Today's agenda

- Administrivia
  - ...
- Processes
  - units of execution
  - ‘living, breathing embodiment of a program’
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 midterms and exams

• 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
    - 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)
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 is most of the time?

Process state transitions

- 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 queue, and linked onto another
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:
  - 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
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, 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);
    }
  }
}
```