CSE 120
Principles of Operating Systems

Fall 2002

Lecture 4: Processes

Geoffrey M. Voelker

Processes

- This lecture starts a class segment that covers processes, threads, and synchronization
  - These topics are perhaps the most important in this class.
  - You can rest assured that they will be covered in the exams.
- Today's topics are processes and process management
  - What are the units of execution?
  - How are those units of execution represented in the OS?
  - How is work scheduled in the CPU?
  - What are the possible execution states of a process?
  - How does a process move from one state to another?

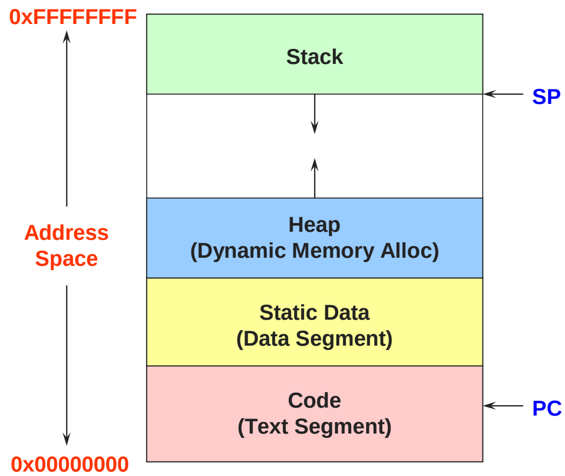
The Process

- The process is the OS abstraction for execution
  - It is the unit of execution
  - It is the unit of scheduling
  - It is the dynamic execution context of a program
- A process is sometimes called a job or a task or a sequential process
- A sequential process is a program in execution
  - It defines the sequential, instruction-at-a-time execution of a program
  - Programs are static entities with the potential for execution

Process Components

- A process contains all of the state for a program in execution
  - An address space
  - The code for the executing program
  - The data for the executing program
  - An execution stack encapsulating the state of procedure calls
  - The program counter (PC) indicating the next instruction
  - A set of general-purpose registers with current values
  - A set of operating system resources
    - » Open files, network connections, etc.
- A process is named using its process ID (PID)

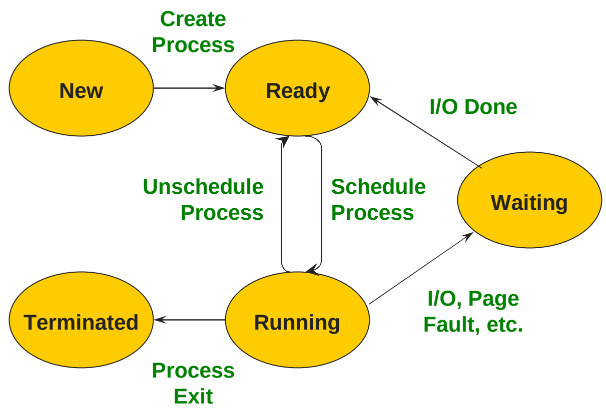
Process Diagram



Process State

- A process has an execution state that indicates what it is currently doing
  - Running: Executing instructions on the CPU
    - » It is the process that has control of the CPU
    - » How many processes can be in the running state simultaneously?
  - Ready: Waiting to be assigned to the CPU
    - » Ready to execute, but another process is executing on the CPU
  - Waiting: Waiting for an event, e.g., I/O completion
    - » It cannot make progress until event is signaled (disk completes)
- As a process executes, it moves from state to state
  - Unix “ps”: STAT column indicates execution state
  - What state do you think a process is in most of the time?

Process State Graph



Process Data Structures

How does the OS represent a process in the kernel?

- At any time, there are many processes in the system, each in its particular state
- The OS data structure representing each process is called the Process Control Block (PCB)
- The PCB contains all of the info about a process
- The PCB also is where the OS keeps all of a process' hardware execution state (PC, SP, regs, etc.) when the process is not running
  - This state is everything that is needed to restore the hardware to the same configuration it was in when the process was switched out of the hardware

PCB Data Structure

- The PCB contains a huge amount of information in one large structure
  - » Process ID (PID)
  - » Execution state
  - » Hardware state: PC, SP, regs
  - » Memory management
  - » Scheduling
  - » Accounting
  - » Pointers for state queues
  - » Etc.
- Unix: PCB is defined in sys/proc.h as `struct proc`
  - FreeBSD: 81 fields, 408 bytes (*not* lightweight)

PCBs and Hardware State

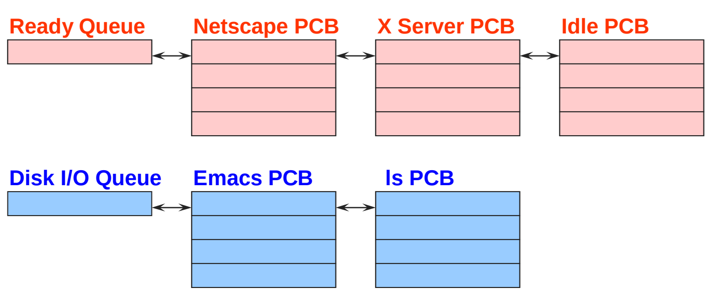
- When a process is running, its hardware state (PC, SP, regs, etc.) is in the CPU
  - The hardware registers contain the current values
- When the OS stops running a process, it saves the current values of the registers into the process' PCB
- When the OS is ready to start executing a new process, it loads the hardware registers from the values stored in that process' PCB
  - What happens to the code that is executing?
- The process of changing the CPU hardware state from one process to another is called a context switch
  - This can happen 100 or 1000 times a second!

State Queues

How does the OS keep track of processes?

- The OS maintains a collection of queues that represent the state of all processes in the system
- Typically, the OS has one queue for each state
  - Ready, waiting, etc.
- Each PCB is queued on a state queue according to its current state
- As a process changes state, its PCB is unlinked from one queue and linked into another

State Queues



Console Queue

Sleep Queue

.
.
.

There may be many wait queues, one for each type of wait (disk, console, timer, network, etc.)

PCBs and State Queues

- PCBs are data structures dynamically allocated in OS memory
- When a process is created, the OS allocates a PCB for it, initialized, and placed on the ready queue
- As the process computes, does I/O, etc., its PCB moves from one queue to another
- When the process terminates, its PCB is deallocated

Process Creation

- A process is created by another process
  - Parent is creator, child is created (Unix: ps “PPID” field)
  - What creates the first process (Unix: init (PID 0 or 1))?
- In some systems, the parent defines (or donates) resources and privileges for its children
  - Unix: Process User ID is inherited – children of your shell execute with your privileges
- After creating a child, the parent may either wait for it to finish its task or continue in parallel (or both)

Process Creation: NT

- The system call on NT for creating a process is called, surprisingly enough, CreateProcess:
  `BOOL CreateProcess(char *prog, char *args)` (simplified)
- CreateProcess
  - Creates and initializes a new PCB
  - Creates and initializes a new address space
  - Loads the program specified by "prog" into the address space
  - Copies "args" into memory allocated in address space
  - Initializes the hardware context to start execution at main (or wherever specified in the file)
  - Places the PCB on the ready queue

Process Creation: Unix

- In Unix, processes are created using fork()
  `int fork()`
- fork()
  - Creates and initializes a new PCB
  - Creates a new address space
  - Initializes the address space with a **copy** of the entire contents of the address space of the parent
  - Initializes the kernel resources to point to the resources used by parent (e.g., open files)
  - Places the PCB on the ready queue
- Fork returns twice
  - Returns the child's PID to the parent, "0" to the child
  - Huh?

fork()

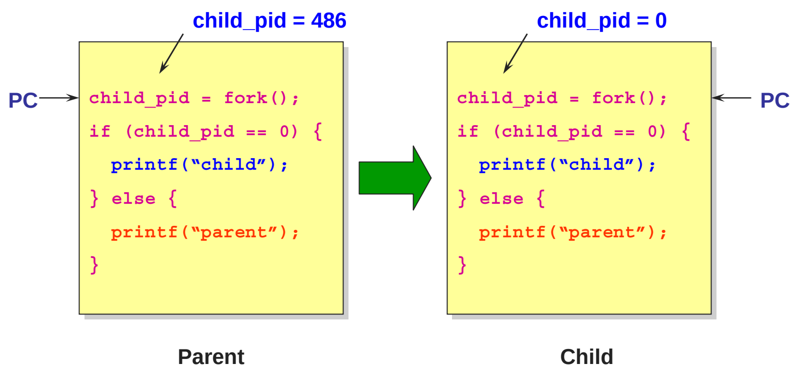
```
int main(int argc, char *argv[])
{
   char *name = argv[0];
   int child_pid = fork();
   if (child_pid == 0) {
       printf("Child of %s is %d\n", name, getpid());
       return 0;
   } else {
       printf("My child is %d\n", child_pid);
       return 0;
   }
}
```

What does this program print?

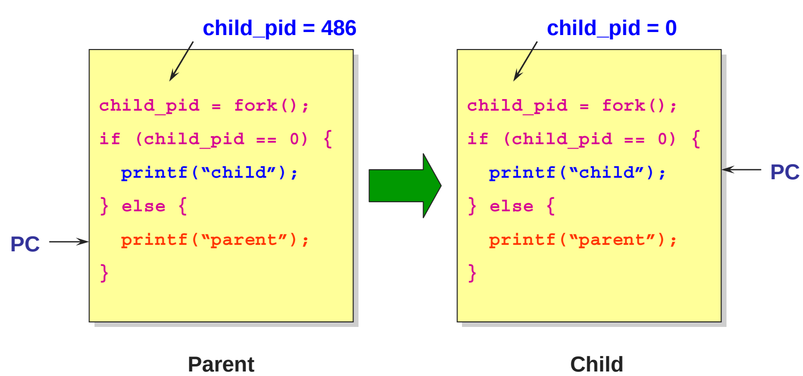
Example Output

alpenglow (18) ~/tmp> cc t.c
alpenglow (19) ~/tmp> a.out
My child is 486
Child of a.out is 486

Duplicating Address Spaces



Divergence



Example Continued

alpenglow (18) ~/tmp> cc t.c
alpenglow (19) ~/tmp> a.out
My child is 486
Child of a.out is 486
alpenglow (20) ~/tmp> a.out
Child of a.out is 498
My child is 498

Why is the output in a different order?

Why fork()?

- Very useful when the child…
  - Is cooperating with the parent
  - Relies upon the parent's data to accomplish its task
- Example: Web server

```
while (1) {
  int sock = accept();
  if ((child_pid = fork()) == 0) {
    Handle client request
  } else {
    Close socket
  }
}
```

Process Creation: Unix (2)

- Wait a second. How do we actually start a new program?

  ```
  int exec(char *prog, char *argv[])
  ```

- exec()
  - Stops the current process
  - Loads the program “prog” into the process’ address space
  - Initializes hardware context and args for the new program
  - Places the PCB onto the ready queue
  - Note: It **does not** create a new process
- What does it mean for exec to return?

Unix Shells

```
while (1) {
    char *cmd = read_command();
    int child_pid = fork();
    if (child_pid == 0) {
        Manipulate STDIN/OUT/ERR file descriptors for pipes,
        redirection, etc.
        exec(cmd);
        panic("exec failed");
    } else {
        wait(child_pid);
    }
}
```

Process Creation: Unix (3)

- Fork is used to create a new process, exec is used to load a program into the address space
  - Why does NT have CreateProcess while Unix uses fork and exec?
- What happens if you run “exec csh” in your shell?
- What happens if you run “exec ls” in your shell? Try it.

Process Summary

- What are the units of execution?
  - Processes
- How are those units of execution represented?
  - Process Control Blocks (PCBs)
- How is work scheduled in the CPU?
  - Process states, process queues, context switches
- What are the possible execution states of a process?
  - Running, ready, waiting
- How does a process move from one state to another?
  - Scheduling, I/O, creation, termination
- How are processes created?
  - CreateProcess (NT), fork/exec (Unix)

Next time…

- Read Chapter 5
- Homework #1 due
- Project 0 due