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

A process’s address space

<table>
<thead>
<tr>
<th>Code (text segment)</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>0x00000000</td>
<td>SP</td>
<td>0xFFFFFFF</td>
<td>0x00000000</td>
<td>PC</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
  – 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!!!

Simple Process Control Block

  process state
  process number
  program counter
  stack pointer
  copies of general-purpose registers
  memory management info
  username of owner
  queue pointers for state queues
  scheduling info (priority, etc.)
  accounting info

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 parents user ID 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( )`

```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
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 cat” 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);
        }
    }
}
```

Windows CreateProcess function

- Open the program file to be executed
- Create the Windows executive process object
- Create the initial thread (stack, context, ...)
- Notify Win32 subsystem about new process
- Start execution of the initial thread
- Complete initialization (eg, load dlls)
- Continue execution in both processes