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).

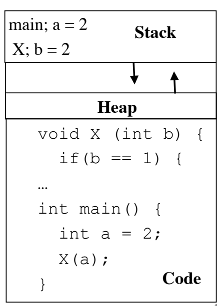
```
void X (int b) {
   if(b == 1) {
…
int main() {
  int a = 2;
  X(a);
}
```


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

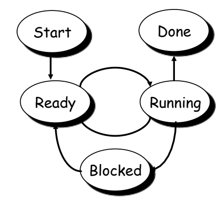
- The OS periodically switches execution from one process to another
- Called a **context switch**, because the OS saves one execution context and loads another

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

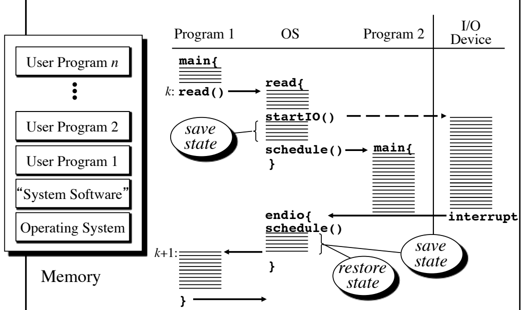
- Processes are always either *executing*, *waiting to execute* or *blocked waiting for an event* to occur



- *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()

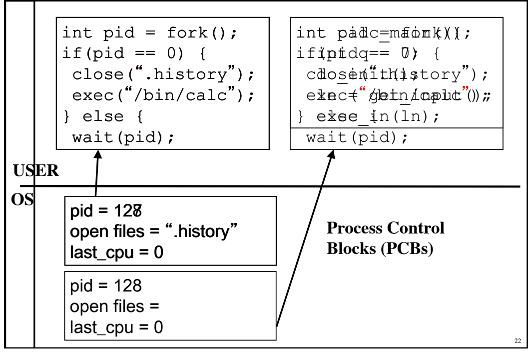
- The exec() call allows a process to "load" a different program and start execution at main (actually _start).
- It allows a process to specify the number of arguments (argc) and the string argument array (argv).
- If the call is successful
  - it is the same process …
  - but it runs a different program !!
- Code, stack & heap is overwritten
  - Sometimes memory mapped files are preserved.
- **Exec does not return!**

General Purpose Process Creation

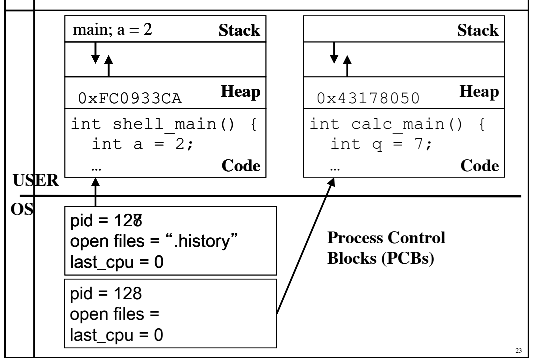
```
In the parent process:
main()
…
int pid =fork();                   // create a child
if(0 == pid) {                     // child continues here
    exec_status = exec("calc", argc, argv0, argv1, …);
    printf("Something is horribly wrong\n");
    exit(exec_status);
} else {                           // parent conti…
    printf("Who's your daddy?");
    …
    child_status = wait(pid);
}
```

Exec should not return

A shell forks and then execs a calculator



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