OS Structure, Processes & Process Management

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Portions courtesy Emmett Witchel

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);
}
```

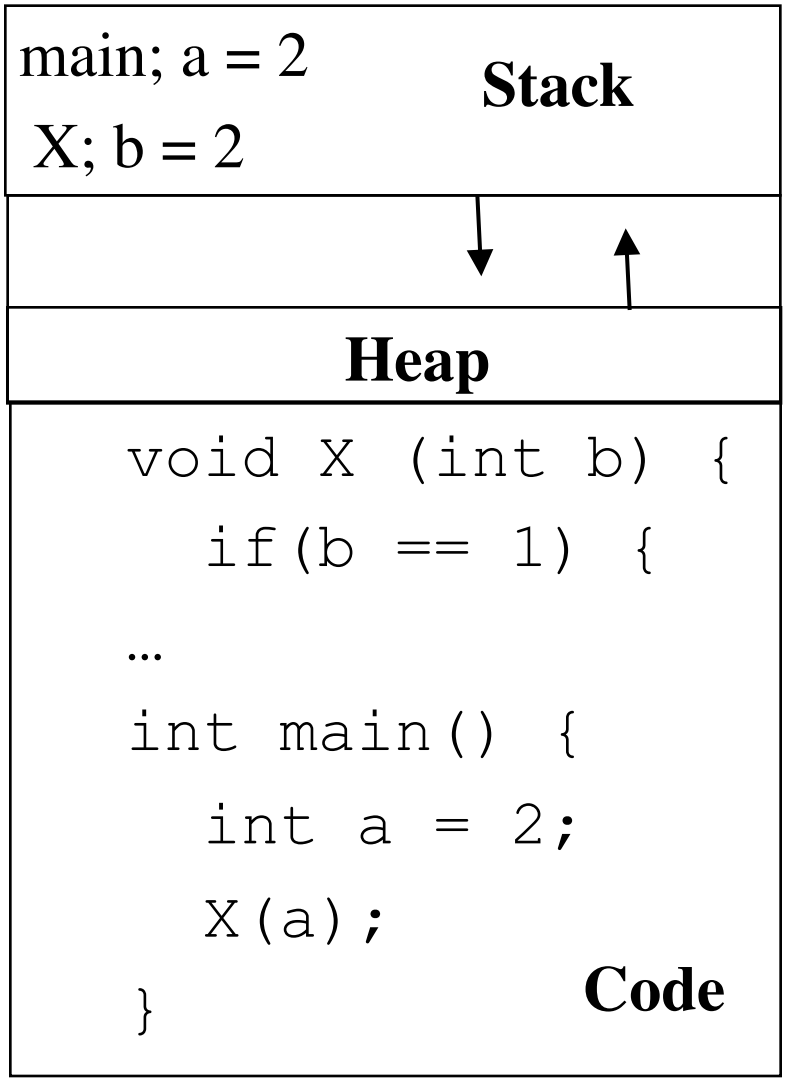
Process in Memory

- 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.



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)

Context Switching

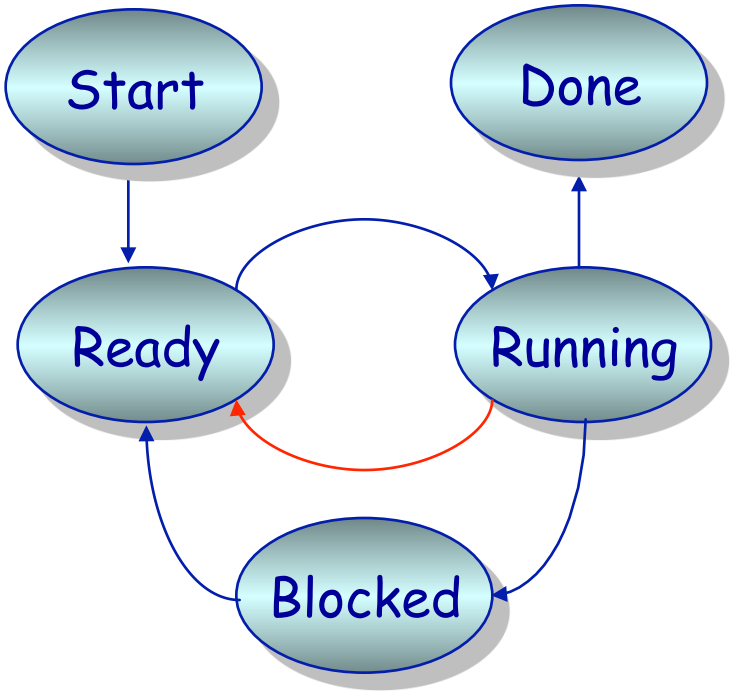
- The OS periodically switches execution from one process to another
- Called a **context switch**, because the OS saves one execution context and loads another

What causes context switches?

- Waiting for I/O (disk, network, etc.)
  - Might as well use the CPU for something useful
  - Called a blocked state
- Timer interrupt (preemptive multitasking)
  - Even if a process is busy, we need to be fair to other programs
- Voluntary yielding (cooperative multitasking)
- A few others
  - Synchronization, IPC, etc.

Process Life Cycle

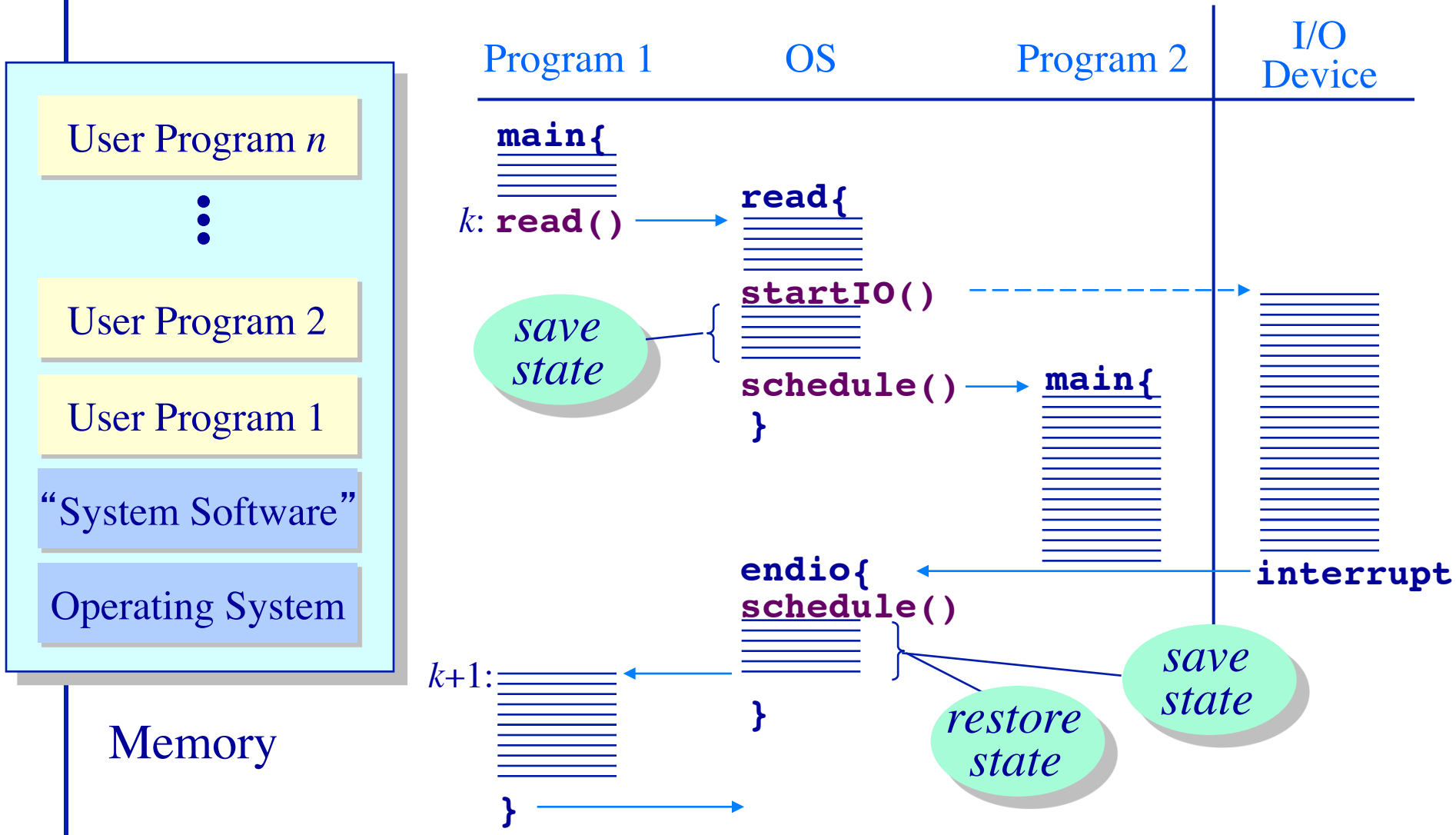
- Processes are always either *executing*, *waiting to execute* or *blocked waiting for an event* to occur



- 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

Where do new processes come from?

- Parent/child model
- An existing program has to spawn a new one
  - Most OSes have a special ‘init’ program that launches system services, logon daemons, etc.
  - When you log in (via a terminal or ssh), the login program spawns your shell

Approach 1: Windows CreateProcess

- In Windows, when you create a new process, you specify a new program
  - And can optionally allow the child to inherit some resources (e.g., an open file handle)

Approach 2: Unix fork/exec()

- In Unix, a parent makes a copy of itself using fork()
  - Child inherits everything, runs same program
  - Only difference is the return value from fork()
- A separate exec() system call loads a new program

- Major design trade-off:
  - How easy to inherit
  - Vs. Security (accidentally inheriting something the parent didn't intend)
  - Note that security is a newer concern, and Windows is a newer design…

The Convenience 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 Convenience 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 pid = fork();                          // create a child
If(0 == pid) {                                    // 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.

General Purpose Process Creation

In the parent process:

```
main()
…
int pid =fork();                        // create a child
if(0 == pid) {                          // 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);
```

USER

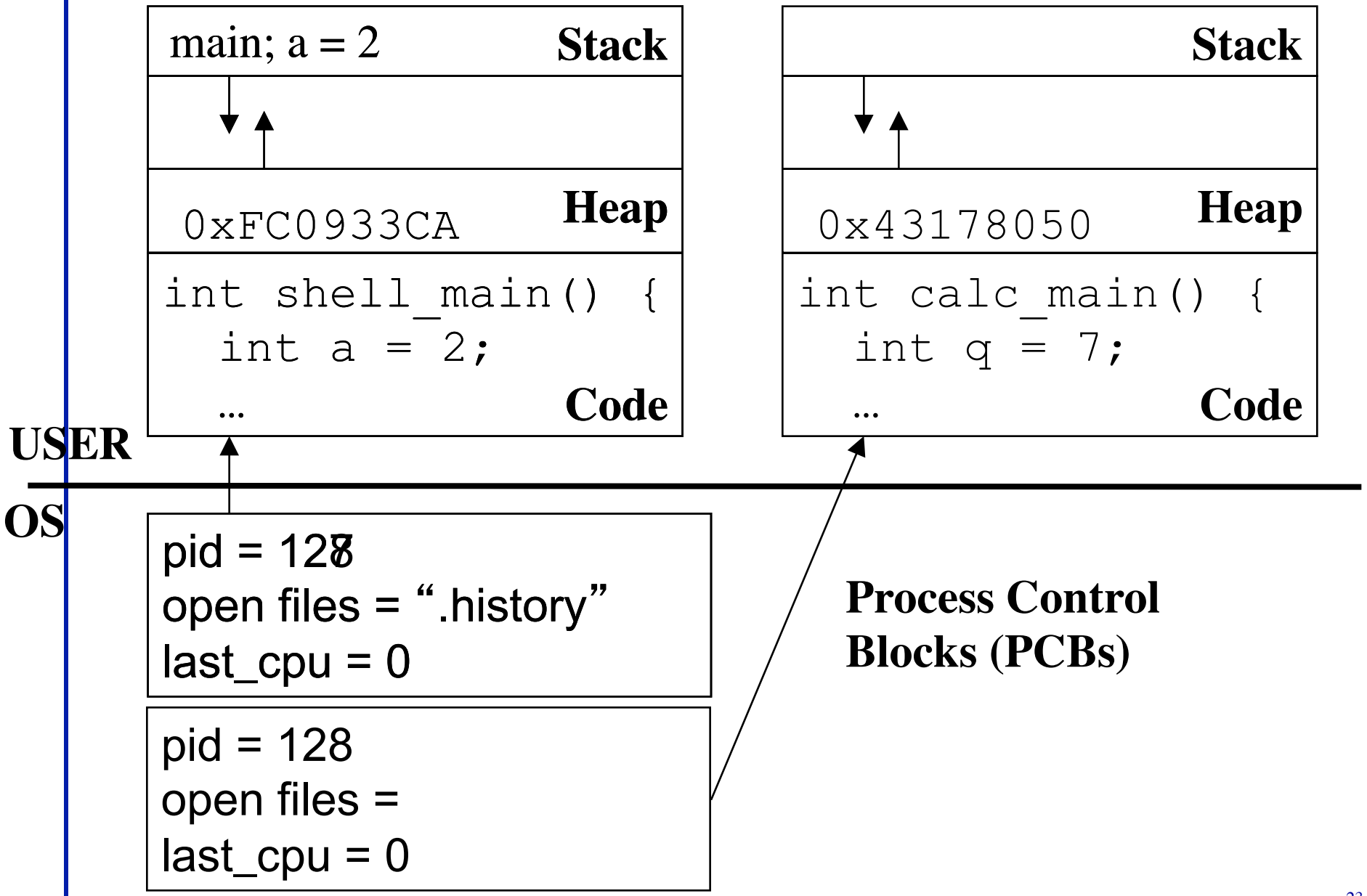
OS

pid = 128
open files = ".history"
last_cpu = 0

pid = 128
open files =
last_cpu = 0

Process Control Blocks (PCBs)

A shell forks and then execs a calculator



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

Summary

- Understand what a process is
- The high-level idea of context switching and process states
- How a process is created
- Pros and cons of different creation APIs
  - Intuition of copy-on-write fork and vfork