## CSE 451: Operating Systems
## Autumn 2009

## Module 4
## Processes

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## Process management

- This module begins a series of topics on processes, threads, and synchronization
  - this is the most important part of the class
  - there definitely will be several questions on these topics on the midterm
- Today: processes and process management
  - what are the OS units of execution?
  - how are they represented inside the OS?
  - how is the CPU scheduled across processes?
  - what are the possible execution states of a process?
    - and how does the system move between them?

## The process

- The process is the OS's abstraction for execution
  - the unit of execution
  - the unit of scheduling
  - the dynamic (active) execution context
    - compared with program: static, just a bunch of bytes
- Process is often called a job, task, or sequential process
  - a sequential process is a program in execution
    - defines the instruction-at-a-time execution of a program

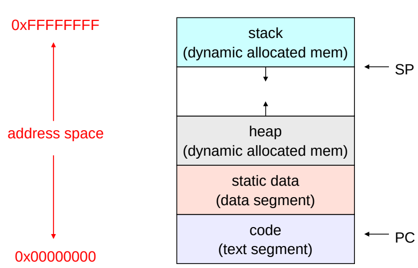
  

## What's "in" a process?

- A process consists of (at least):
  - an address space
    - the code for the running program
    - the data for the running program
    - an execution stack
  - stack pointer (SP)
    - traces state of procedure calls made
  - the program counter (PC), indicating the next instruction
  - general-purpose processor registers and their values
  - a set of OS resources
    - open files, network connections, sound channels, …
- In other words, it's all the stuff you need to run the program
  - or to re-start it, if it's interrupted at some point

## A process's address space



## The process control block

- There's a data structure called the process control block (PCB) that holds all this stuff
  - The PCB is identified by an integer process ID (PID)
- OS keeps all of a process's hardware execution state in the PCB when the process isn't running
  - PC, SP, registers, etc.
  - when a process is unscheduled, the state is transferred out of the hardware into the PCB
- Also pointers to OS resources, address space, etc.
- Note: It's natural to think that there must be some esoteric techniques being used
  - fancy data structures that'd you'd never think of yourself

*Wrong! It's pretty much just what you'd think of!*

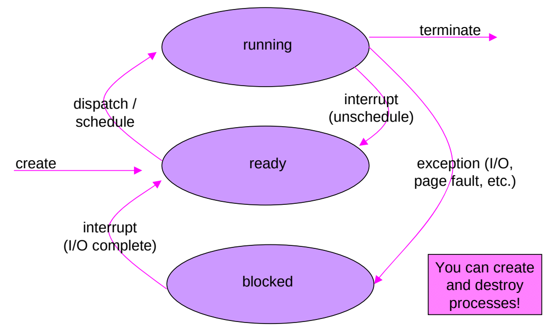
  

## Process states

- Each process has an execution state, which indicates what it is currently doing
  - ready: waiting to be assigned to CPU
    - could run, but another process has the CPU
  - running: executing on the CPU
    - is the process that currently controls the CPU
    - pop quiz: how many processes can be running simultaneously?
  - waiting: waiting for an event, e.g., I/O
    - cannot make progress until event happens
- As a process executes, it moves from state to state
  - UNIX: run **ps**, STAT column shows current state
  - which state is a process in most of the time?



## Process state transitions






## The PCB revisited

- The PCB is a data structure with many, many fields:
  - process ID (PID)
  - execution state
  - program counter, stack pointer, registers
  - address space info
  - UNIX username of owner
  - scheduling priority
  - accounting info
  - pointers for state queues
- In linux:
  - defined in **`task_struct`** (**`include/linux/sched.h`**)
  - over 95 fields!!!



## PCBs and hardware state

- When a process is running, its hardware state is inside the CPU
  - PC, SP, registers
  - CPU contains current values
- When the OS stops running a process (puts it in the waiting state), it saves the registers' values in the PCB
  - when the OS puts the process in the running state, it loads the hardware registers from the values in that process's PCB
- The act of switching the CPU from one process to another is called a context switch
  - timesharing systems may do 100s or 1000s of switches/sec.
  - takes about 5 microseconds on today's hardware



| |
|---|
| Process ID |
| Pointer to parent |
| List of children |
| Process state |
| Pointer to address space descriptor |
| **Program counter**<br>**stack pointer**<br>**(all) register values** |
| uid (user id)<br>gid (group id)<br>euid (effective user id) |
| Open file list |
| Scheduling priority |
| Accounting info |
| Pointers for state queues |
| Exit ("return") code value |

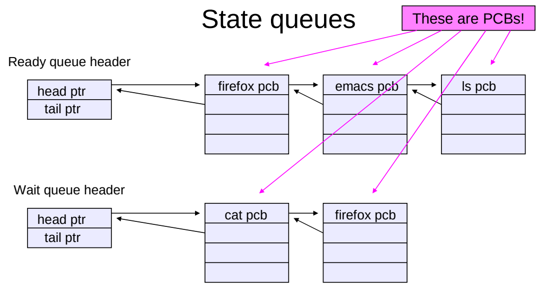
This is (a simplification of) what each of those PCBs looks like inside!



## State queues

- The OS maintains a collection of queues that represent the state of all processes in the system
  - typically one queue for each state
    - e.g., ready, waiting, …
  - each PCB is queued onto a state queue according to the current state of the process it represents
  - as a process changes state, its PCB is unlinked from one queue, and linked onto another
- Once again, *this is just as straightforward as it sounds!* The PCBs are moved between queues, which are represented as linked lists. *There is no magic!*

## State queues




- There may be many wait queues, one for each type of wait (particular device, timer, message, …)

## PCBs and state queues

- PCBs are data structures
  - dynamically allocated inside OS memory
- When a process is created:
  - OS allocates a PCB for it
  - OS initializes PCB
  - OS puts PCB on the correct queue
- As a process computes:
  - OS moves its PCB from queue to queue
- When a process is terminated:
  - PCB may hang around for a while (exit code, etc.)
  - eventually, OS deallocates the PCB

## Process creation

- New processes are created by existing processes
  - creator is called the parent
  - created process is called the child
  - UNIX: do **ps**, look for PPID field
  - what creates the first process, and when?
- In some systems, parent defines or donates resources and privileges for its children
  - UNIX: child inherits parent's uid, environment, open file list, etc.
- When child is created, parent may either wait for it to finish, or may continue in parallel, or both!

## UNIX process creation

- UNIX process creation through **`fork()`** system call
  - creates and initializes a new PCB
  - creates a new address space
  - initializes new address space with a copy of the entire contents of the address space of the parent
  - initializes kernel resources of new process with resources of parent (e.g., open files)
  - places new PCB on the ready queue
- the **`fork()`** system call "returns twice"
  - once into the parent, and once into the child
  - returns the child's PID to the parent
  - returns 0 to the child
- **`fork()`** = "clone me"

## testparent – use of fork( )

```
#include <sys/types.h>
#include <unistd.h>
#include <stdio.h>

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

## testparent output

```
spinlock% gcc -o testparent testparent.c
spinlock% ./testparent
My child is 486
Child of testparent is 0
spinlock% ./testparent
Child of testparent is 0
My child is 571
```

## Exec vs. fork

- So how do we start a new program, instead of just forking the old program?
  - the **exec()** system call!
  - **int exec(char *prog, char ** argv)**
- **exec()**
  - stops the current process
  - loads program 'prog' into the address space
  - initializes hardware context, args for new program
  - places PCB onto ready queue
  - note: does not create a new process!





## UNIX shells

```
int main(int argc, char **argv)
{
  while (1) {
    char *cmd = get_next_command();
    int pid = fork();
    if (pid == 0) {
       manipulate STDIN/STDOUT/STDERR fd's
       exec(cmd);
       panic("exec failed!");
    } else {
       wait(pid);
    }
  }
}
```





## Input/output redirection

- $ ./myprog <input.txt >output.txt   # UNIX
  - each process has an open file table
  - by (universal) convention:
    - 0: stdin
    - 1: stdout
    - 2: stderr
  - a child process inherits the parent's open file table
- So the shell…
  - copies its current stdin/stdout open file entries
  - opens input.txt as stdin and output.txt as stdout
  - fork…
  - restore original stdin/stdout