CPU Virtualization: Processes

CS 537: Introduction to Operating Systems

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Administrivia

- Check that you have a **~cs537-1/handin/<username>/P1/** directory and that you can write to it. This is where you should turn in your project 1 solution.
- Want to learn the GNU/Linux Command Line? Read the online book at https://linuxcommand.org/
- **UPDATE: The `wgroff` instructions were showing the wrong slash for the beginning of an ANSI command. ANSI commands should begin with a backslash (\) (e.g. bold is `\033[1m`) .**

Agenda

Today

- What is a process and what is its lifecycle? (abstraction)
- How does an OS manage processes? (mechanism)
- How can you create and work with processes? (API)

Next Time

- How should the OS decide which process gets to execute and for how long (policy)

Aside – CS Terms

Abstraction a concept-object that mirrors common features or attributes of non-abstract objects.

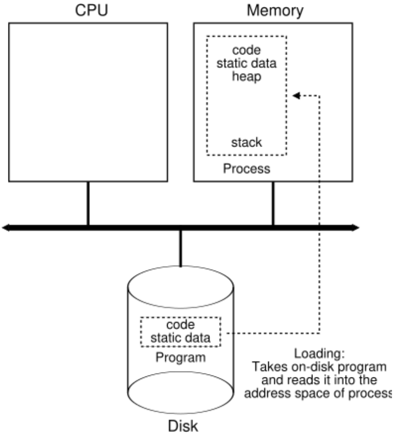
Mechanism Low-level machinery (methods or protocols) that implement a needed piece of functionality.

Policy An algorithm for making some decision within the OS.

API Application Program Interface is a type of public interface a program offers as a service to other programs.

Process

While a computer program is a passive collection of instructions typically stored in a file on disk, **a process** is the execution of those instructions after being loaded from the disk into memory. – wikipedia



Creation of A Process by OS

- Load data from disk to memory
- Allocate space for the run-time **stack** and initialize the stack with arguments (i.e. fill in the parameters for `argc` and `argv`)
- Allocate memory for program's **heap**. Initially small, but OS may grow the heap as needed.
- Setup initial **file descriptors** (stdin, stdout, stderr).
- Transfer control of the CPU to the newly-created process (i.e. `main()`).

OS Control of Processes

- **Create** – When you type a command (or click on an application icon), the OS is invoked to create a new process.
- **Destroy** – OS provides a way to forcefully destroy a process.
- **Wait** – It is useful to be able to wait for a process to stop running.
- **Miscellaneous Control** – e.g. suspend (temporarily stop) a process and resume it again.
- **Status** – Get information about a process (e.g. how long has it run for?)

Machine State of a Process (Context)

The **machine state**: What a program can read or change when it is running.

- **Registers** (general purpose, stack pointer, PC, IP, frame pointer, etc.)
- **Address space** (heap, stack, etc.)
- **Open files**

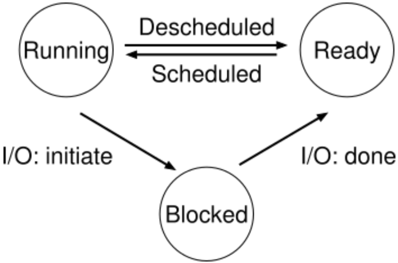
If the OS wants to suspend and later resume a process, the OS must keep track of the context of the process.

Aside – OSTEP Homeworks

- Optional homeworks corresponding to chapters in book
- Little simulators to help you understand
- Can generate problems and solutions

https://pages.cs.wisc.edu/~remzi/OSTEP/Homework/homework.html

Process State




```
./process.py -l 3:100,3:50
```

Time	PID: 0	PID: 1	CPU	IOs
1	RUN:cpu	READY	1	
2	RUN:cpu	READY	1	
3	RUN:cpu	READY	1	
4	DONE	RUN:cpu	1	
5	DONE	RUN:io	1	
6	DONE	BLOCKED		1
7	DONE	BLOCKED		1
8	DONE	BLOCKED		1
9	DONE	BLOCKED		1
10	DONE	BLOCKED		1
11*	DONE	RUN:io_done	1	
12	DONE	RUN:cpu	1	

All IO takes 5 time slices

Direct Execution

- Allow user process to run directly on hardware
- OS creates process and transfers control to the start of the process (i.e. `main()`)

Problems

1. Process could do something restricted
   Could read/write to other processes data (disk or memory)
2. Process could run forever
   OS needs to be able to switch between processes
3. Process could do something slow
   OS wants to use resources efficiently

Solution

LIMITED DIRECT EXECUTION – OS and hardware maintain some control

Limited Direct Execution Prob #1 – Restricted Ops

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

Solution – Privilege Levels Suppported by Hardware (bit of status)

- User processes run in user mode (restricted mode)
- OS runs in kernel mode (not restricted)
  - Instructions for interacting with devices
  - Could have many privilege levels (advanced topic)

How can process perform restricted instruction?

- Ask the OS to do it through a system call
- Change privilege level as system call is made (trap)

System Call

Figure 1: System Call

- P can only see its own memory because it runs in **user mode**.
- P wants to call read() but no way to call it directly.

XV6 Traps and Sys Calls

trap.h

```
#define T_ALIGN        17      // aligment ch
#define T_MCHK         18      // machine che
#define T_SIMDERR      19      // SIMD floati

// These are arbitrarily chosen, but with care
// processor defined exceptions or interrupt v
#define T_SYSCALL      64      // system call
#define T_DEFAULT     500      // catchall
```

syscall.h

```
#define SYS_wait    3
#define SYS_pipe    4
#define SYS_read    5
#define SYS_kill    6
#define SYS_exec    7
#define SYS_fstat   8
#define SYS_chdir   9
```

System Call

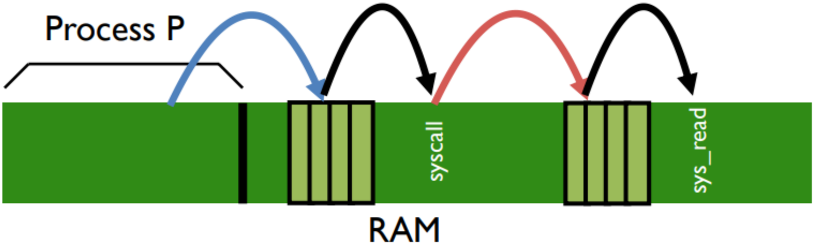


Figure 2: System Call

movl **$5**, %eax;

int **$64**

System Call

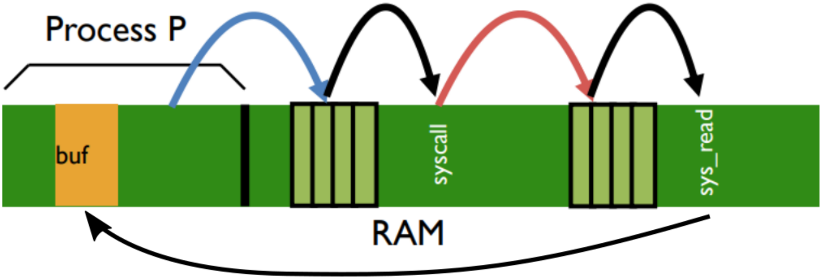


Figure 3: System Call

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

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 Prob #2 CPU Sharing

- Could wait for current process to yield the CPU (Cooperative Approach)
- Could interrupt current process to regain control (True Multi-tasking)
  - Guarantee OS can obtain control periodically
  - Hardware generates timer interrupt, running OS's dispatcher:

```
while (1) {
  run process A for some time-slice
  stop process A and save its context
  load context of another process B
}
```

Context Switch

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

Intialize Trap Table and Start Timer

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 Data Structures for Managing Processes

- **Process Control Block** (PCB) in xv6

```
// Per-process state
struct proc {
  uint sz;                     // Size of process memory (bytes)
  pde_t* pgdir;                // Page table
  char *kstack;                // Bottom of kernel stack for this process
  enum procstate state;        // Process state
  int pid;                     // Process ID
  struct proc *parent;         // Parent process
  struct trapframe *tf;        // Trap frame for current syscall
  struct context *context;     // swtch() here to run 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
  char name[16];               // Process name (debugging)
};
```

- **Process List** – A list containing a PCB for each process

Linux API for Processes

- **fork()** – Used to create a new process
- **exec()** – Replaces the current process image with a new process image (whole family of functions: `execl()`, `execlp()`, `execle()`, `execv()`, `execvp()`, `execvpe()`)
- **wait()** – Waits for a child process to stop or terminate

Demo

Run chapter 5's demo code p1, p2, p3, and p4 to see how these three system calls work.

Quiz 1 - Processes

Processes

You must use your UW-Madison account to access.

https://tinyurl.com/cs537-fa23-q1