Process Management

- This lecture begins a series of topics on processes, threads, and synchronization
  - this is perhaps 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
  - a set of general-purpose processor registers and their values
  - a set of OS resources
    - open files, network connections, sound channels, ...
- The process is a container for all of this state
  - a process is named by a process ID (PID)
    - just an integer (actually, typically a short)
A process’s address space

<table>
<thead>
<tr>
<th>Address Space</th>
<th>Stack (dynamic allocated mem)</th>
<th>Heap (dynamic allocated mem)</th>
<th>Static Data (data segment)</th>
<th>Code (text segment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xFFFFFFFF</td>
<td>SP</td>
<td></td>
<td></td>
<td>PC</td>
</tr>
<tr>
<td>0x00000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Process states

- Each process has an execution state, which indicates what it is currently doing
  - ready: waiting to be assigned to CPU
  - running: executing on the CPU
  - 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 most of the time?

Process state transitions

- New → Ready
- Ready → Running
- Running → Waiting
- Waiting → New
- Terminated → New

- What can cause schedule/unschedule transitions?

Process data structures

- How does the OS represent a process in the kernel?
  - at any time, there are many processes, each in its own particular state
  - the OS data structure that represents each is called the process control block (PCB)
- PCB contains all info about the process
  - OS keeps all of a process’ hardware execution state in the PCB when the process isn’t running
    - PC
    - SP
    - registers
  - when process is unscheduled, the state is transferred out of the hardware into the PCB
PCB

- The PCB is a data structure with many, many fields:
  - process ID (PID)
  - execution state
  - program counter, stack pointer, registers
  - memory management info
  - UNIX username of owner
  - scheduling priority
  - accounting info
  - pointers into 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' 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/s
  - 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 its current state
  - as a process changes state, its PCB is unlinked from one queue, and linked onto another

- 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:
  - 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 it 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

```c
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, child_pid);
        return 0;
    } else {
        printf("My child is %d\n", child_pid);
        return 0;
    }
}
```
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 486
```

Fork and exec

- 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!
- what does it mean for `exec` to return?
  - what happens if you “exec csh” in your shell?
  - what happens if you “exec ls” in your shell?

UNIX shells

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