



COS 318: Operating Systems

Processes and Threads

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(<http://www.cs.princeton.edu/courses/cos318/>)



Today's Topics

- ◆ Concurrency
- ◆ Processes
- ◆ Threads

- ◆ Reminder:
 - Hope you're all busy working on your implementations



Concurrency and Processes

◆ Concurrency

- Hundreds of jobs going on in a system
- CPU is shared, as are I/O devices

◆ 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 computer

◆ Example: gcc (via “gcc -pipe -v”) launches the following

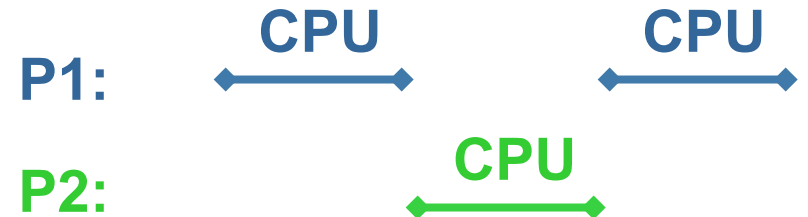
- `/usr/libexec/cpp | /usr/libexec/cc1 | /usr/libexec/as | /usr/libexec/elf/ld`
- Each instance of `cpp`, `cc1`, `as` and `ld` running is a process



Process Concurrency

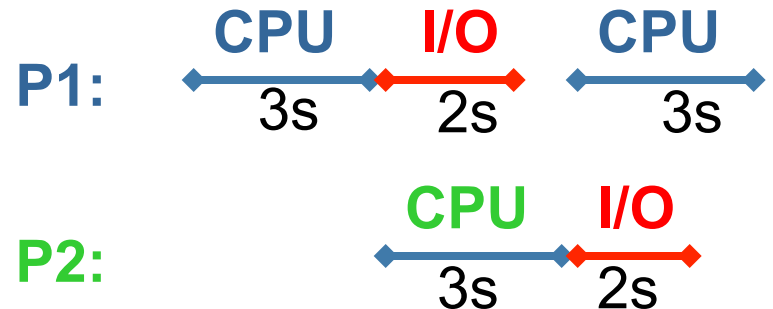
◆ Virtualization

- Processes interleaved on CPU



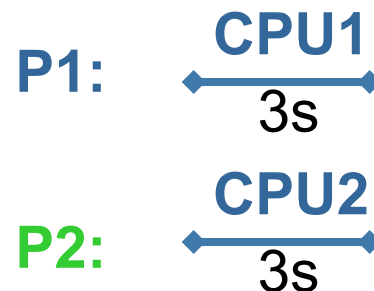
◆ I/O concurrency

- I/O for P1 overlapped with CPU for P2
- 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



Parallelism

- ◆ Parallelism is common in real life
 - A single sales person sells \$1M annually
 - Hire 100 sales people to generate \$100M revenue
- ◆ Speedup
 - Ideal speedup is factor of N
 - Reality: bottlenecks + coordination overhead reduce speedup
- ◆ Questions
 - Can you speed up by working with a partner?
 - Can you speed up 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
 - ...



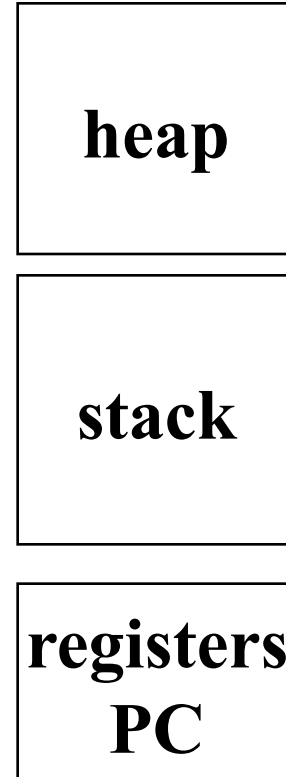
Program and Process

```
main ()  
{  
  ...  
  foo ()  
  ...  
}  
  
bar ()  
{  
  ...  
}
```

Program

```
main ()  
{  
  ...  
  foo ()  
  ...  
}  
  
bar ()  
{  
  ...  
}
```

Process



Process vs. Program

- ◆ Process > program
 - Program is just the code; just part of process state
 - Example: many users can run the same program
- ◆ Process < program
 - A program can invoke more than one process
 - Example: Fork off processes
 - Many processes can be running the same program



Managing Processes: Process Control Block (PCB)

- ◆ 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



API for Process Management

- ◆ Creation and termination
 - Exec, Fork, Wait, Kill
- ◆ Signals
 - Action, Return, Handler
- ◆ Operations
 - Block, Yield
- ◆ 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



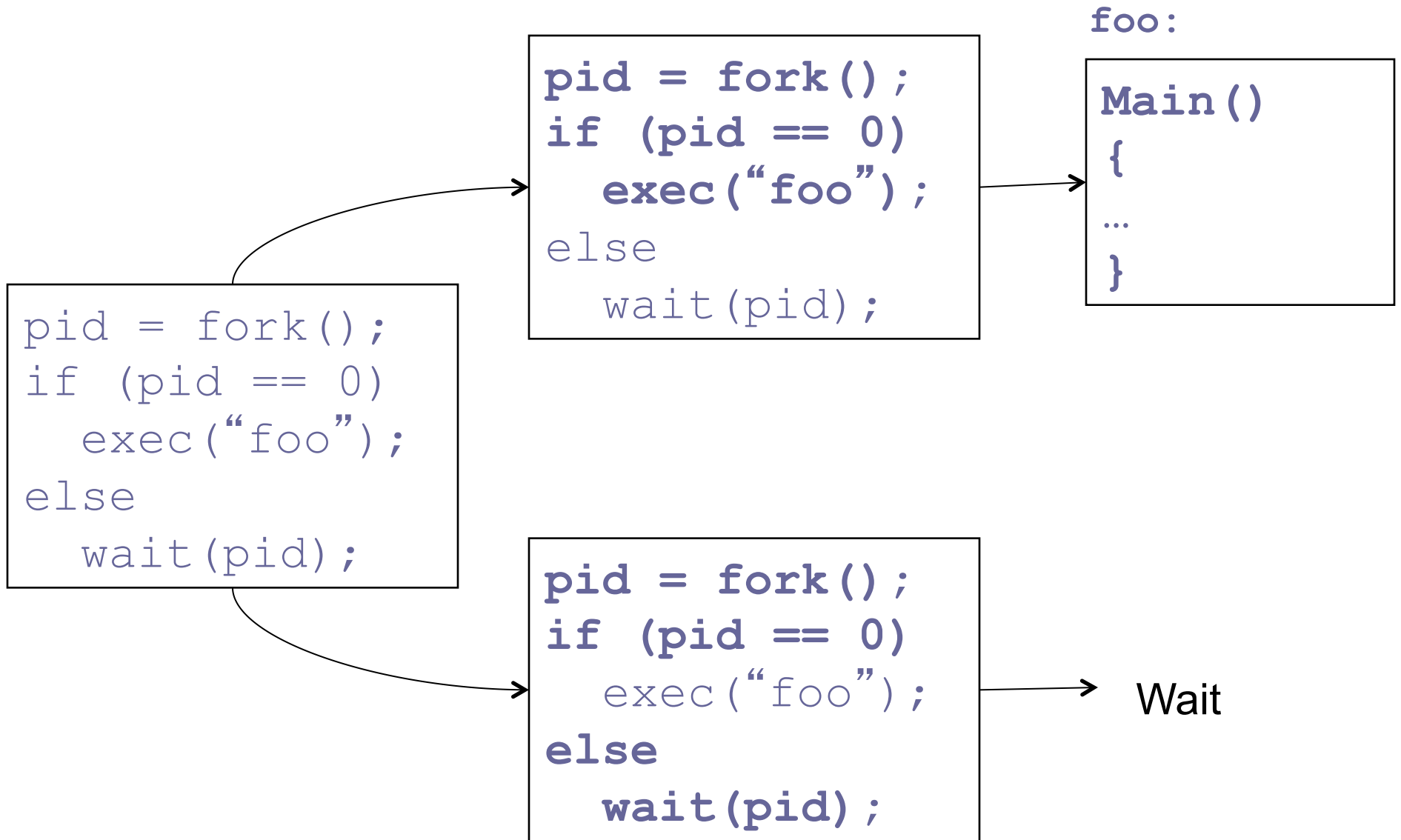
Unix Example

- ◆ Methods to 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 */
```

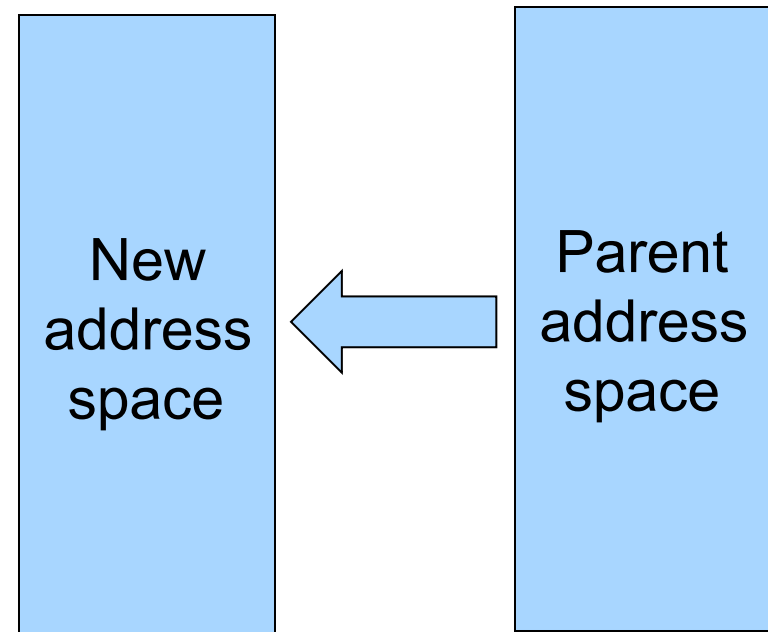


Fork and Exec in Unix



More on Fork

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

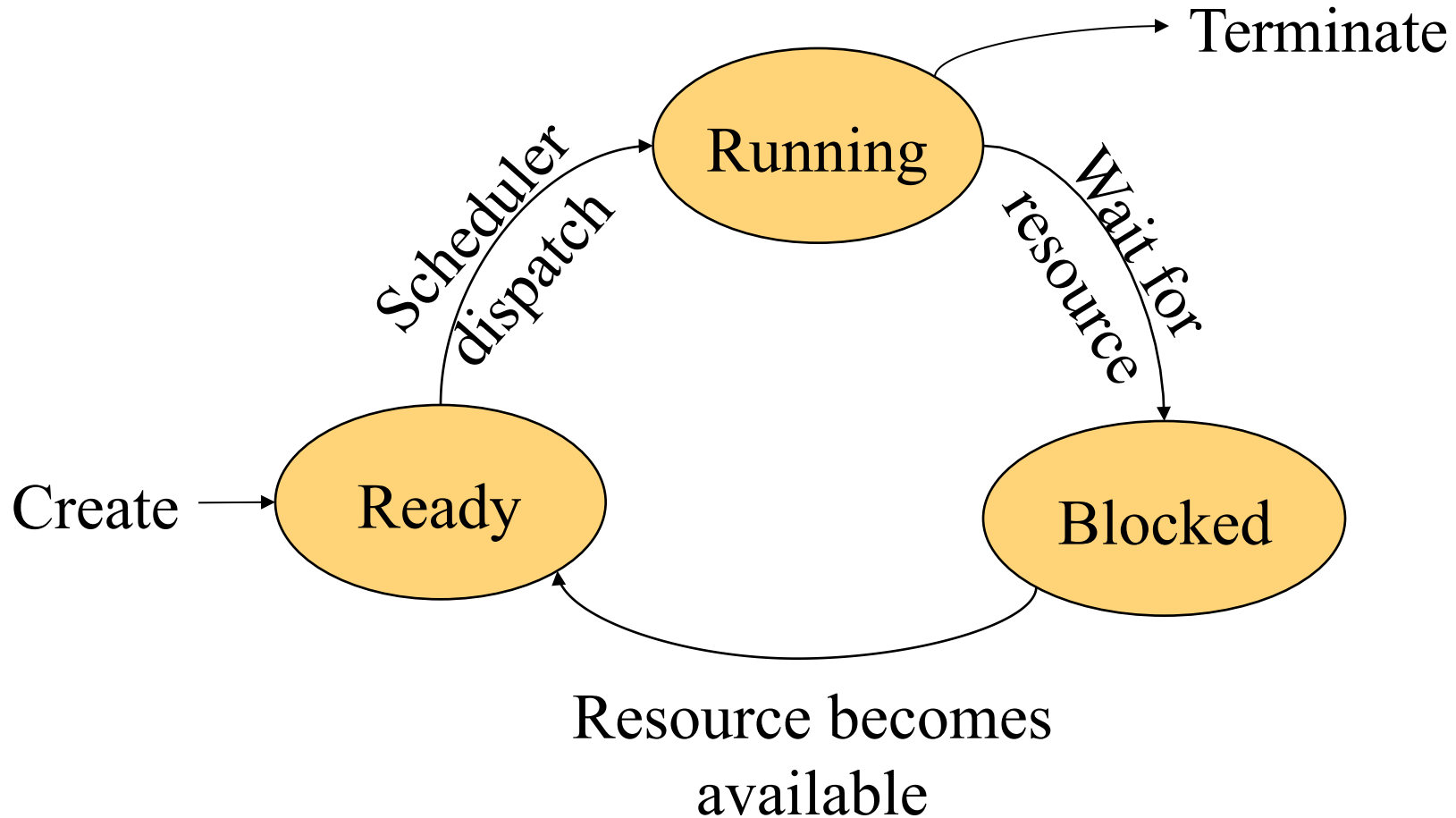


Process Context Switch

- ◆ 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?
- ◆ 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



(Reduced) Process State Transition



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 overlapping I/O and CPU with threads than with signals
- Human being likes to do several things at a time
- A server (e.g. file server) serves multiple requests
- 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



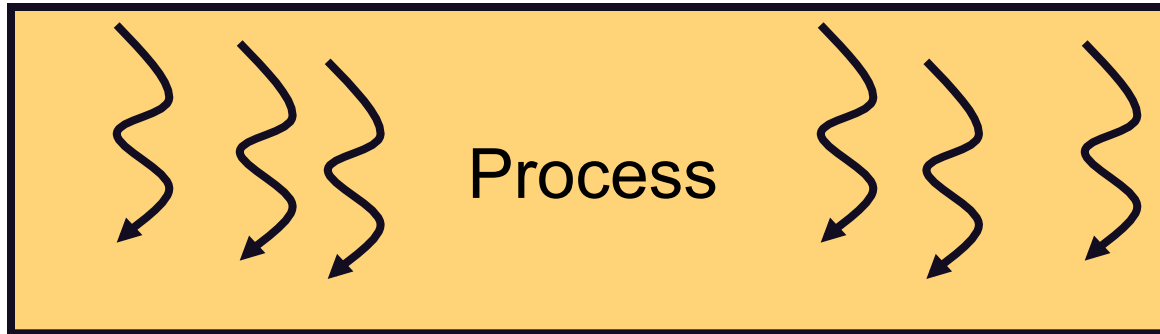
Typical Thread API

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



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?
- ◆ 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:

```
save active caller registers  
call foo
```

```
foo() {  
    do stuff  
}
```

```
restore caller regs
```



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 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 Macintosh	Traditional Unix
Many threads per address spaces	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 application concurrency
- ◆ Threads
 - Abstraction for concurrency within an application

