CSE 451: Operating Systems
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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 and 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

The process control block

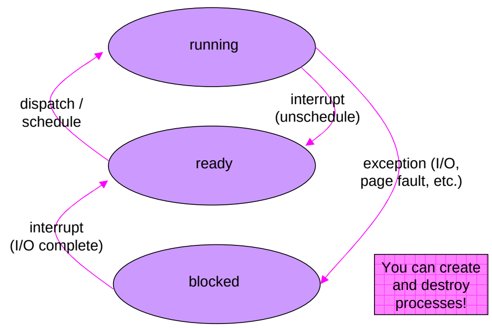
- There's a data structure called the process control block (PCB) that holds all this stuff
  - The PCB is identified by an integer process ID (PID)
- OS keeps all of a process's hardware execution state in the PCB when the process isn't running
  - PC, SP, registers, etc.
  - when a process is unscheduled, the state is transferred out of the hardware into the PCB
- 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?

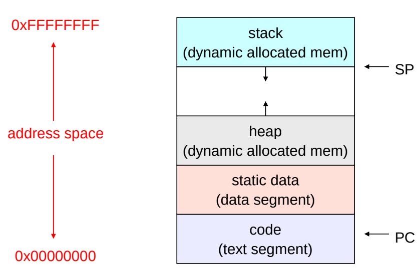
States of a process



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!!!

A process's address space



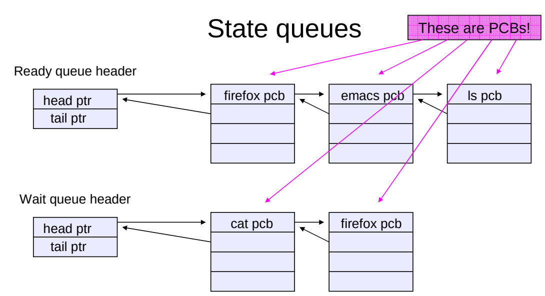
PCBs and hardware state

- 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

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, …)

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

process ID
process state
program counter
stack pointer
32 general-purpose registers
address space info
username of owner
scheduling priority
accounting info
pointers for state queues

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:
  - OS deallocates its PCB

Process creation

- One process can create another process
  - 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 userID field, 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( )

```
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);
    }
  }
}
```