# CS5460: Operating Systems

## Lecture 4: Process Management

*(Chapters 4, 5, 6)*

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# Assignment 1

- Due Tue Feb 2

# Problem #1: Restricted Ops

How can we ensure user process can't harm others?

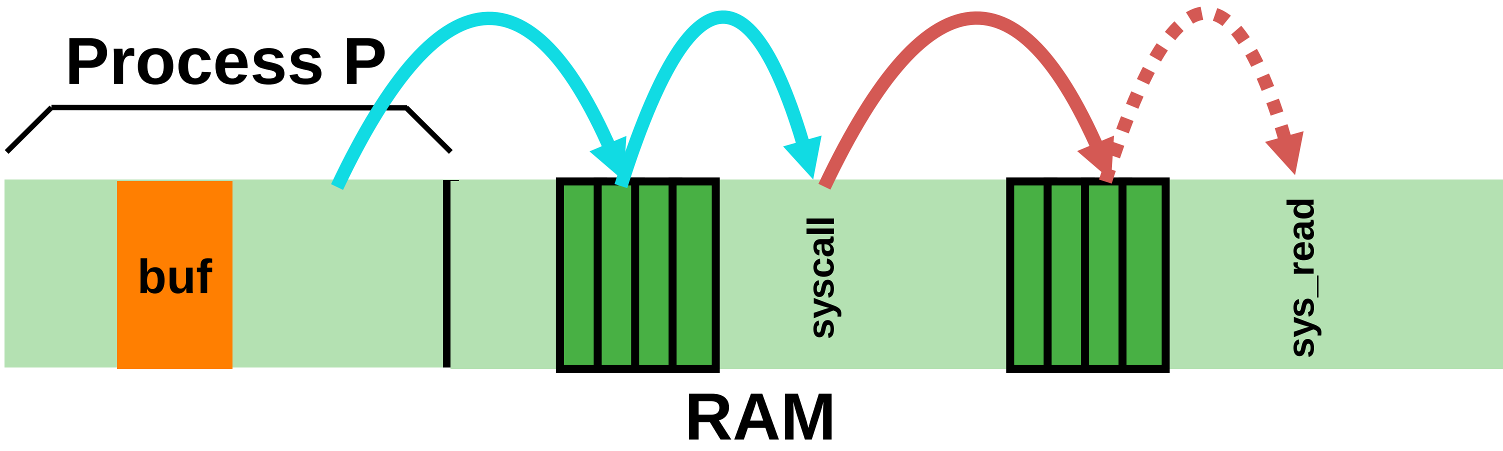
Solution: privilege levels supported by hw (status bit)

- User processes run in user mode (restricted mode) (Ring 3)
- OS runs in kernel mode (not restricted) (Ring 0)
  - Instructions for interacting with devices
  - Access to all memory
  - Ability to reconfigure CPU control registers (IDT, PTBR/CR3)

How can processes access devices?

- System calls (function call implemented by OS)
- Change privilege level through system call (trap)

# System Call




```
movl $6, %eax;    int $64
```

**syscall-table index** **trap-table index**

**Kernel can access user memory to fill in user buffer**
**return-from-trap at end to return to Process P**

# Problem #2: Take CPU Away?

OS requirements for multiprogramming (multitasking):

- Policy: Decision-maker optimizing a performance metric
  - Process Scheduler: Which process when?
- Mechanism: Low-level code that implements the decision
  - Dispatcher and Context Switch: How?

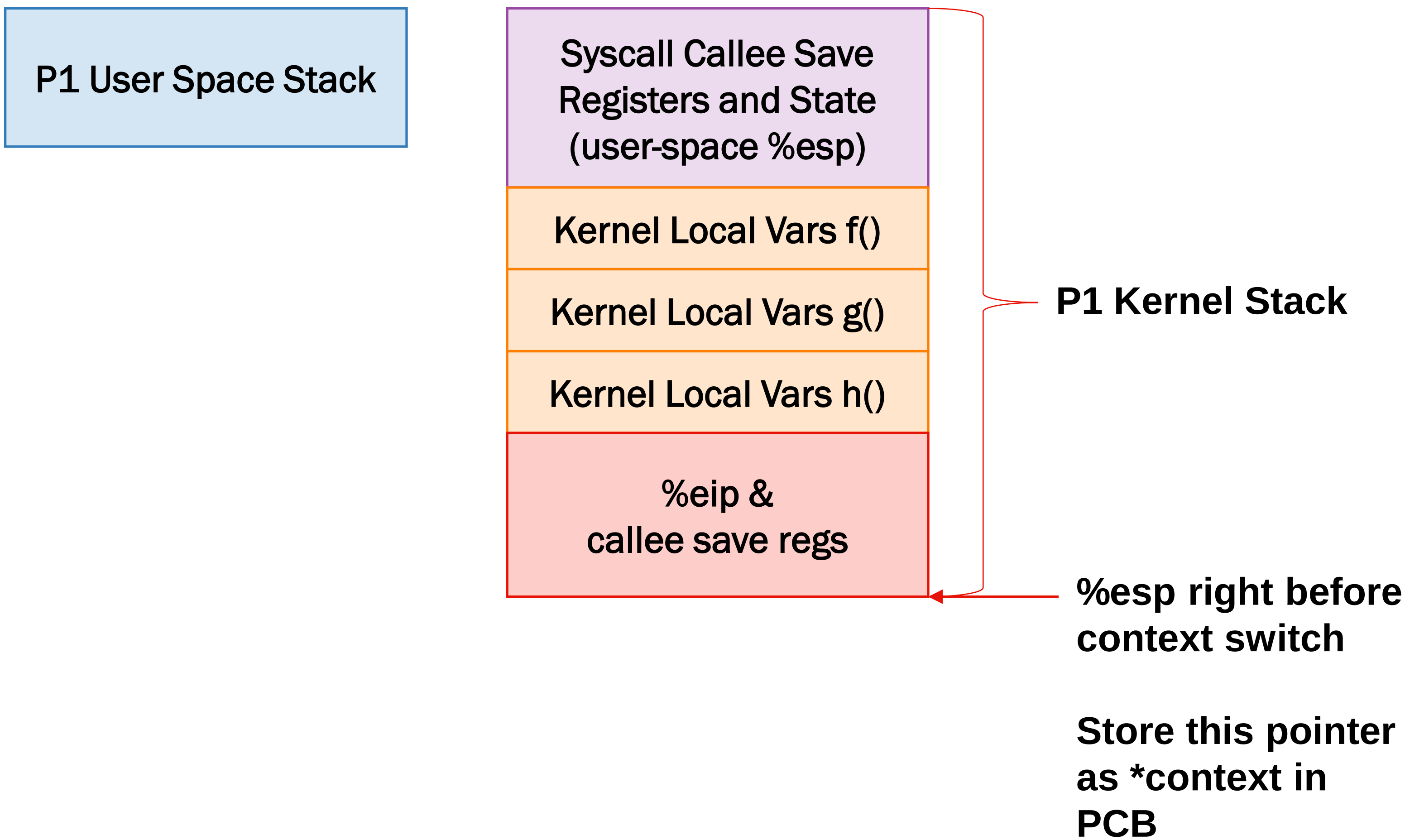
Example of separation of policy and mechanism

# Q1: How does OS get control?

Option 2: Preemptive Multitasking

- Guarantee OS can obtain control periodically
- Enter OS by enabling periodic alarm clock
  - Hardware generates timer interrupt (CPU or separate chip)
  - Example: Every 10ms
- User must not be able to mask timer interrupt
- Dispatcher counts interrupts between context switches
  - Example: Waiting 20 timer ticks gives 200 ms time slice
  - Common time slices range from 4 ms to a few hundred ms

# Zooming In: Registers & KStack



| Operating System | Hardware | Program |
|---|---|---|
| | | **Process A** |
| | | **…** |
| | Syscall or timer interrupt<br>Hw switches to kstack<br>Raises to kernel mode<br>Save regs(A) to kstack(A)<br>Jump to trap handler | |
| Handle the trap<br>Call **swtch()** routine<br>Save regs(A) to PCB(A)<br>Restore regs(B) from PCB(B)<br>Switch to kstack(B)<br>Return to running B in kernel mode | | |
| | Execute return-from-trap:<br>Restore regs(B) from kstack(B)<br>Move to user mode<br>Jump to B’s IP | |
| | | **Process B** |
| | | **…** |

# xv6 PCB

```
struct context
{
  uint edi;
  uint esi;
  uint ebx;
  uint ebp;
  uint eip;
};
```

```
enum proc_state { UNUSED, EMBRYO, SLEEPING,
                  RUNNABLE, RUNNING, ZOMBIE };
struct proc {
  uint sz;                     // Proc mem size (bytes)
  pde_t* pgdir;                // Page table
  char* kstack;                // Bottom of kstack
  enum procstate state;        // Process state
  int pid;                     // Process ID
  struct proc* parent;         // Parent process
  struct trapframe* tf;        // Trap frm for syscall
  struct context* context;     // swtch() here to run
  void* chan;                  // If !0, sleep on chan
  int killed;                  // If !0, been killed
  struct file* ofile[NOFILE];  // Open files
  struct inode* cwd;           // Current directory
  char name[16];               // Process name
};
```

# Context Switch

- Context switches are fairly expensive
  - Time sharing systems do 100-1000 context switches per second
  - When?  Timer interrupt, packet arrives on network, disk I/O completes, user moves mouse, …

- lab2-15    3.8 μs
- gamow    1.6 μs
- home    1.0 μs

- How might one go about measuring this?

# Problem #3: Slow Ops (I/O)?

On op that does not use CPU,
OS switches to other processes

OS must track process states:

**Running**:

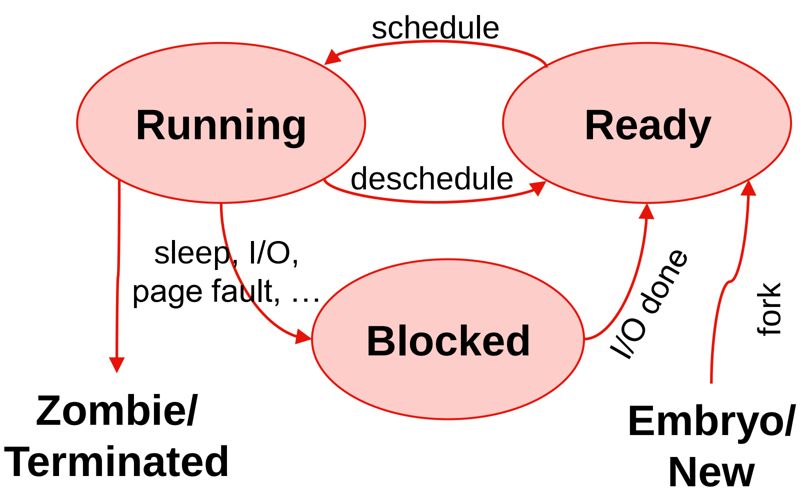
On the CPU (1 on a uniprocessor)

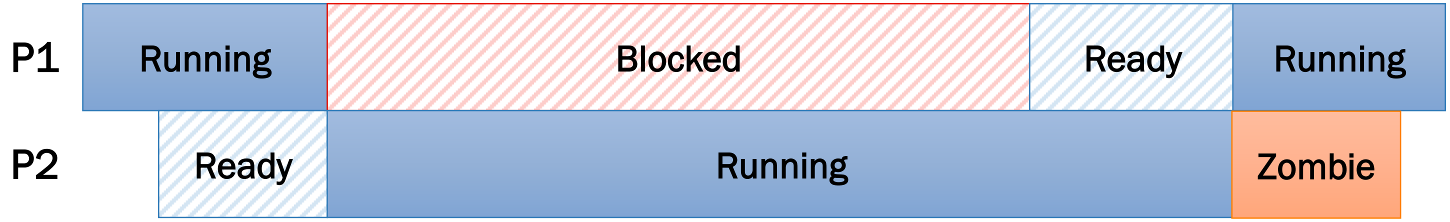
**Ready**:

Waiting for the CPU

**Blocked**:

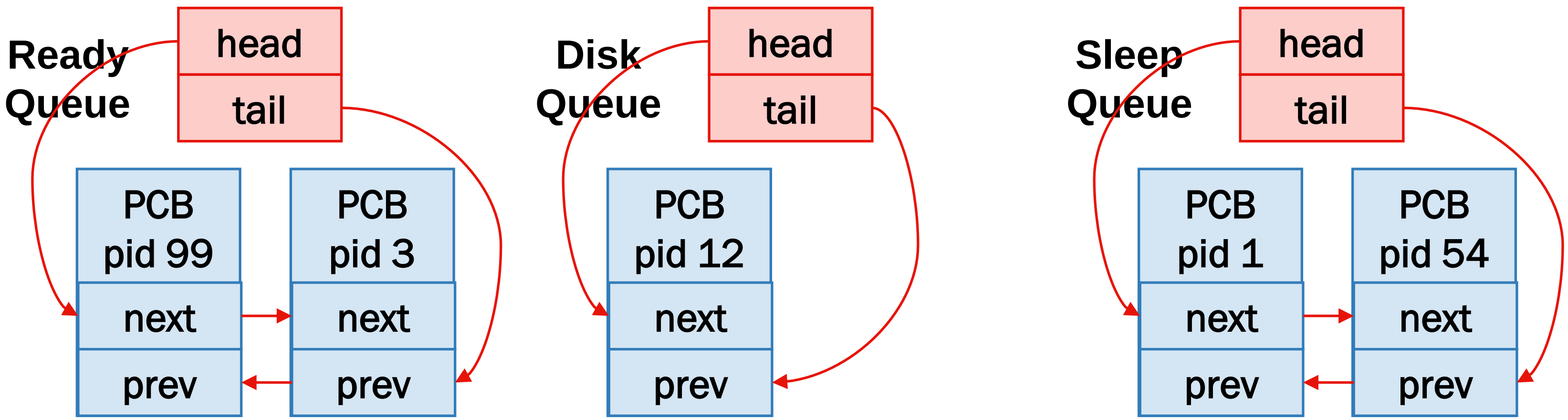
Asleep: Waiting for I/O or synchronization to complete



# Problem #3: Slow Ops (I/O)?

- OS maintains queues of all PCBs
  - Ready queue: Contains all ready processes
  - Event queue: One logical queue per event
    - e.g., disk I/O and locks
    - Contains all processes waiting for that event to complete
- Invariant: each process in 1 state and on 1 queue



# CPU Virtualization Summary

- Virtualization:
  Context switching gives each process impression it has its own CPU
- Direct execution makes processes fast
- Limited execution at key points to ensure OS retains control
- Hardware provides a lot of OS support
  - user vs kernel mode
  - timer interrupts
  - automatic register saving on syscall

# Process Management

- OS manages processes:
  - Creates, deletes, suspends, and resumes processes
  - Schedules processes to manage CPU allocation
  - Manages inter-process communication and synchronization
  - Allocates resources to processes (and takes them away)

- Processes use OS functionality to cooperate
  - Signals, sockets, pipes, files to communicate

# Practical Process Management

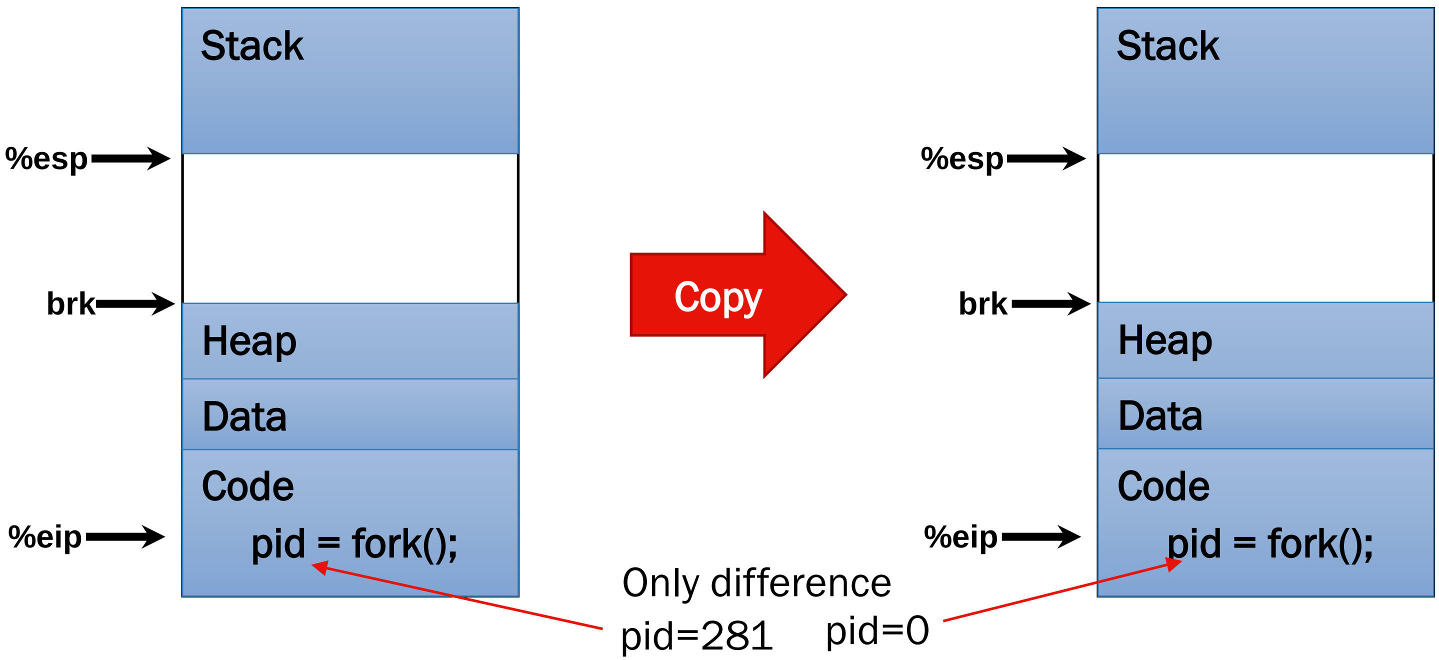
- On a Unix machine, try:
  - ps –Af: lots of info on all running processes
  - kill –9 547: terminates process with PID 547
  - top : displays dynamic info on top running jobs
  - Write a program that calls:
    - getpid(): returns current process's PID (process id)
    - fork(): create a new process
    - wait(): wait for exit of a child process
    - exec(): load a new program into the current process
    - sleep(): puts current process to sleep for specified time
- Commands work on macOS
- On Windows → Task manager (CTL-ALT-DEL)

# Creating Processes: fork()

- Creates process that is near-clone of forking parent
  Address space and running state is cloned
- Return of fork() differs:
  0 in child
  child PID in parent
- Many kernel resources are shared
  open files and sockets

- wait() lets a process wait for the exit of a child
- To spawn new program, use some form of exec()

# Semantics of fork()




- fork(), exit(), and exec() are weird!
  - fork() returns twice – once in each process
  - exit() does not return at all
  - exec() usually “does not return”: replaces process’ program

# fork() and wait()

```
int main(int argc, char *argv) {
  printf("parent %d\n", (int)getpid());
  pid_t rc = fork();
  assert(rc >= 0)

  if (rc == 0) {                     // child
    printf("child %d\n", (int)getpid());
  } else {                           // parent
    wait(NULL);
    printf("%d is parent of %d\n", (int)getpid(), rc);
  }
  return 0;
}
```

```
$ ./fork-wait
parent 13037
child 13039
13037 is parent of 13039
```

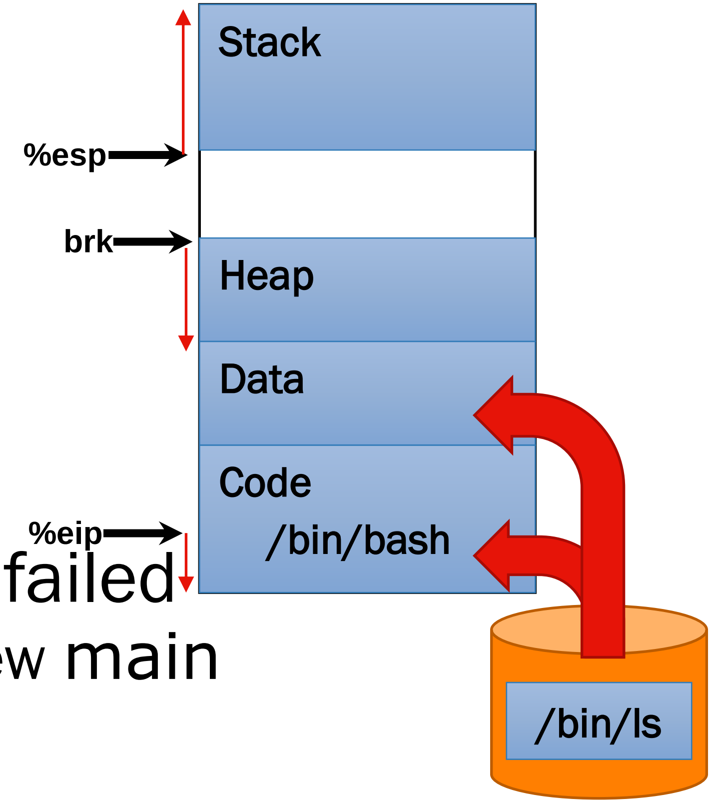
What is the output without wait()?

# exec(): Run Another Program

- Can't write entire system in one program!
  - Need to replace process with another program

- Loads program from filesystem
  - Replaces code, data segments
  - Put `argv` on stack; reset `%esp`
  - Release heap memory
  - Reset `%eip` to `main`

- `exec()` only returns to caller if failed
  - Otherwise process is now in a new `main`



# Why Separate fork and exec?

- Lots of parameters on creating a process
  - Shell may want to
  - redirect output of children
  - change child environment
  - change child working directory
  - run child as a different user
- Hard to create simple, expressive-enough API
- Separation allows policy to be expressed in parent’s program but in child’s process
- Tradeoff: child may inherit things it doesn't need (or shouldn't have)

# Example: Output Redirection

```
pid_t rc = fork();

if (rc == 0) {                      // child
  close(STDOUT_FILENO);             // close fd 1
  open("./p4.output", O_CREAT|O_WRONLY|O_TRUNC, S_IRWXU); // new fd 1

  const char *myargs[3];
  myargs[0] = "wc";
  myargs[1] = "p4.c";
  myargs[2] = NULL;
  execvp(myargs[0], myargs);  // runs "wc p4.c > p4.output"
} else {                            // parent
  wait(NULL);
}
```

# Termination: exit(), kill()

- When process dies, OS reclaims resources
  - Record exit status in PCB
  - Close files, sockets
  - Free memory
  - Free (nearly) all kernel structures

- Process terminates with exit()
- Process terminates another with kill()

```
int main(int argc, char* argv[]) {
  pid_t pid = fork();
  if (pid == 0) {
    sleep(10);
    printf(“Child exiting!\n”);
    exit(0);
  } else {
    sleep(5);
    if (kill(pid, SIGKILL) != -1)
      printf(“Sent kill!\n”);
  }
}
```

# Orphans and Zombies

```
systemd─┬─acpid
        ├─5*[agetty]
        ├─cron
        ├─login───bash───compute
        ├─rsyslogd
        ├─sshd─┬─sshd───sshd───rsync───rsync
        │      └─sshd───sshd───bash───pstree
        ├─systemd-journal
        └─systemd-udevd
```

- Parent wait() on child returns status
- Must keep around PCB with status after child exit
- **Zombie**: exited process with uncollected status
- Parent exits before child? **Orphaned**
  - init adopts orphans
  - Collects and discards status of reparented children after exit
  - Useful for "daemons" (nohup)

# Important Terms and Ideas

- Process, programs
- Process Control Blocks
- syscall, user/kernel mode
- Dispatcher, context switch
- Process State Machine
- New (Embryo), Ready, Running, Blocked, Terminated (Zombie)
- fork(), wait(), exec(), exit(), kill()
- Orphans, zombies, init