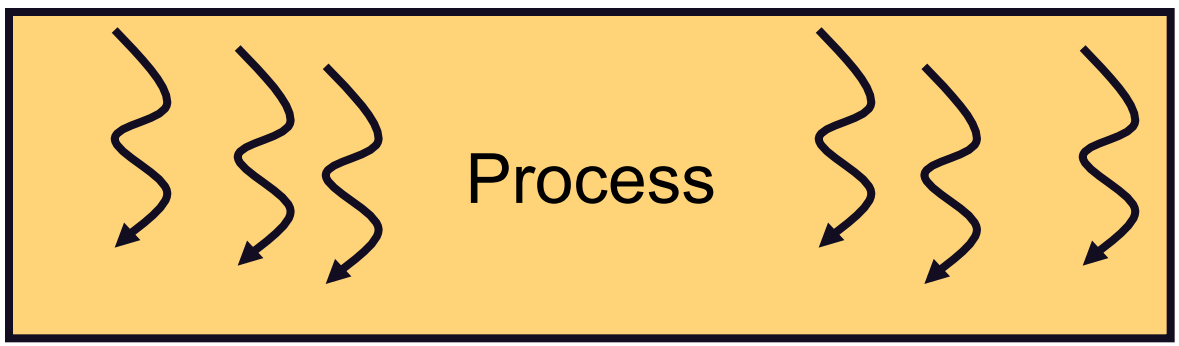
- State
  - Ready: ready to run
  - Running: currently running
  - Blocked: waiting for resources
- Registers
- Status (EFLAGS)
- Program counter (EIP)
- Stack
- Code

# Typical Thread API

- Creation
  - Create, Join, Exit
- Mutual exclusion
  - Acquire (lock), Release (unlock)
- Condition variables
  - Wait, Signal, Broadcast

# Revisit Process

- Process
  - Threads
  - Address space
  - Environment for the threads to run on OS (open files, etc)
- Simplest process has 1 thread

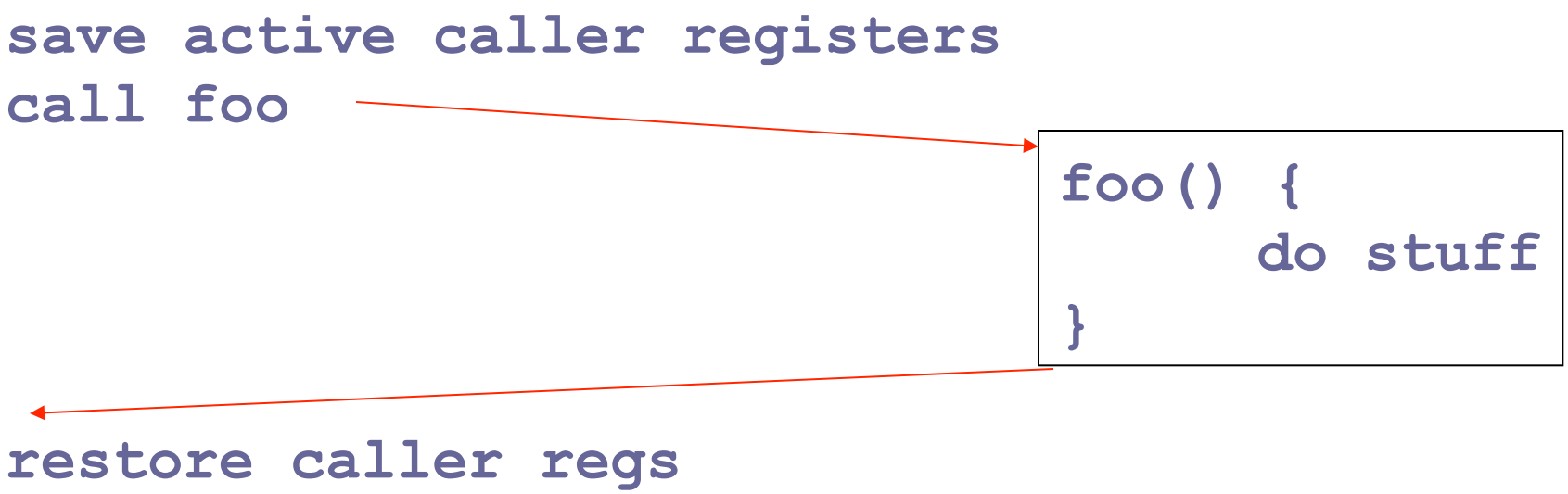



# Thread Context Switch

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

# Procedure Call

- Caller or callee save some context (same stack)
- Caller saved example:




# Threads vs. Procedures

- Threads may resume out of order
  - Cannot use LIFO stack to save state
  - Each thread has its own stack
- Threads switch less often
  - Do not partition registers
  - Each thread “has” its own CPU
- Threads can be asynchronous
  - Procedure call can use compiler to save state synchronously
  - Threads can run asynchronously
- Multiple threads
  - Multiple threads can run on multiple CPUs in parallel
  - Procedure calls are sequential

# Process vs. Threads

- Address space
  - Processes do not usually share memory
  - Process context switch changes page table and other memory mechanisms
  - Threads in a process share the entire address space
- Privileges
  - Processes have their own privileges (file accesses, e.g.)
  - Threads in a process share all privileges
- Question
  - Do you really want to share the “entire” address space?

# 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 spaces | Embedded OS,<br>Pilot | VMS, Mach (OS-X), OS/2,<br>Windows NT/XP/Vista,<br>Solaris, HP-UX, Linux |

# Summary

- Concurrency
  - CPU and I/O
  - Among applications
  - Within an application
- Processes
  - Abstraction for application concurrency
- Threads
  - Abstraction for concurrency within an application