Operating System Labs

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Announcement

- Project 1 due
  - 21:00 Oct. 15

Operating System Labs

- The abstraction of process
- Process API
  - fork(), exec(), wait()
  - Project 1a
- CPU virtualization
  - Low level & high level mechanisms
  - Project 1b

The Abstraction of Process

- Process
  - Running programs
- What does a running program require?
  - CPU
    - Program Counter (PC)
    - Stack Pointer / Frame Pointer
  - Memory
    - Address space
  - Disk
    - Set of file descriptors

The Abstraction of Process

- The Linux kernel has two primary functions
  - **control access** (to physical devices on the computer)
  - **schedule** (when and how processes interact with these devices)

The Abstraction of Process

- proc file system
  - /proc/ directory contains a hierarchy of special files
  - the current state of the kernel — allowing applications and users to peer into the kernel's view of the system.

The Abstraction of Process

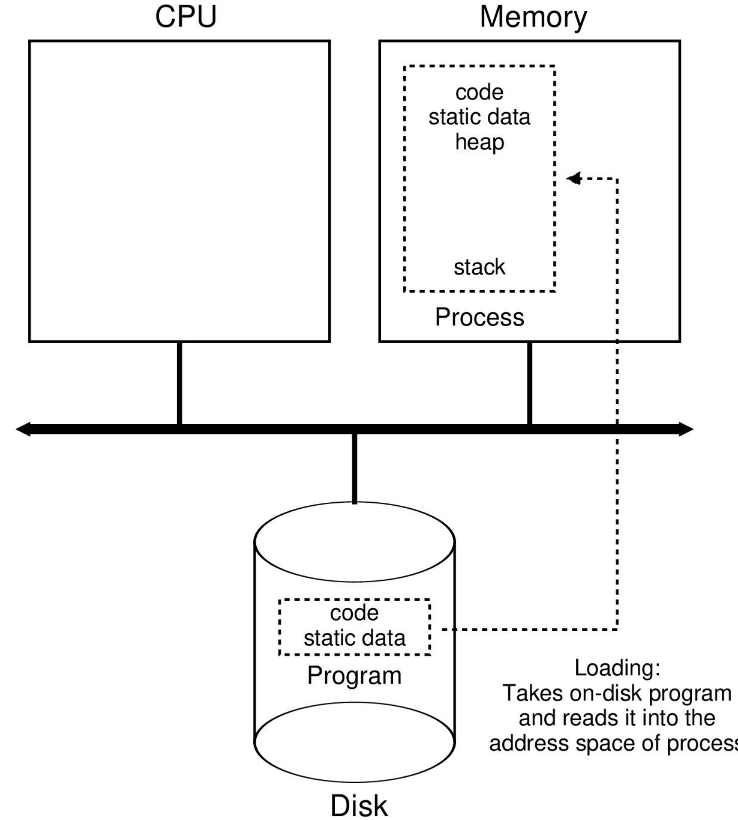
- proc file system
  - processes as files ("Everything is file")
  - Example
    - cat /proc/<PID>/status
    - cat /proc/<PID>/maps
    - cat /proc/<PID>/fd
    - cat /proc/<PID>/io
  - /proc/interrupts, /proc/meminfo, /proc/mounts, /proc/partitions
  - Provide a method of communication between kernel space and user space
    - ps command

The Abstraction of Process

- Process operations
  - Create
  - Destroy
  - Wait
  - Miscellaneous Control
  - Get status

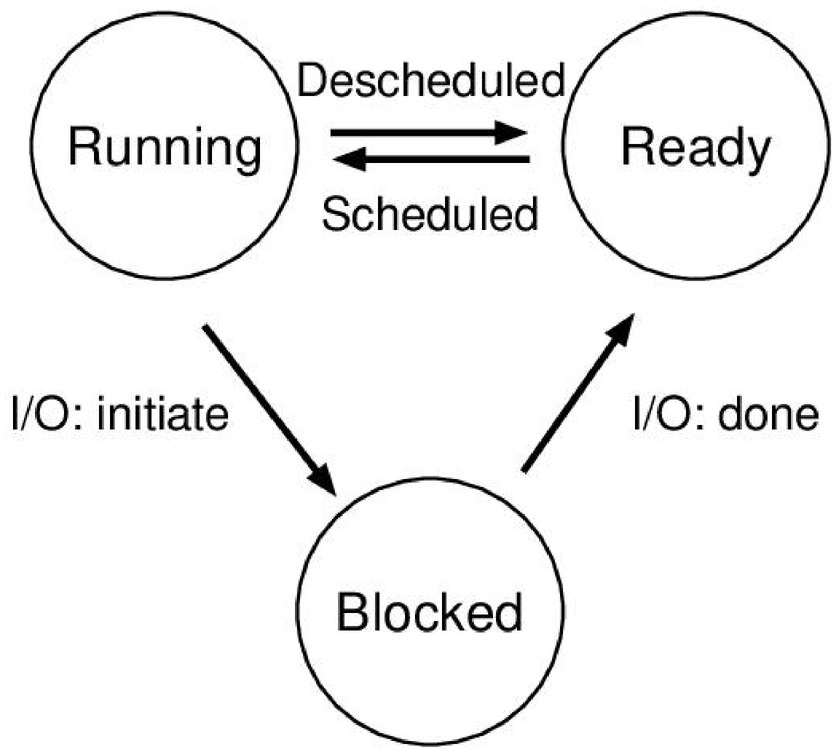
The Abstraction of Process

- Example: process creation
  - Load code and static data
  - Establish stack
    - local variables, function calls
  - Init heap
    - malloc, free
  - Allocate file descriptors
    - STDIN_FILENO
    - STDOUT_FILENO
    - STDERR_FILENO



The Abstraction of Process

- Process States



The Abstraction of Process

- Process States

Time	$Process_0$	$Process_1$	Notes
1	Running	Ready	
2	Running	Ready	
3	Running	Ready	
4	Running	Ready	$Process_0$ now done
5	–	Running	
6	–	Running	
7	–	Running	
8	–	Running	$Process_1$ now done

Time	$Process_0$	$Process_1$	Notes
1	Running	Ready	
2	Running	Ready	
3	Running	Ready	$Process_0$ initiates I/O
4	Blocked	Running	$Process_0$ is blocked,
5	Blocked	Running	so $Process_1$ runs
6	Blocked	Running	
7	Ready	Running	I/O done
8	Ready	Running	$Process_1$ now done
9	Running	–	
10	Running	–	$Process_0$ now done

The Abstraction of Process

- Data structures

```
// the registers xv6 will save and restore
// to stop and subsequently restart a process
struct context {
  int eip;
  int esp;
  int ebx;
  int ecx;
  int edx;
  int esi;
  int edi;
  int ebp;
};

// the different states a process can be in
enum proc_state { UNUSED, EMBRYO, SLEEPING,
                  RUNNABLE, RUNNING, ZOMBIE };

// the information xv6 tracks about each process
// including its register context and state
struct proc {
  char *mem;                  // Start of process memory
  uint sz;                    // Size of process memory
  char *kstack;               // Bottom of kernel stack
                              // for this process
  enum proc_state state;      // Process state
  int pid;                    // Process ID
  struct proc *parent;        // Parent process
  void *chan;                 // If non-zero, sleeping on chan
  int killed;                 // If non-zero, have been killed
  struct file *ofile[NOFILE]; // Open files
  struct inode *cwd;          // Current directory
  struct context context;     // Switch here to run process
  struct trapframe *tf;       // Trap frame for the
                              // current interrupt
};
```

Process API

- Process API
  - fork(), exec(), wait(), exit()
  - Create, execute, wait and terminate a process
  - May be the strangest API you've ever met

Process API

- fork()
  - Create a new process
  - Exactly copy the calling process
- The return code of fork() is different
  - In parent: fork() return the pid of the child
  - In child: fork() return 0
- Who will run first is not determined

Process API

- wait()
  - Wait for a child to finish his job
  - The parent will not proceed until wait() return.
- waitpid()

Process API

- exec()
  - Execute a different program in child process
- A group of system calls:
  - execl, execv, execle, execve, execlp, execvp, fexecv

Process API

- Some Coding
  - fork
  - fork, wait
  - fork, wait, execvp

Process API

- What's happening behind fork()?
  - The child get a “copy” of parent's data space, stack, heap
    - the system call: clone()
  - “Copy-on-write”
    - Not really copy the data, but share the data with “read only” flag
    - If parent or child writes on a shared address, the kernel make a copy of that piece of memory only (usually a page)

Process API

- What's happening behind fork()?
  - File sharing
    - fd
    - File offsets

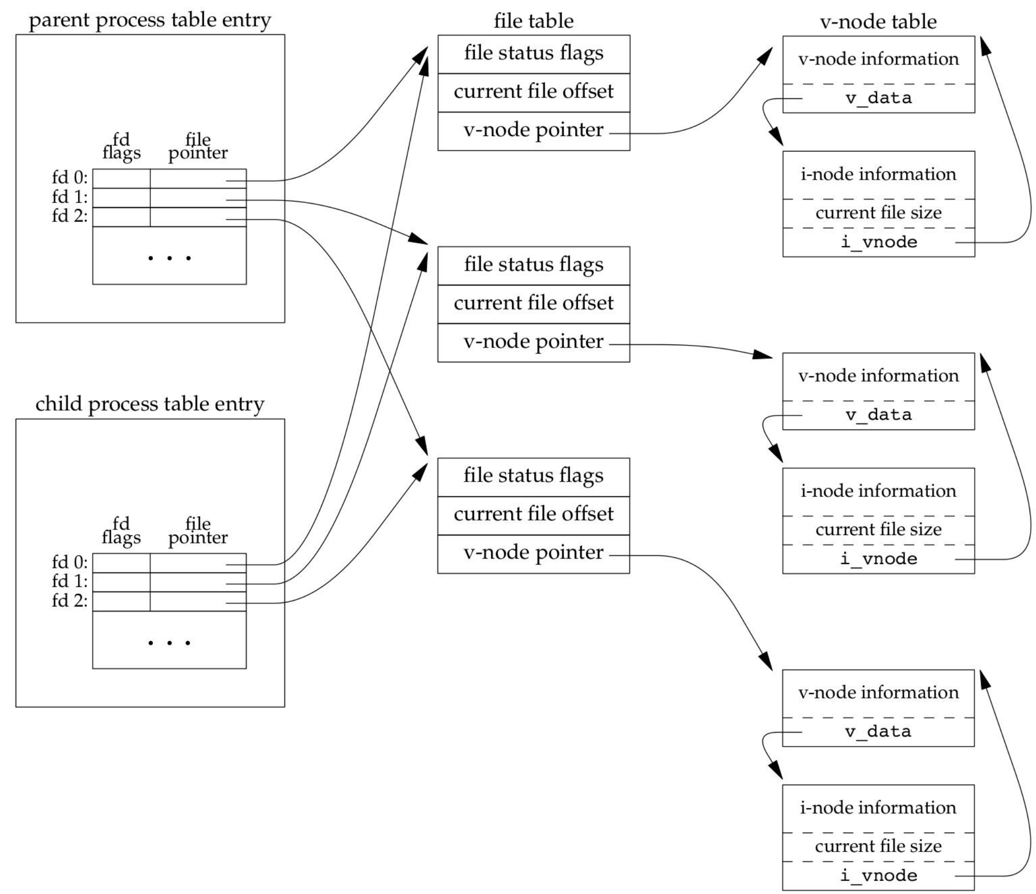


Figure 8.2 Sharing of open files between parent and child after `fork`

Process API

- What's happening behind fork()?
  - Other shared data:
    - User ID, group ID…
    - Current working directory
    - Environment
    - Memory mapping
    - Resources limits
    - ...

Process API

- What's happening behind exit()?
  - Close all fds, release all memory, …
  - Inform the exit status to the parent process, which can be captured by wait()

Process API

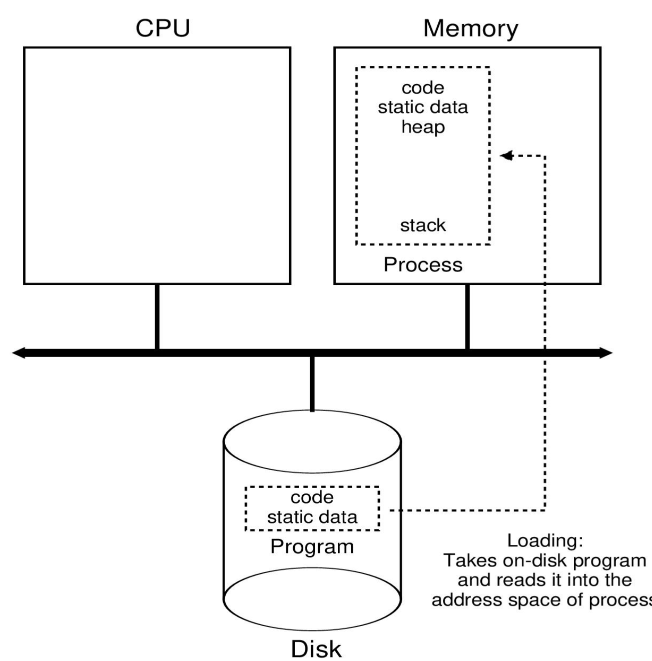
- What's happening behind wait()?
  - The parent terminates first?
    - The init process (PID=0)
  - The child terminates first?
    - The kernel keeps a small amount of information for every terminating process
    - Available when the parent calls wait()
      - PID, termination status, the amount of CPU time
    - zombies

Process API

- What's happen behind wait()/waitpid()
  - wait(): block the caller until a child process terminates
  - waitpid(): wait which child, and some other options

Process API

- What's happening behind exec()?
  - Replace the current process with a new program from disk
    - Text, data, heap, stack
  - Start from the main() of that program



Process API

- Process API summary
  - fork(): create a new process
  - wait(): wait for a child
  - exit(): destroy a process
  - exec(): execute a program in child

Project1a

- Implement your own shell
  - Use fork, wait, execvp
  - Also open, close, dup2

Project1a Details

- Basic shell
  - Run your shell by: ./mysh
  - It will print a prompt:

    mysh>

  - You can type some commands

    mysh> ls

  - Hit ENTER, the command will be executed

Project1a Details

- Build-in Commands
  - When “mysh” execute a command, it will check weather it is a **build-in** or not.
  - For build-in commands, you should involve your implementation.
  - They are:
    - exit
    - wait
    - cd
    - pwd

Project1a Details

- Redirection
  - Your shell should support redirection:

    mysh> ls -l > output

  - The file “output” contain the result of “ls -l”

Project1a Details

- Background Jobs
  - Your shell should be able to run jobs in the background

    mysh> ls &

  - Your shell will continue to work rather than wait.

Project1a Details

- Batch mode
  - Your shell should be able to run in batch mode

    ./mysh batch_file

  - Your shell will run the commands in batch_file
  - E.g, "batch_file" contains

    ls -l

    echo hello

Project1a Details

- Bonus: Pipe
  - The pipe connect the input/output of different commands

    mysh> grep “hello” FILE | wc -l

  - How many lines have “hello”

CPU Virtualization

- What
  - Provide the illusion of many CPUs
- Why
  - Multi-task
- How
  - Time sharing

CPU Virtualization

- Mechanisms
  - Low level mechanisms
    - Context switch
  - High level intelligence
    - Scheduling policy

CPU Virtualization

- Low level mechanisms
  - Direct Execution
    - Just run a program on CPU directly

OS	**Program**
Create entry for process list	
Allocate memory for program	
Load program into memory	
Set up stack with argc/argv	
Clear registers	
Execute **call** main()	
	Run main()
	Execute **return** from main
Free memory of process	
Remove from process list	

Direct Execution

- Problems of direct execution
  - Visit any memory address
  - Open any file
  - Directly play with hardwares (e.g. I/O)

Lost control

Limited Direct Execution

- Limited Direct Execution
  - Kernel model and user model
  - “restricted operations”
    - By OS
  - When a thread needs “restricted operations”
    - System call

Limited Direct Execution

- User mode
  - The behavior of the code is restricted
- Kernel mode
  - The code can do whatever it wants to do
    - Issue I/O, executing all types of instructions,...
- How to switch?
  - System call

System Call

- Hardware supports on system call
  - A bit in CPU identifies kernel/user mode
  - “trap” instruction
  - “return-from-trap” instruction
  - Save the registers before do the restricted operation (kernel stack)

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
		Run main() ... Call system call **trap** into OS

OS @ run (kernel mode)	Hardware	Program (user mode)
		Run main()
		...
		Call system call
		trap into OS
	save regs to kernel stack	
	move to kernel mode	
	jump to trap handler	

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
		Run main()
		...
		Call system call
		trap into OS
	save regs to kernel stack	
	move to kernel mode	
	jump to trap handler	
Handle trap		
Do work of syscall		
return-from-trap		

OS @ run (kernel mode)	Hardware	Program (user mode)
		Run main() ... Call system call **trap** into OS
	save regs to kernel stack move to kernel mode jump to trap handler	
Handle trap Do work of syscall **return-from-trap**		
	restore regs from kernel stack move to user mode jump to PC after trap	

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
Create entry for process list		
Allocate memory for program		
Load program into memory		
Setup user stack with argv		
Fill kernel stack with reg/PC		
return-from-trap		
	restore regs from kernel stack	
	move to user mode	
	jump to main	
		Run main()
		...
		Call system call
		trap into OS
	save regs to kernel stack	
	move to kernel mode	
	jump to trap handler	
Handle trap		
Do work of syscall		
return-from-trap		
	restore regs from kernel stack	
	move to user mode	
	jump to PC after trap	

OS @ run **(kernel mode)**	**Hardware**	**Program** **(user mode)**
Create entry for process list		
Allocate memory for program		
Load program into memory		
Setup user stack with argv		
Fill kernel stack with reg/PC		
return-from-trap		
	restore regs from kernel stack	
	move to user mode	
	jump to main	
		Run main()
		...
		Call system call
		trap into OS
	save regs to kernel stack	
	move to kernel mode	
	jump to trap handler	
Handle trap		
Do work of syscall		
return-from-trap		
	restore regs from kernel stack	
	move to user mode	
	jump to PC after trap	
		...
		return from main
		trap (via `exit()`)
Free memory of process		
Remove from process list		

OS @ boot (kernel mode)	**Hardware**
initialize trap table	
	remember address of... syscall handler

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
Create entry for process list Allocate memory for program Load program into memory Setup user stack with argv Fill kernel stack with reg/PC **return-from-trap**		
	restore regs from kernel stack move to user mode jump to main	
		Run main() ... Call system call **trap** into OS
	save regs to kernel stack move to kernel mode jump to trap handler	
Handle trap Do work of syscall **return-from-trap**		
	restore regs from kernel stack move to user mode jump to PC after trap	
		... return from main **trap** (via `exit()`)
Free memory of process Remove from process list		

Limited Direct Execution

- Switching between processes
  - Cooperative approach
    - OS trusts the process to yield CPU properly
  - Non-cooperative approach
    - OS revokes the control of CPU periodically
    - Time interrupt
    - Scheduler

OS @ boot (kernel mode)	**Hardware**	
initialize trap table		
	remember addresses of... syscall handler timer handler	
start interrupt timer		
	start timer interrupt CPU in X ms	

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
		Process A ...
	timer interrupt save regs(A) to k-stack(A) move to kernel mode jump to trap handler	
Handle the trap Call `switch()` routine save regs(A) to proc-struct(A) restore regs(B) from proc-struct(B) switch to k-stack(B) **return-from-trap (into B)**		
	restore regs(B) from k-stack(B) move to user mode jump to B's PC	
		Process B ...

Limited Direct Execution

- Low-level mechanisms: summary
  - Direct execution
  - Limited direct execution
  - Switch between processes

Scheduling Policy

- High level intelligence
  - Scheduling policy
    - First In, First Out
    - Shortest job first
    - Shortest time to complete first
    - Round Roubin

CPU virtualization

- Summary of CPU virtualization
  - Low level mechanisms
    - A little hardware support goes a long way
  - High level mechanisms

Project1b Details

- Adding a system call for xv6
  - Understanding the low-level mechanism
  - Kernel mode, user mode
  - Trap
  - Interrupt handler

Project1b Details

- The system call
  - int getreadcount()
  - Return how many times the read() system call has been called

Project1b Details

- Get familiar with xv6
  - QEMU emulator
    - Installed with make
  - Compile and run xv6
    - Compile: make
    - Run: make qemu-nox
    - Debug: make qemu-nox-gdb