Lecture Note 2: Processes

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Chap 6. Mechanism: Limited Direct Execution

- ✓ Basic Technique: Limited Direct Execution
- ✓ Switch between Modes
- ✓ Switch between Processes

Chap 3. A Dialogue on Virtualization

Virtualization

Student: *But what is virtualization, oh noble professor?*

Professor: *Imagine we have a peach.*

Student: *A peach? (incredulous)*

Professor: *Yes, a peach. Let us call that the* ***physical*** *peach. But we have many eaters who would like to eat this peach. What we would like to present to each eater is their own peach, so that they can be happy. We call the peach we give eaters* ***virtual*** *peaches; we somehow create many of these virtual peaches out of the one physical peach. And the important thing: in this illusion, it looks to each eater like they have a physical peach, but in reality they don't.*

Student: *So you are sharing the peach, but you don't even know it?*

Professor: *Right! Exactly.*

Student: *But there's only one peach.*

Professor: *Yes. And...?*

Student: *Well, if I was sharing a peach with somebody else, I think I would notice.*

Professor: *Ah yes! Good point. But that is the thing with many eaters; most of the time they are napping or doing something else, and thus, you can snatch that peach away and give it to someone else for a while. And thus we create the illusion of many virtual peaches, one peach for each person!*

Student: *Sounds like a bad campaign slogan. You are talking about computers, right Professor?*

Professor: *Ah, young grasshopper, you wish to have a more concrete example. Good idea! Let us take the most basic of resources, the CPU. Assume there is one physical CPU in a system (though now there are often two or four or more). What virtualization does is take that single CPU and make it look like many virtual CPUs to the applications running on the system. Thus, while each application*

Chap 4. The Abstraction: The Process

Process definition

- ✓ A running program, scheduling entity
  - c.f.) program: a lifeless thing, sit on the disk and waiting to spring into action
  - Run on memory and CPU
- ✓ There exist multiple processes (e.g. browser, editor, player, and so on)
  - Each process has its own memory (address space), virtual CPU, state, …

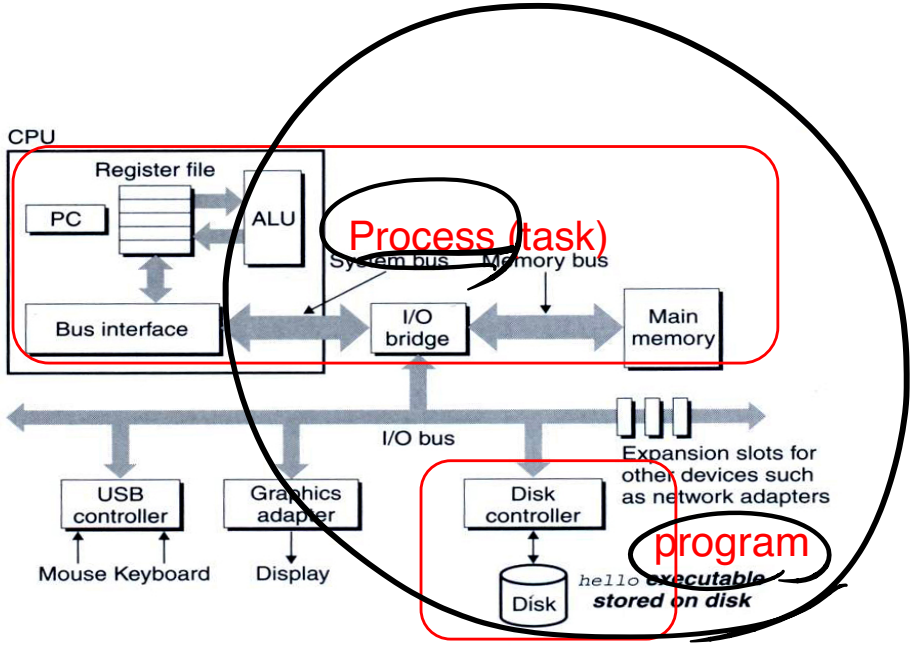
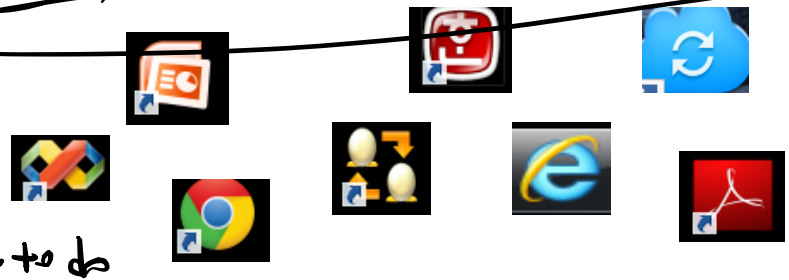


Figure 1.4 **Hardware organization of a typical system.** CPU: Central Processing Unit, ALU: Arithmetic/Logic Unit, PC: Program Counter, USB: Universal Serial Bus.

(Source: computer systems: a programmer perspective)

Chap 4: The Abstraction: The Process

How to virtualize CPU? Time sharing on multiple processes



How to do

- Mechanism
  - context switch: an ability to stop running a program and start running another on a given CPU
- Policy
  - scheduling policy: based on historical information or workload knowledge or performance metric.

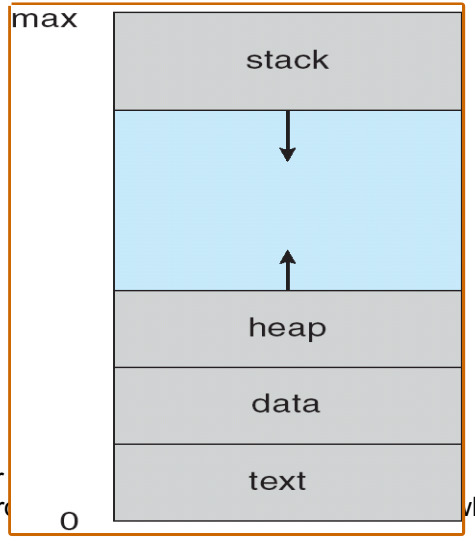
what to do

? Time sharing vs. Space sharing

4.1 Process

Process structure

- ✓ Need resources to run:
  - CPU
    - Registers such as PC, SP, ..
  - Memory (address space)
    - Text: program codes
    - Data: global variables
    - Stack: local variables, parameters, …
    - Heap: allocated dynamically
  - I/O information
    - Opened files (including devices)



- ✓ cf.) program
  - Passive entity
  - A file containing instructions stored on disk (executable file or
  - Execute a program twice ? result in creating two processes (fr hile
  - others (data, stack) vary (1-to-n)

(Source: A. Silberschatz, "Operating system Concept")

4.2 Process API

Basic APIs for a process

- **Create:** An operating system must include some method to create new processes. When you type a command into the shell, or double-click on an application icon, the OS is invoked to create a new process to run the program you have indicated.
- **Destroy:** As there is an interface for process creation, systems also provide an interface to destroy processes forcefully. Of course, many processes will run and just exit by themselves when complete; when they don't, however, the user may wish to kill them, and thus an interface to halt a runaway process is quite useful.
- **Wait:** Sometimes it is useful to wait for a process to stop running; thus some kind of waiting interface is often provided.
- **Miscellaneous Control:** Other than killing or waiting for a process, there are sometimes other controls that are possible. For example, most operating systems provide some kind of method to suspend a process (stop it from running for a while) and then resume it (continue it running).
- **Status:** There are usually interfaces to get some status information about a process as well, such as how long it has run for, or what state it is in.

Refer to chapter 5 in OSTEP

4.3 Process Creation: A Little More Detail

How to start a program

- ✓ **Load**
  - Bring code and static data into the address space
  - Based on executable format (e.g. ELF, PE, BSD, …)
  - Eagerly vs. Lazily (paging, swapping)
- ✓ **Dynamic allocation**
  - Stack
  - Initialize parameters (argc, argv)
  - Heap if necessary
- ✓ **Initialization**
  - file descriptors (0, 1, 2)
  - I/O or signal related structure
- ✓ **Jump to the entry point: main()**

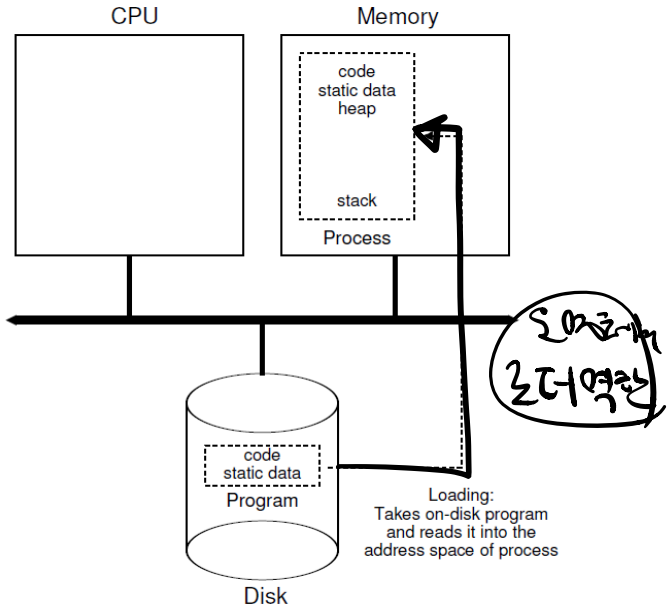
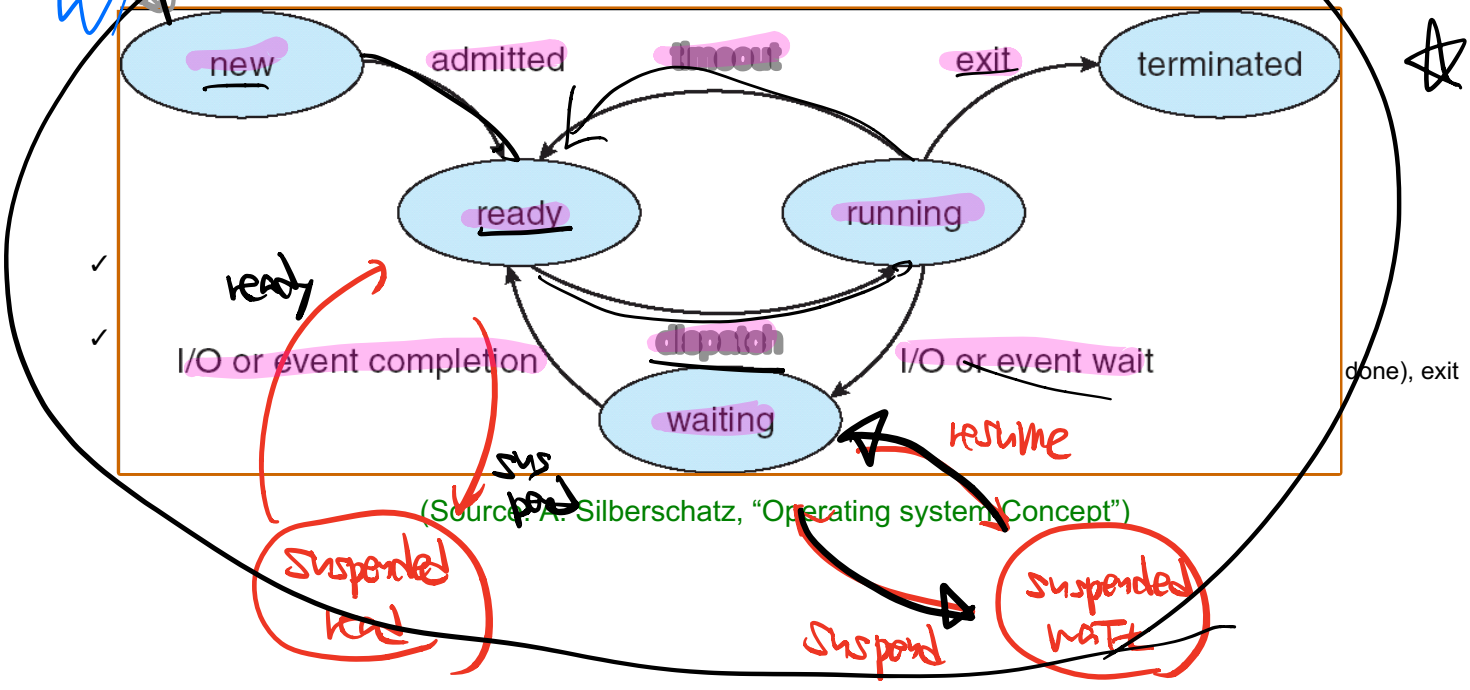


Figure 4.1: **Loading: From Program To Process**

4.4 Process States

State and transition



4.4 Process States

Example

- ✓ Used resources: CPU only ? Figure 4.3
- ✓ Used resources: CPU and I/O ? Figure 4.4

Note: I/O usually takes quite longer than CPU

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

Figure 4.3: **Tracing Process State: CPU Only**

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

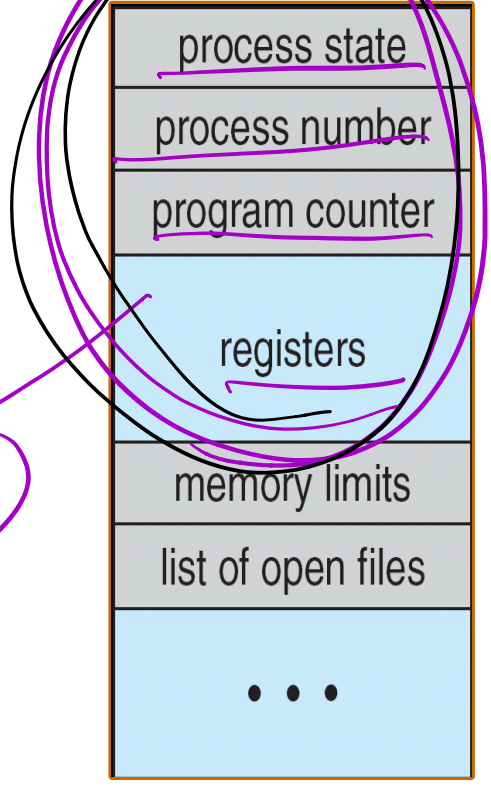
Figure 4.4: **Tracing Process State: CPU and I/O**

? At the end of time 6 in Figure 4.4, OS can decide to 1) continue running the process1 or 2) switch back to process 0. Which one is better? Discuss tradeoff.

4.5 Data Structure

PCB (Process Control Block)

- Information associated with each process
  - Process state
  - Process ID (pid)
  - Program counter, CPU registers
    - Used during context switch
    - Architecture dependent
  - CPU scheduling information
  - Memory-management information
  - Opened files
  - I/O status information
  - Accounting information
- Managed in the kernel's data segment



(Source: A. Silberschatz, "Operating system Concept")

4.5 Data Structure

Implementation example

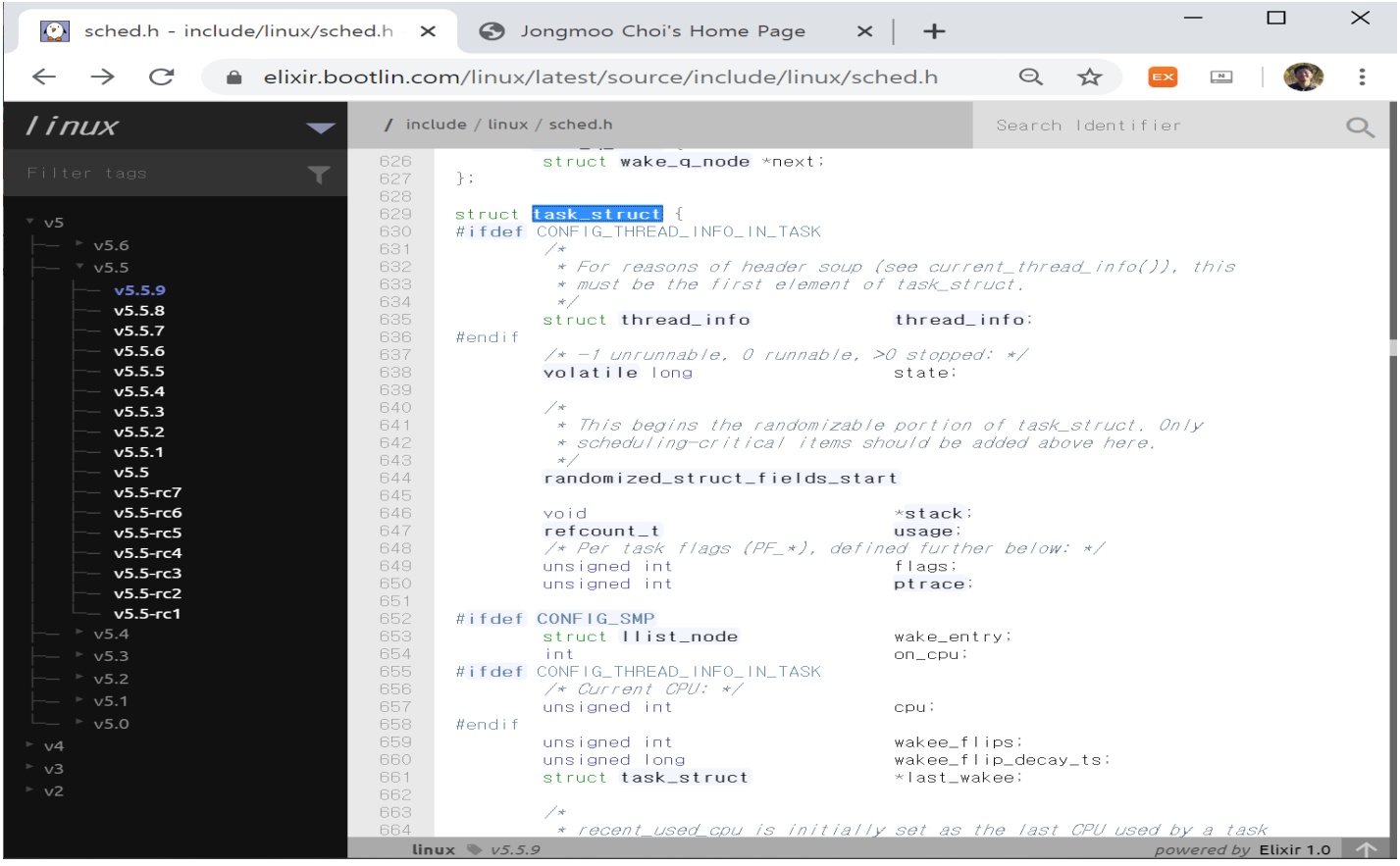
- ✓ OS is a program, implementing a process using data structure (e.g. struct proc and struct context)
- ✓ All "proc" structures are manipulated using a list

```
// 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
};
```

Figure 4.5: **The xv6 Proc Structure**

4.5 Data Structure (Optional)

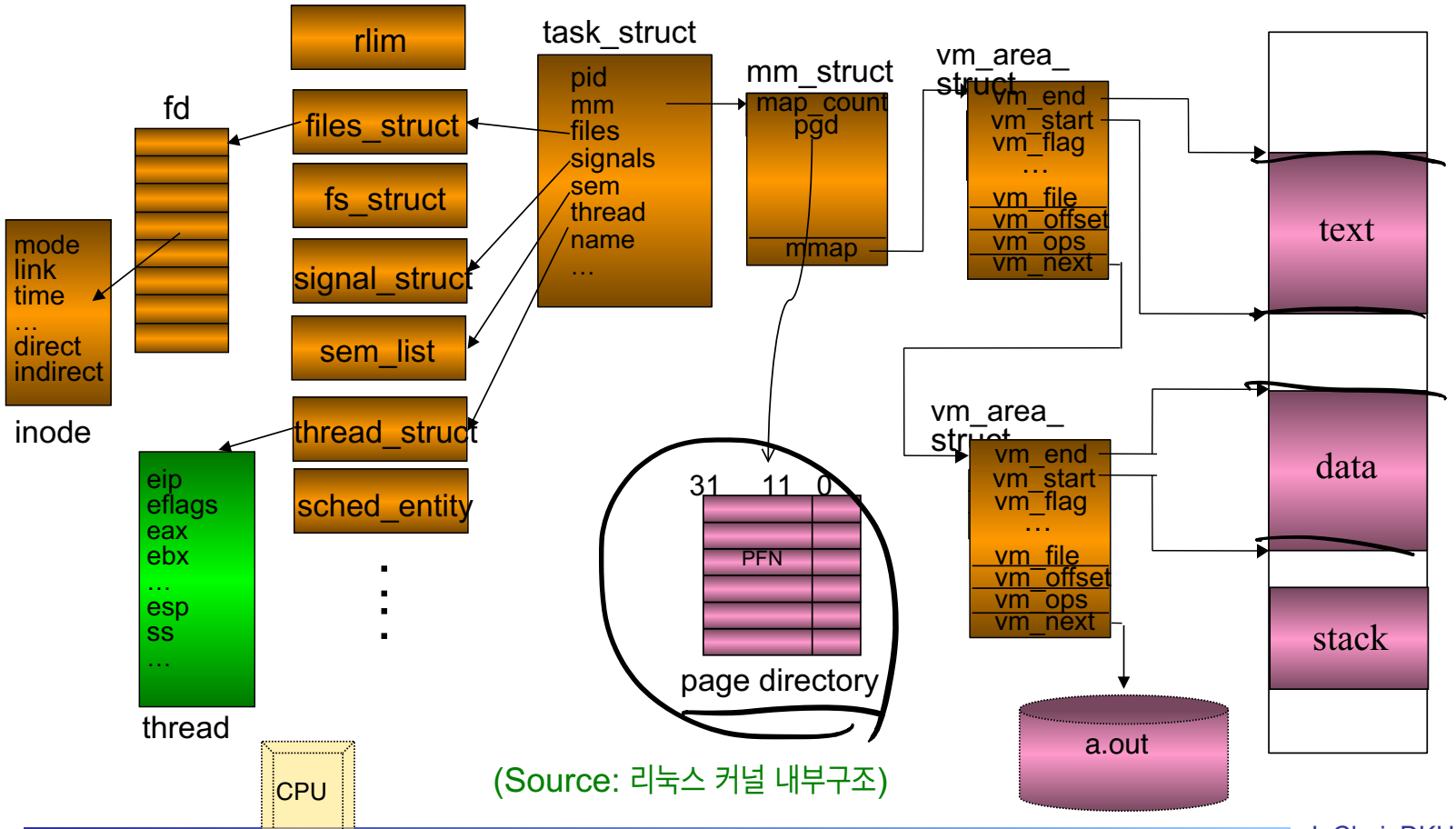
PCB in real OS (task structure in Linux)



<https://elixir.bootlin.com/linux/latest/source/include/linux/sched.h >

4.5 Data Structure (Optional)

PCB in real OS (task structure in Linux)



(Source: 리눅스 커널 내부구조)

Comments for Interlude by Remzi

ASIDE: INTERLUDES

Interludes will cover more practical aspects of systems, including a particular focus on operating system APIs and how to use them. If you don't like practical things, you could skip these interludes. But you should like practical things, because, well, they are generally useful in real life; companies, for example, don't usually hire you for your non-practical skills.

5.1 fork() system call

fork()

- ✓ Create a new process: parent, child
- Return two values: one for parent and the other for child
- Non-determinism: not decide which one run first.

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4
5   int
6   main(int argc, char *argv[])
7   {
8       printf("hello world (pid:%d)\n", (int) getpid());
9       int rc = fork();
10      if (rc < 0) {           // fork failed; exit
11          fprintf(stderr, "fork failed\n");
12          exit(1);
13      } else if (rc == 0) { // child (new process)
14          printf("hello, I am child (pid:%d)\n", (int) getpid());
15      } else {                // parent goes down this path (main)
16          printf("hello, I am parent of %d (pid:%d)\n",
17                  rc, (int) getpid());
18      }
19      return 0;
20  }
```

Figure 5.1: Calling `fork()` (p1.c)

5.2 wait() system call

wait()

- ✓ Block a calling process until one of its children finishes
- ✓ Now, deterministic ? synchronization

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4   #include <sys/wait.h>
5
6   int
7   main(int argc, char *argv[])
8   {
9       printf("hello world (pid:%d)\n", (int) getpid());
10      int rc = fork();
11      if (rc < 0) {          // fork failed; exit
12          fprintf(stderr, "fork failed\n");
13          exit(1);
14      } else if (rc == 0) { // child (new process)
15          printf("hello, I am child (pid:%d)\n", (int) getpid());
16      } else {               // parent goes down this path (main)
17          int wc = wait(NULL);
18          printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
19                 rc, wc, (int) getpid());
20      }
21      return 0;
22  }
```

Figure 5.2: Calling `fork()` And `wait()` (p2.c)

5.3 exec() system call

exec()

- ✓ Load and overwrite code and static data, re-initialize stack and heap, and execute it (never return) ? refer to 8 page
- ✓ 6 variations: execl, execlp, execle, execv, execvp, execve

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4   #include <string.h>
5   #include <sys/wait.h>
6
7   int
8   main(int argc, char *argv[])
9   {
10      printf("hello world (pid:%d)\n", (int) getpid());
11      int rc = fork();
12      if (rc < 0) {           // fork failed; exit
13          fprintf(stderr, "fork failed\n");
14          exit(1);
15      } else if (rc == 0) { // child (new process)
16          printf("hello, I am child (pid:%d)\n", (int) getpid());
17          char *myargs[3];
18          myargs[0] = strdup("wc");    // program: "wc" (word count)
19          myargs[1] = strdup("p3.c"); // argument: file to count
20          myargs[2] = NULL;           // marks end of array
21          execvp(myargs[0], myargs);  // runs word count
22          printf("this shouldn't print out");
23      } else {                    // parent goes down this path (main)
24          int wc = wait(NULL);
25          printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
26                  rc, wc, (int) getpid());
27      }
28      return 0;
29  }
```

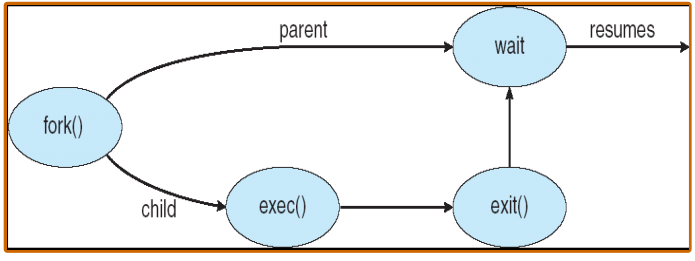
Figure 5.3: Calling fork(), wait(), And exec() (p3.c)

? Comments from Remzi: Do it on a Linux system. "Type in the code and run it is better for understanding"

5.4 Why? Motivating the API (optional)

Why separate fork() from exec()?

- ✓ Modular approach of UNIX (especially for shell)




```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4   #include <string.h>
5   #include <fcntl.h>
6   #include <sys/wait.h>
7
8   int
9   main(int argc, char *argv[])
10  {
11      int rc = fork();
12      if (rc < 0) {           // fork failed; exit
13          fprintf(stderr, "fork failed\n");
14          exit(1);
15      } else if (rc == 0) { // child: redirect standard output to a file
16          close(STDOUT_FILENO);
17          open("./p4.output", O_CREAT|O_WRONLY|O_TRUNC, S_IRWXU);
18
19          // now exec "wc"...
20          char *myargs[3];
21          myargs[0] = strdup("wc");    // program: "wc" (word count)
22          myargs[1] = strdup("p4.c"); // argument: file to count
23          myargs[2] = NULL;            // marks end of array
24          execvp(myargs[0], myargs);  // runs word count
25      } else {                // parent goes down this path (main)
26          int wc = wait(NULL);
27      }
28      return 0;
29  }
```

Figure 5.4: All Of The Above With Redirection (p4.c)

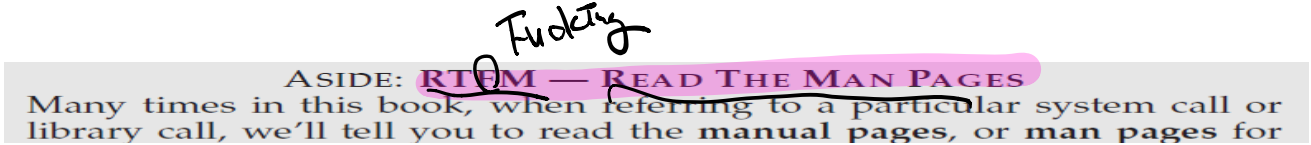
5.5 Other parts of the API

Other APIs

- ✓ getpid(): get process id
- ✓ kill(): send a signal to a process
- ✓ signal(): register a signal catch function
- ✓ scheduling related
- ✓ …

Command and tool

- ✓ ps, top, perf, …
- ✓ read the man pages for commands and tools

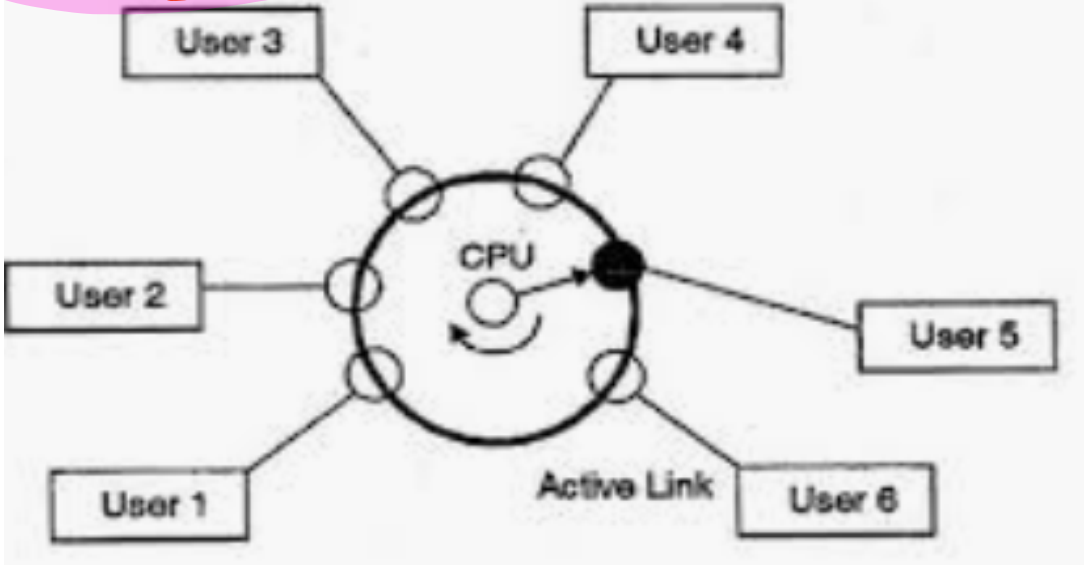


- Any questions? Send an email to me: choijm@dankook.ac.kr
- Simple question to take attendance: Explain which process you prefer to schedule when there are two processes, browser and synchronizer (backup apps) in page 5 (until 6 PM, March 26th)
- Interactive Q&A announcement
  - March 31th(Tuesday) at class time (10:30 am for Section 2, 2:30 pm for Section 3)
  - Zoom Meeting ID: 240-964-9989

Chap 6. Mechanism: Limited Direct Execution

Time sharing

- ✓ Key technique for virtualizing CPU
- ✓ Issues
  - Performance: how to minimize the virtualization overhead?
  - Control: how to run processes while retaining control over the CPU?



(Source: Google image. Users can be replaced with programs or processes)

6.1 Basic Technique: Limited Direct Execution

Performance-oriented Direct execution

- ✓ Run the program directly on the CPU
- ✓ Efficient but not controllable

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	

Figure 6.1: **Direct Execution Protocol (Without Limits)**

See 8 page in LN2

Control is particularly important to OS. Without control, a process could run forever, monopolizing resources.

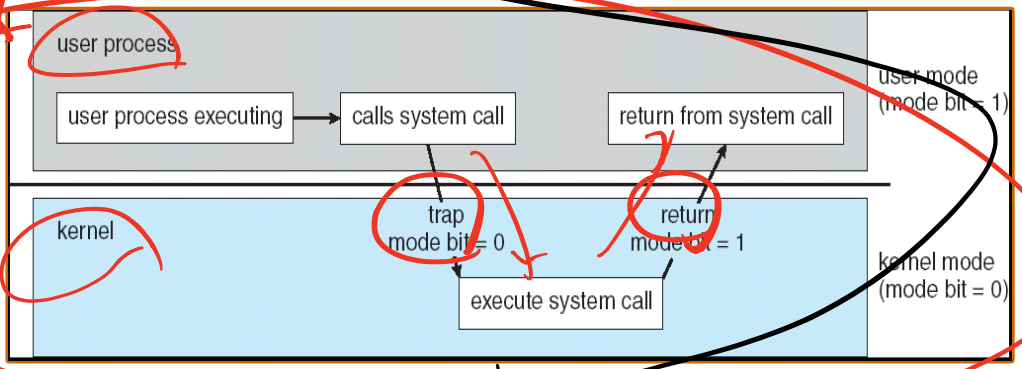
6.2 Problem #1: Restricted Operation

Control mechanism 1: Restrict operations

- Operations that should run indirectly (in a privileged mode)
  - Gain more system resources such as CPU and memory
  - Issue an I/O request directly to a disk
- Through a well defined APIs (system call)
  - E.g.) fork(), nice(), malloc(), open(), read(), write(), …

Mechanism: User mode vs. Kernel mode

- User mode: do privileged operation ? cause exception and killed
- Kernel mode: do privileged operation ? allowed
- Mode switch: using trap instruction, two stacks (user and kernel stack)



(Source: A. Silberschatz, "Operating system Concept")

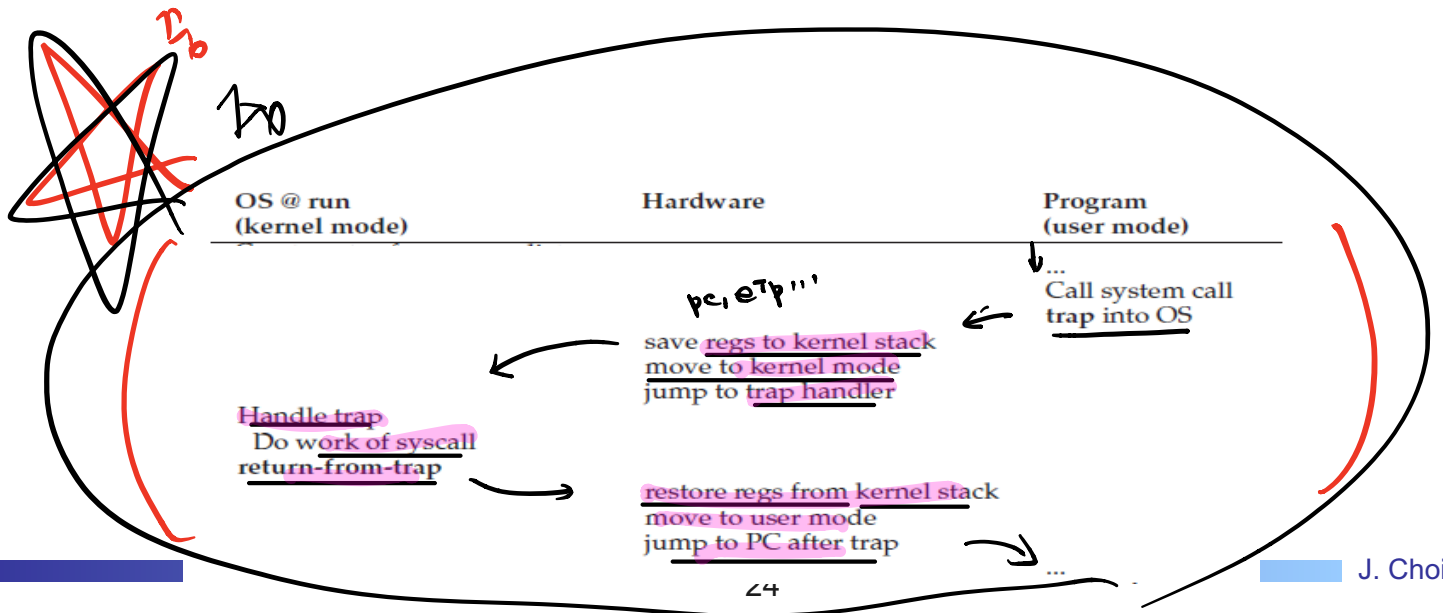
6.2 Problem #1: Restricted Operation

How to handle trap in OS?

- ✓ Using trap table (a.k.a interrupt vector table)
- ✓ Trap table consists of a set of trap handlers
  - Trap (interrupt) handler: a routine that deals with a trap in OS
  - system call handler, div_by_zero handler, segment fault handler, page fault handler, and hardware interrupt handler (disk, KBD, timer, …)
  - Initialized at boot time
- ✓ E.g.: System call processing
  - System call (e.g. fork()) ? trap ? save context and switch stack ? jump to the trap handler ? eventually in kernel mode
  - Return from system call ? switch stack and restore context ? jump to the next instruction of the system call ? user mode

0	divide_by_zero()
1	page_fault()
2	segment_fault()
..	…
80	system_call()

trap table



6.2 Problem #1: Restricted Operation

Global view

Initialize (Boot)

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

Process create

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

Trap (syscall)

	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()`)

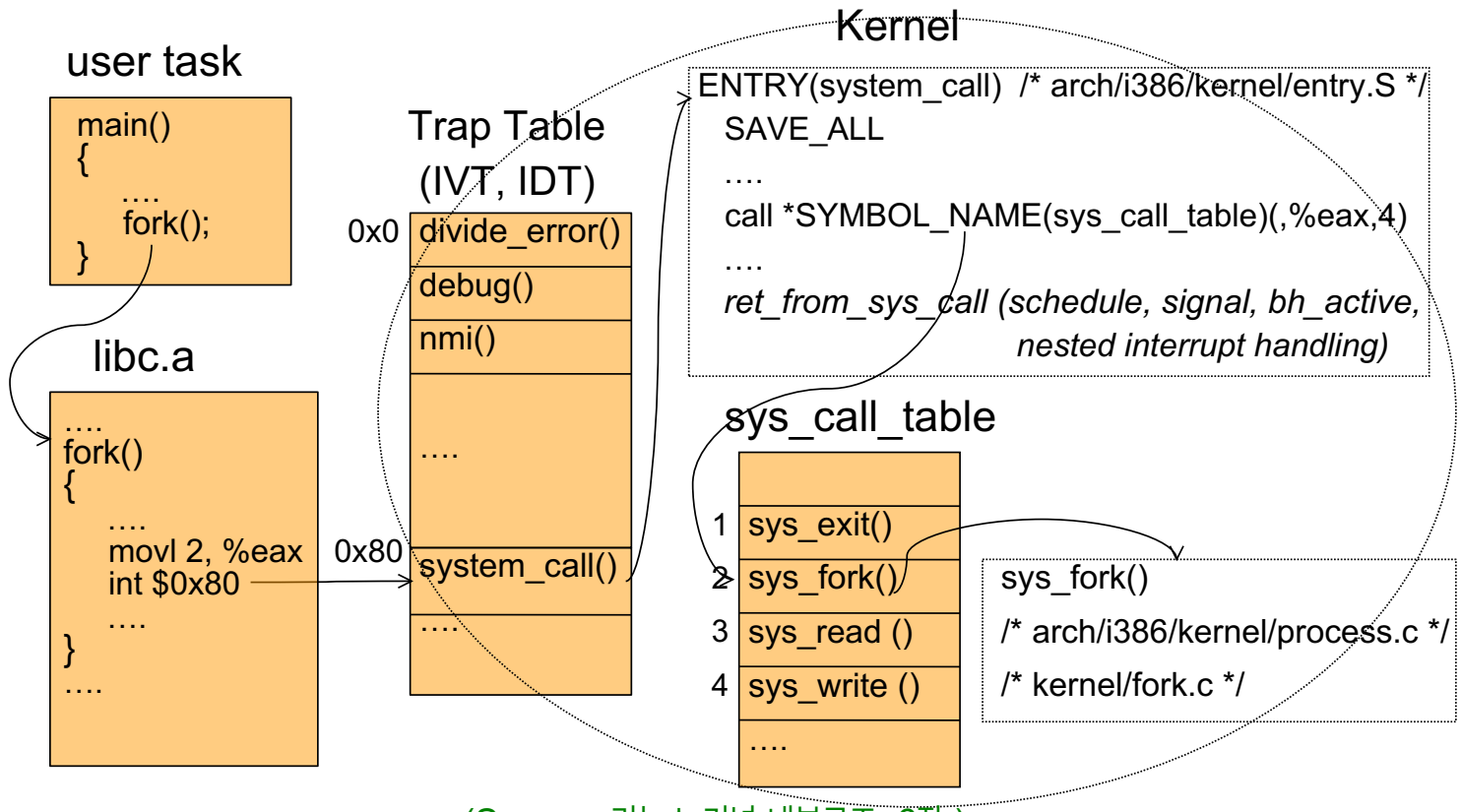
Process destroy

Free memory of process		
Remove from process list		

Figure 6.2: Limited Direct Execution Protocol

6.2 Problem #1: Restricted Operation (optional)

System call Implementation: Linux case study



(Source: 리눅스 커널 내부구조, 6장)

Note: This mechanism is a little different in 64bit CPU, but the concept is the same

6.3 Problem #2: Switching between Processes

Control mechanism 2: Context switch with Timer interrupt

- ✓ Time sharing: Process A → Process B → Process A → ….
- ✓ By the way, how can OS regain control of the CPU so that it can switch between processes?

Two approach

- A cooperative approach: exploiting system calls
  - Processes use a system call → control transfer to OS → do scheduling (and switching)
  - A process causes exception (e.g. page fault or divide by zero) → transfer control to OS
  - A process that seldom uses a system call → invoke an yield() system call explicitly
  - No method for a process that does an infinite loop
- A Non-cooperative approach: using timer interrupt

6.3 Problem #2: Switching between Processes

A Non-cooperative approach: using timer interrupt

- Interrupt: a mechanism that a device notify an event to OS
  - Interrupt happens → current running process is halted → a related interrupt hander is invoked via interrupt table → transfer control to OS
- Timer interrupt (like a heart in human)
  - A timer device raises an interrupt every milliseconds (programmable) → a timer interrupt handler → do scheduling (and switching) if necessary
- Context switch
  - Context: information of a process needed when it is re-scheduled later ? hardware registers
  - Context save and restore
    - E.g. 1) Process A → Process B: save the context of the process A and restore the context of process B. 2) later Process B ? Process A: save the context of the process B and restore the saved context of process A
    - Where to save: proc structure in general

6.3 Problem #2: Switching between Processes

Context switch: global view

Initialize (Boot)

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

Interrupt (timer)

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	

Scheduling and Context Switch

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)		

Return from Interrupt

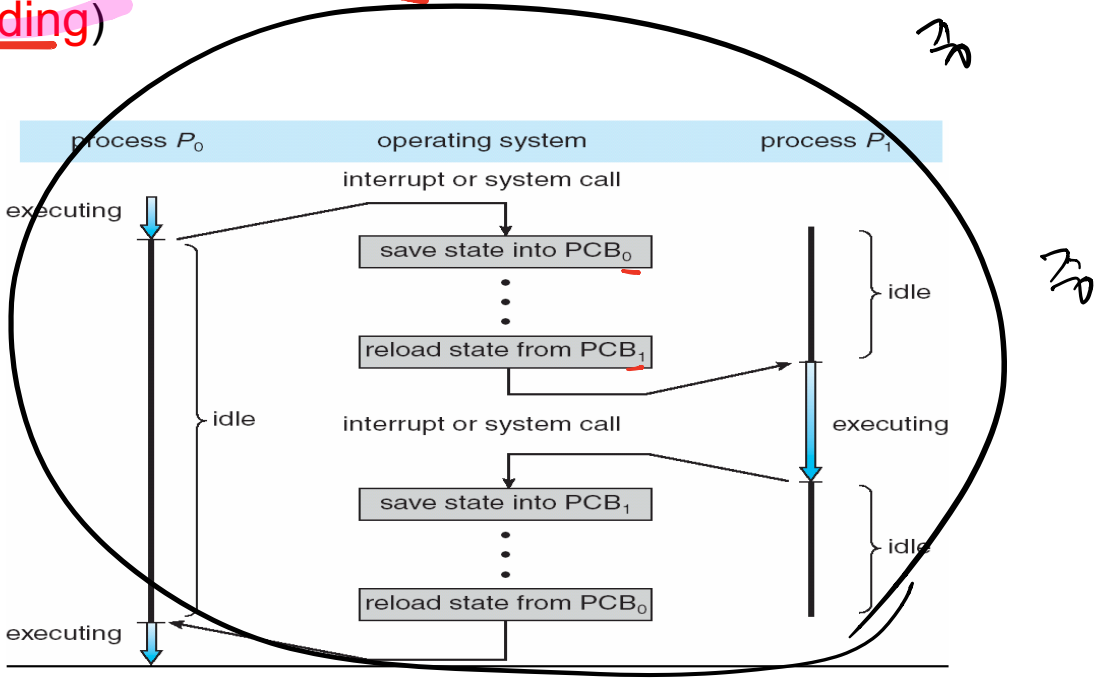
	restore regs(B) from k-stack(B)	
	move to user mode	
	jump to B's PC	
		Process B
		...

Figure 6.3: Limited Direct Execution Protocol (Timer Interrupt)

6.3 Problem #2: Switching between Processes

Context switch

- ✓ Memorize the last state of a process when it is preempted
  - Context save (state save): storing CPU registers into PCB (in memory)
  - Context restore (state restore): loading PCB into CPU registers
- ✓ Context-switch time is overhead (the system does no useful work while switching) → utilizing hardware support (hyper-threading)



(Source: A. Silberschatz, "Operating system Concept")

6.3 Problem #2: Switching between Processes

Context switch: pseudo code

```
1   # void swtch(struct context **old, struct context *new);
2   #
3   # Save current register context in old
4   # and then load register context from new.
5   .globl swtch
6   swtch:
7     # Save old registers
8     movl 4(%esp), %eax  # put old ptr into eax
9     popl 0(%eax)        # save the old IP
10    movl %esp, 4(%eax)  # and stack
11    movl %ebx, 8(%eax)  # and other registers
12    movl %ecx, 12(%eax)
13    movl %edx, 16(%eax)
14    movl %esi, 20(%eax)
15    movl %edi, 24(%eax)
16    movl %ebp, 28(%eax)
17
18    # Load new registers
19    movl 4(%esp), %eax  # put new ptr into eax
20    movl 28(%eax), %ebp # restore other registers
21    movl 24(%eax), %edi
22    movl 20(%eax), %esi
23    movl 16(%eax), %edx
24    movl 12(%eax), %ecx
25    movl 8(%eax), %ebx
26    movl 4(%eax), %esp  # stack is switched here
27    pushl 0(%eax)       # return addr put in place
28    ret                 # finally return into new ctxt
```

Figure 6.4: The xv6 Context Switch Code

6.4 Worried about concurrency?

Some issues

- What happens when you are handling one interrupt and another one occurs?
- What happen when, during a system call, a timer interrupt occurs?

Some solutions

- Disable interrupt (note: disable interrupt too long is dangerous)
- Priority
- Locking mechanism
- [?] actually Concurrency issue

Summary

Process (Chapter 4)

- ✓ Process definition
- ✓ Process state
- ✓ Process management (PCB, struct proc, struct task)

Process manipulation (Chapter 5)

- ✓ fork(), wait(), exec(), kill() , …

Mechanism (Chapter 6)

- ✓ Limited Direct Execution: 1) Mode switch, 2) Context switch
- ✓ Performance: system call ? 4 us, context switch ? 6 us on P6 CPU

- Suggestion:
  - check the questions in Chap. 5 (homework) and 6 (measurement homework)
  - Exercise them on a Linux server

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Appendix

Answers for questions commonly asked by students

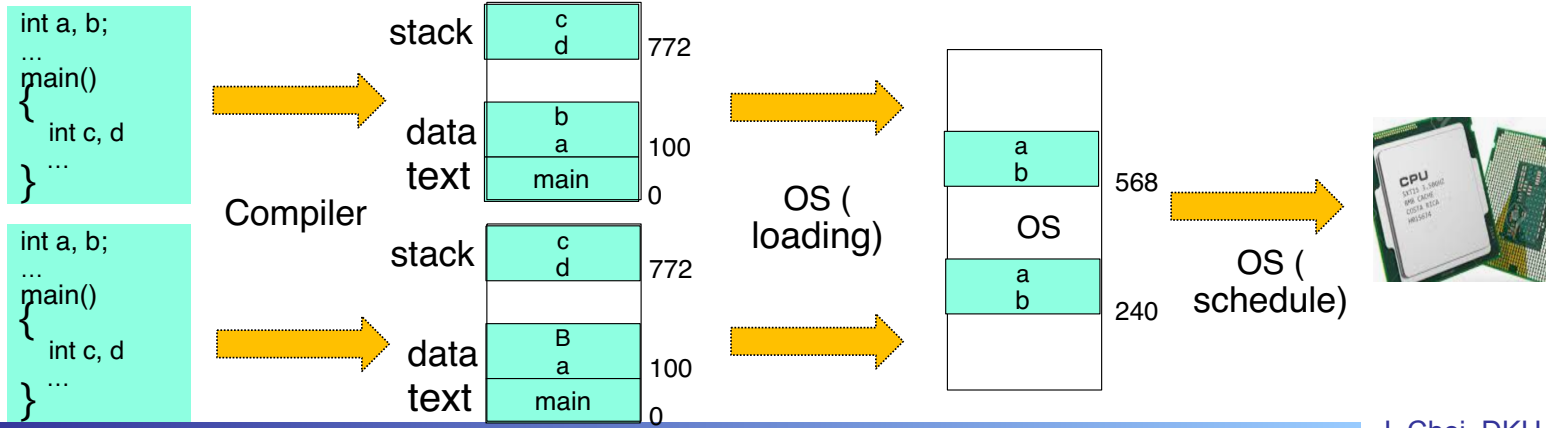
```c
#include <unistd.h>
#include <stdio.h>
#include <stdlib.h>
#include "common.h"

int
main(int argc, char *argv[])
{
    int *p = malloc(sizeof(int));                    // a1
    assert(p != NULL);
    printf("(%d) address pointed to by p: %p\n",
           getpid(), p);                             // a2
    *p = 0;                                          // a3
    while (1) {
        Spin(1);
        *p = *p + 1;
        printf("(%d) p: %d\n", getpid(), *p);        // a4
    }
    return 0;
}
```

Figure 2.3: A Program That Accesses Memory (mem.c)

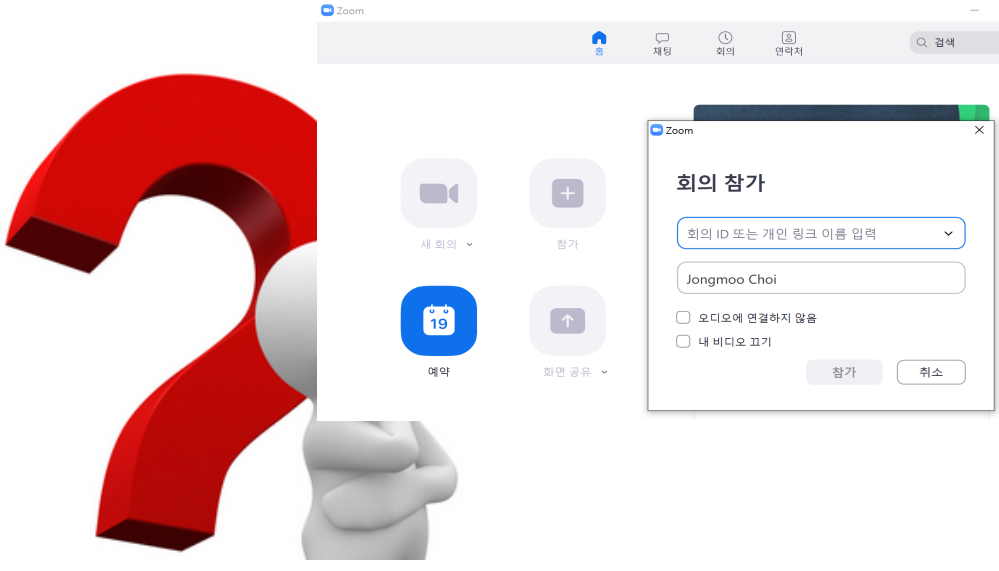
```
prompt> ./mem &; ./mem &
[1] 24113
[2] 24114
(24113) address pointed to by p: 0x200000
(24114) address pointed to by p: 0x200000
(24113) p: 1
(24114) p: 1
(24114) p: 2
(24113) p: 2
(24113) p: 3
(24114) p: 3
(24113) p: 4
(24114) p: 4
...
```

Figure 2.4: Running The Memory Program Multiple Times

(Source: Chapter 2 in OSTEP)



Appendix



- Any questions? Send an email to me: choijm@dankook.ac.kr
- 5th Simple question to take attendance: Explain the similarity between “context switch” and “kakao talk with multiple chatting room concurrently” (until 6 PM, April first)
- Interactive Q&A announcement
  - March 31th(Tuesday) at class time (10:30 am for Section 2, 2:30 pm for Section 3)
  - Zoom Meeting ID: 240-964-9989