OS Structure,
Processes & Process Management

What is a Process?

- A process is a program during execution.
  - Program = static file (image)
  - Process = executing program = program + execution state.
- A process is the basic unit of execution in an operating system
  - Each process has a number, its process identifier (pid).
- Different processes may run different instances of the same program
  - E.g., my javac and your javac process both run the Java compiler
- At a minimum, process execution requires following resources:
  - Memory to contain the program code and data
  - A set of CPU registers to support execution

Program to Process

- We write a program in e.g., Java.
- A compiler turns that program into an instruction list.
- The CPU interprets the instruction list (which is more a graph of basic blocks).

```
void X (int b) {
   if(b == 1) {
…
int main() {
  int a = 2;
  X(a);
}
```

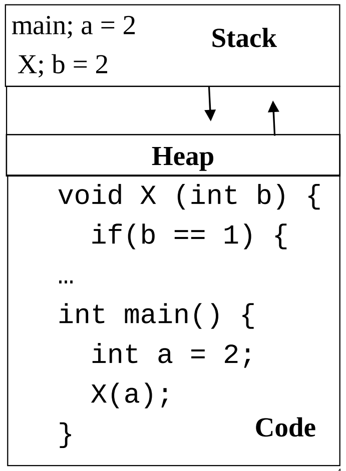
Process in Memory

- Program to process.
- What you wrote

```
void X (int b) {
  if(b == 1) {
…
int main() {
  int a = 2;
  X(a);
}
```

- What must the OS track for a process?

- What is in memory.



```
void X (int b) {
  if(b == 1) {
…
int main() {
  int a = 2;
  X(a);
}
```

Processes and Process Management
Details for running a program

- A program consists of code and data
- On running a program, the loader:
  - ➢ reads and interprets the executable file
  - ➢ sets up the process's memory to contain the code & data from executable
  - ➢ pushes "argc", "argv" on the stack
  - ➢ sets the CPU registers properly & calls "_start()"
- Program starts running at _start()

```
_start(args) {
    initialize_java();
    ret = main(args);
    exit(ret)
}
```

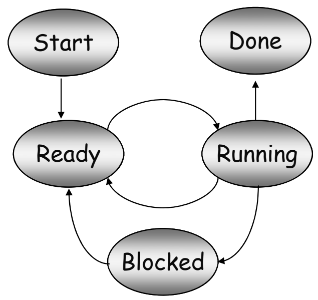
  we say "process" is now running, and no longer think of "program"
- When main() returns, OS calls "exit()" which destroys the process and returns all resources

Keeping track of a process

- A process has code.
  - ➢ OS must track program counter (code location).
- A process has a stack.
  - ➢ OS must track stack pointer.
- OS stores state of processes' computation in a process control block (PCB).
  - ➢ E.g., each process has an identifier (process identifier, or PID)
- Data (program instructions, stack & heap) resides in memory, metadata is in PCB (which is a kernel data structure in memory)

Process Life Cycle

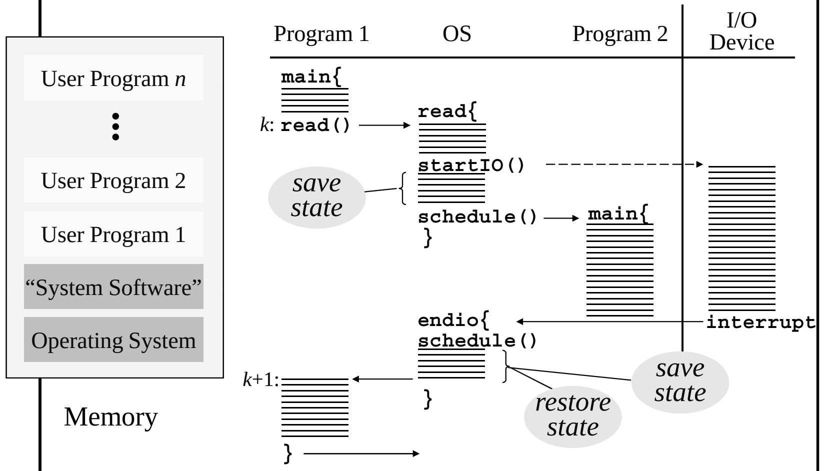
- Processes are always either *executing*, *waiting to execute* or *blocked waiting for an event* to occur



- A preemptive scheduler will force a transition from running to ready. A non-preemptive scheduler waits.

Process Contexts

Example: Multiprogramming



When a process is waiting for I/O what is its scheduling state?

1. Ready
2. Running
3. Blocked
4. Zombie
5. Exited

Scheduling Processes

- OS has PCBs for active processes.
- OS puts PCB on an appropriate queue.
  - Ready to run queue.
  - Blocked for IO queue (Queue per device).
  - Zombie queue.
- Stopping a process and starting another is called a context switch.
  - 100-10,000 per second, so must be fast.

Why Use Processes?

Consider a Web server
- get network message (URL) from client
- fetch URL data from disk
- compose response
- send response

How well does this web server perform?

With many incoming requests?

That access data all over the disk?

Why Use Processes?

Consider a Web server
- get network message (URL) from client
- create child process, send it URL

Child
- fetch URL data from disk
- compose response
- send response

- If server has configuration file open for writing
  - ➢ Prevent child from overwriting configuration
- How does server know child serviced request?
  - ➢ Need return code from child process

The Genius of Separating Fork/Exec

- Life with `CreateProcess(filename);`
  - But I want to close a file in the child.
    `CreateProcess(filename, list of files);`
  - And I want to change the child's environment.
    `CreateProcess(filename, CLOSE_FD, new_envp);`
  - Etc. (and a very ugly etc.)
- **`fork()`** = split this process into 2 (new PID)
  - Returns 0 in child
  - Returns pid of child in parent
- **`exec()`** = overlay this process with new program
  (PID does not change)

The Genius of Separating Fork/Exec

- Decoupling fork and exec lets you do anything to the child's process environment without adding it to the CreateProcess API.

```
int ppid = getpid();        // Remember parent's pid
fork();                      // create a child
if(getpid() != ppid) {                          // child continues here
    // Do anything (unmap memory, close net connections…)
    exec("program", argc, argv0, argv1, …);
}
```

- fork() creates a child process that inherits:
  - identical copy of all parent's variables & memory
  - identical copy of all parent's CPU registers (except one)
- Parent and child execute at the same point after **fork()** returns:
  - by convention, for the child, fork() returns 0
  - by convention, for the parent, fork() returns the process identifier of the child
  - fork() return code a convenience, could always use getpid()

Program Loading: exec()

- The exec() call allows a process to “load” a different program and start execution at main (actually _start).
- It allows a process to specify the number of arguments (argc) and the string argument array (argv).
- If the call is successful
  - it is the same process …
  - but it runs a different program !!
- Code, stack & heap is overwritten
  - Sometimes memory mapped files are preserved.

What creates a process?

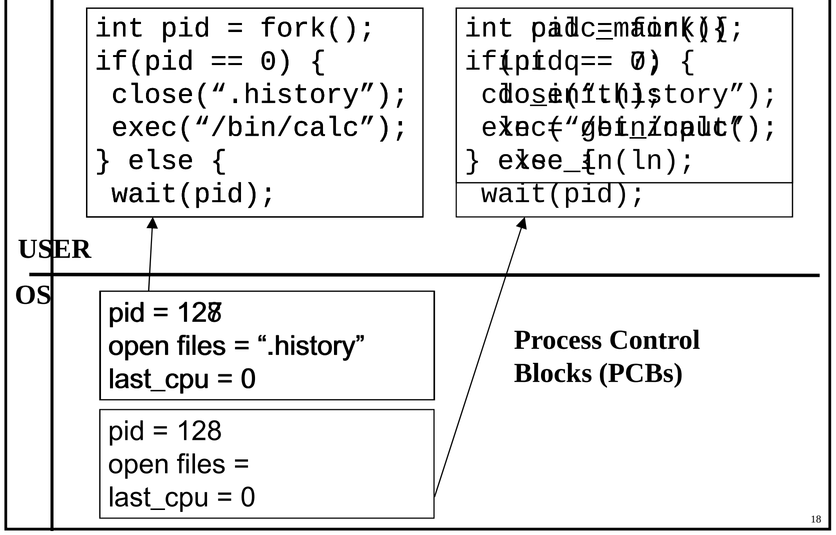
1. Fork
2. Exec
3. Both

General Purpose Process Creation

In the parent process:

```
main()
…
int ppid = getpid();                    // Remember parent's pid
fork();                                 // create a child
if(getpid() != ppid) {                  // child continues here
     exec_status = exec("calc", argc, argv0, argv1, …);
     printf("Why would I execute?");
}
else {                                  // parent continues here
    printf("Who's your daddy?");
    …
   child_status = wait(pid);
}
```

A shell forks and then execs a calculator

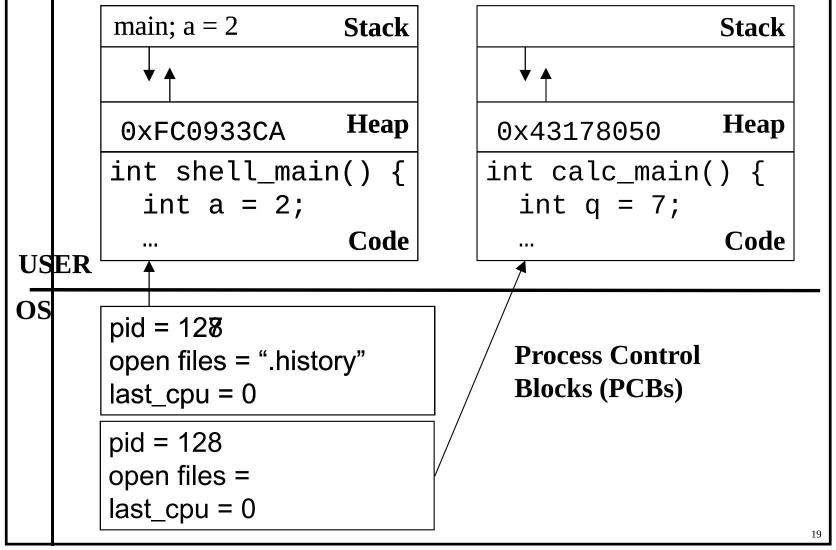


```
int pid = fork();
if(pid == 0) {
 close(".history");
 exec("/bin/calc");
} else {
 wait(pid);
```

```
int pid = fork();
if(pid == 0) {
 close(".history");
 exec("/bin/calc");
} else {
 wait(pid);
```

```
calc_main(){
 int q = 7;
 do_init();
 ln = get_input();
 exec_in(ln);
```

A shell forks and then execs a calculator



```
0xFC0933CA
int shell_main() {
  int a = 2;
  …
```

```
0x43178050
int calc_main() {
  int q = 7;
  …
```

pid = 127
open files = “.history”
last_cpu = 0

pid = 128
open files =
last_cpu = 0

At what cost, fork()?

- Simple implementation of fork():
  - allocate memory for the child process
  - copy parent’s memory and CPU registers to child’s
  - *Expensive* !!
- In 99% of the time, we call exec() after calling fork()
  - the memory copying during fork() operation is useless
  - the child process will likely close the open files & connections
  - overhead is therefore high
- vfork()
  - a system call that creates a process “without” creating an identical memory image
  - child process should call exec() almost immediately
  - Unfortunate example of implementation influence on interface
    - Current Linux & BSD 4.4 have it for backwards compatibility
  - Copy-on-write to implement fork avoids need for vfork

Orderly Termination: exit()

- After the program finishes execution, it calls *exit*()
- This system call:
  - takes the "result" of the program as an argument
  - closes all open files, connections, etc.
  - deallocates memory
  - deallocates most of the OS structures supporting the process
  - checks if parent is alive:
    - If so, it holds the result value until parent requests it; in this case, process does not really die, but it enters the zombie/defunct state
    - If not, it deallocates all data structures, the process is dead
  - cleans up all waiting zombies
- Process termination is the ultimate garbage collection (resource reclamation).

The wait() System Call

- A child program returns a value to the parent, so the parent must arrange to receive that value

- The wait() system call serves this purpose
  - it puts the parent to sleep waiting for a child's result
  - when a child calls exit(), the OS unblocks the parent and returns the value passed by exit() as a result of the wait call (along with the pid of the child)
  - if there are no children alive, wait() returns immediately
  - also, if there are zombies waiting for their parents, wait() returns one of the values immediately (and deallocates the zombie)

Process Control

OS must include calls to enable special control of a process:

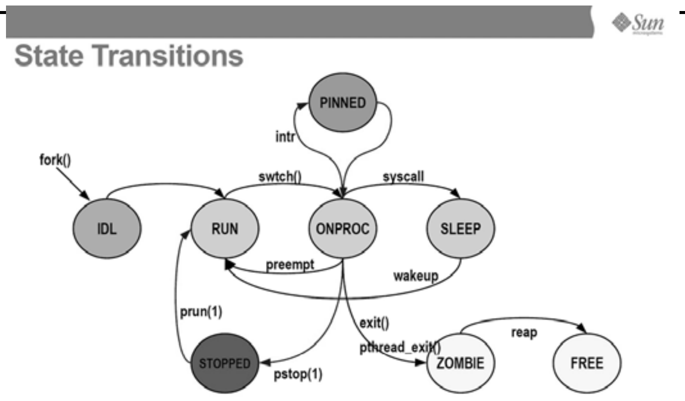
- Priority manipulation:
  - nice(), which specifies base process priority (initial priority)
  - In UNIX, process priority decays as the process consumes CPU
- Debugging support:
  - ptrace(), allows a process to be put under control of another process
  - The other process can set breakpoints, examine registers, etc.
- Alarms and time:
  - Sleep puts a process on a timer queue waiting for some number of seconds, supporting an alarm functionality

Tying it All Together: The Unix Shell

```
while(! EOF) {
read input
handle regular expressions
int pid = fork();                     // create a child
if(pid == 0) {                        // child continues here
    exec("program", argc, argv0, argv1, …);
}
else {                                // parent continues here
…
}
```

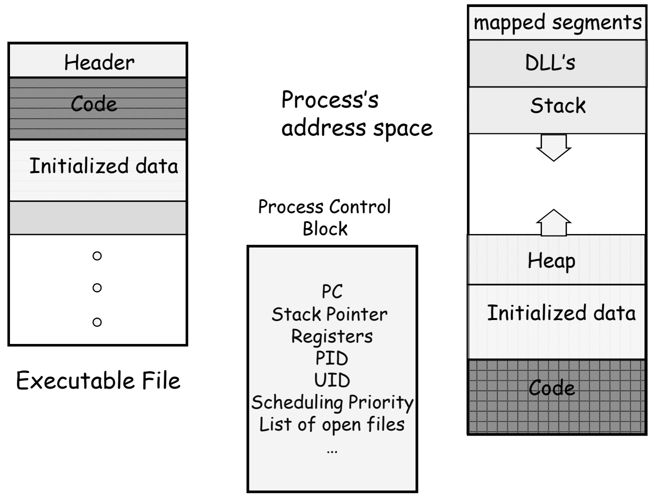
- Translates <CTRL-C> to the kill() system call with SIGKILL
- Translates <CTRL-Z> to the kill() system call with SIGSTOP
- Allows input-output redirections, pipes, and a lot of other stuff that we will see later

A Dose of Reality: Scheduling in Solaris



- Close to our scheduling diagram, but more complicated

Anatomy of a Process



Unix fork() example

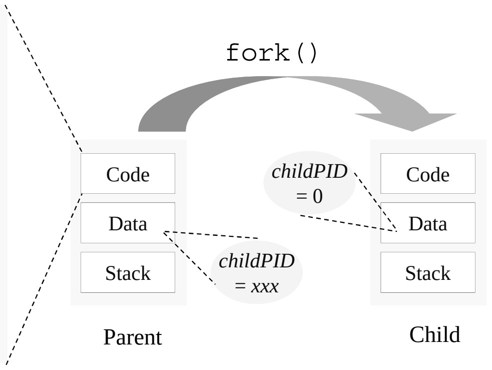
- The execution context for the child process is a *copy* of the parent's context at the time of the call
  - fork() returns child PID in parent, and 0 in child

```
main {
  int childPID;
  S1;

  childPID = fork();

  if(childPID == 0)
     <code for child process>
  else {
      <code for parent process>
      wait();
   }

  S2;
 }
```


fork()
childPID = 0
Code
Data
Stack
Code
Data
Stack
childPID = xxx
Parent
Child