Welcome back!

VIRTUALIZATION: CPU

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CS 537, Spring 2020

ADMINISTRIVIA

- Project 1a is out! Due Jan 29 at 10.00pm
- Signup for Piazza https://piazza.com/wisc/spring2020/cs537
- Lecture notes at pages.cs.wisc.edu/~shivaram/cs537-sp20/
- Drop? Waitlist? Email enrollment@cs.wisc.edu and cc me

AGENDA / OUTCOMES

Abstraction

- What is a Process ? What is its lifecycle ?

Mechanism

- How does process interact with the OS ?
- How does the OS switch between processes ?

ABSTRACTION: PROCESS

PROGRAM VS PROCESS

cpu.c

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

int main(int argc, char *argv[]) {
     char *str = argv[1];

     while (1) {
       printf("%s\n", str);
       Spin(1);
     }
     return 0;
}
```

Static

Disk

Program

Running

CPU

Process

more than one process same program

WHAT IS A PROCESS?

Stream of executing instructions and their "context"

Instruction Pointer

Part of the Process context

```
pushq   %rbp
movq    %rsp, %rbp
subq    $32, %rsp
movl    $0, -4(%rbp)
movl    %edi, -8(%rbp)
movq    %rsi, -16(%rbp)
cmpl    $2, -8(%rbp)
je      LBB0_2
```

Contents of

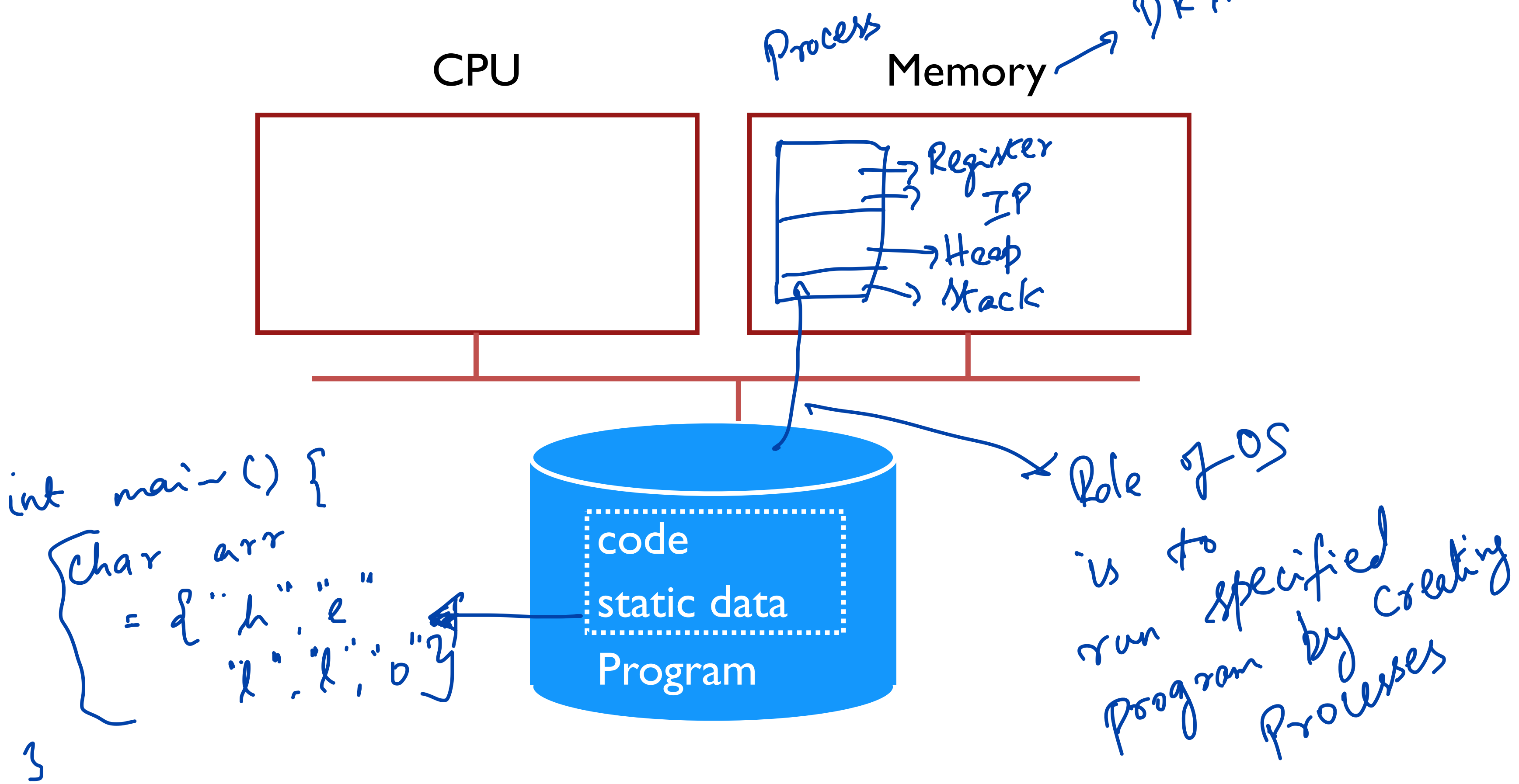
Registers

Memory addrs

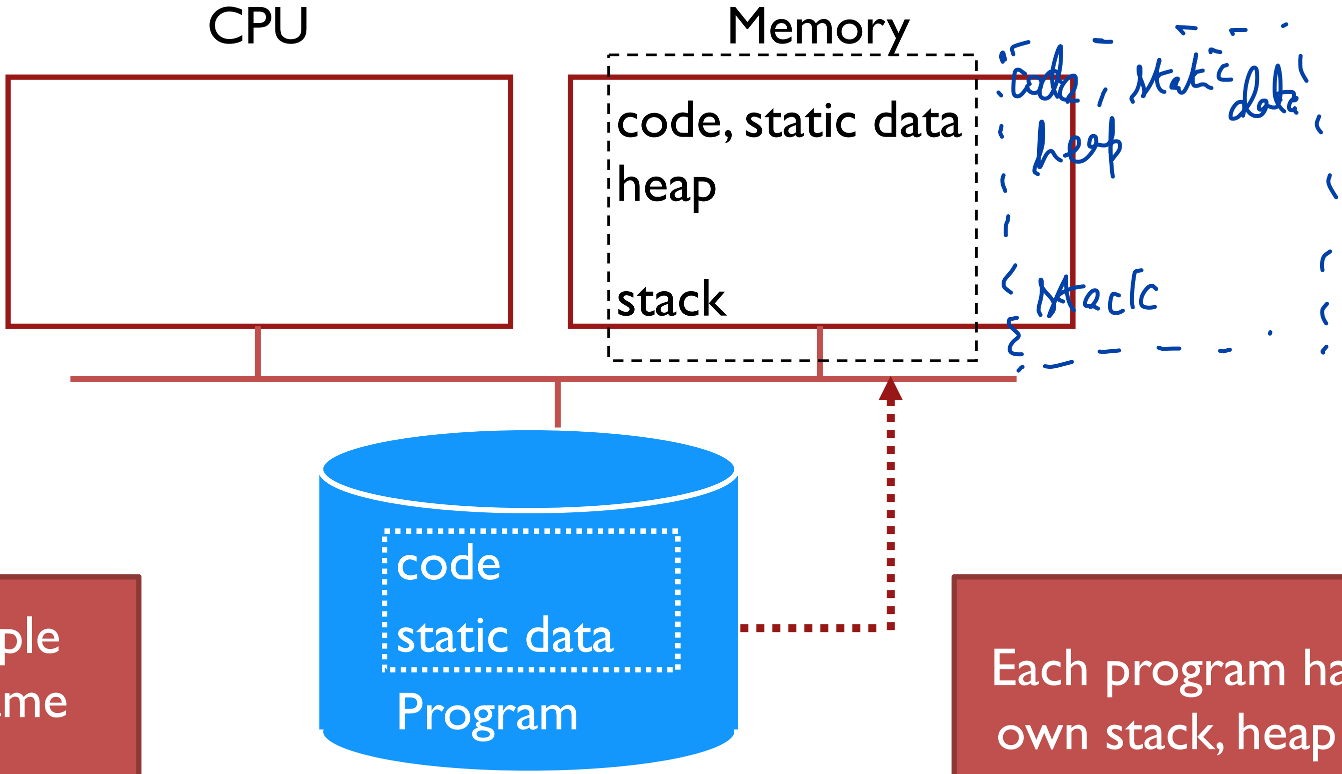
malloc

File descriptors

PROCESS CREATION



PROCESS CREATION



Can run multiple instances of same program

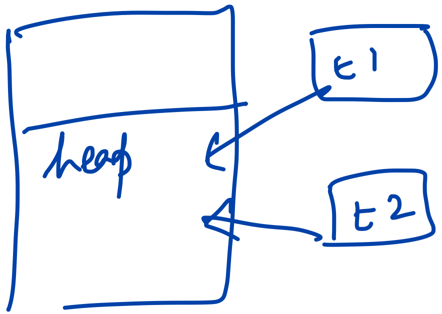
Each program has its own stack, heap etc.

PROCESS VS THREAD

Threads: “Lightweight process”

Execution streams that share an address space
Can directly read / write memory

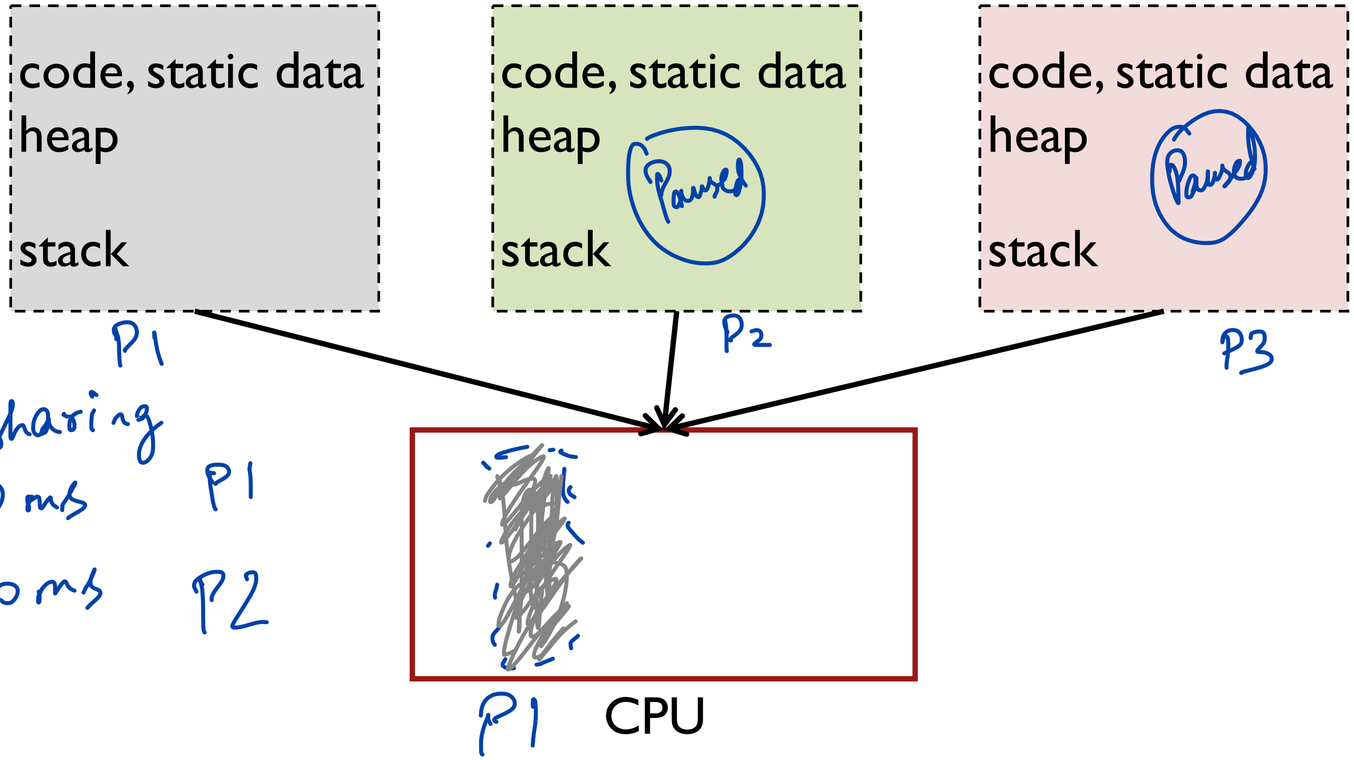
Can have multiple threads within a single process



Demo?

SHARING THE CPU

SHARING CPU

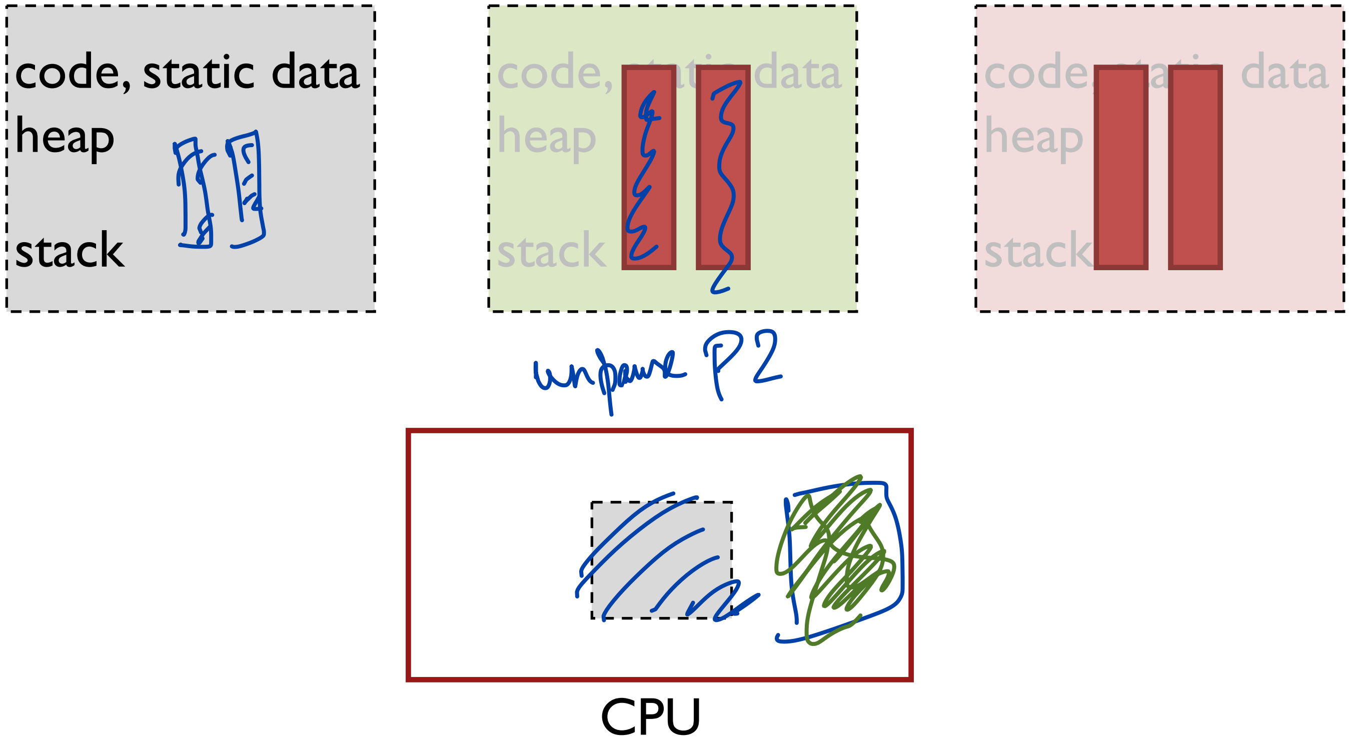


time sharing

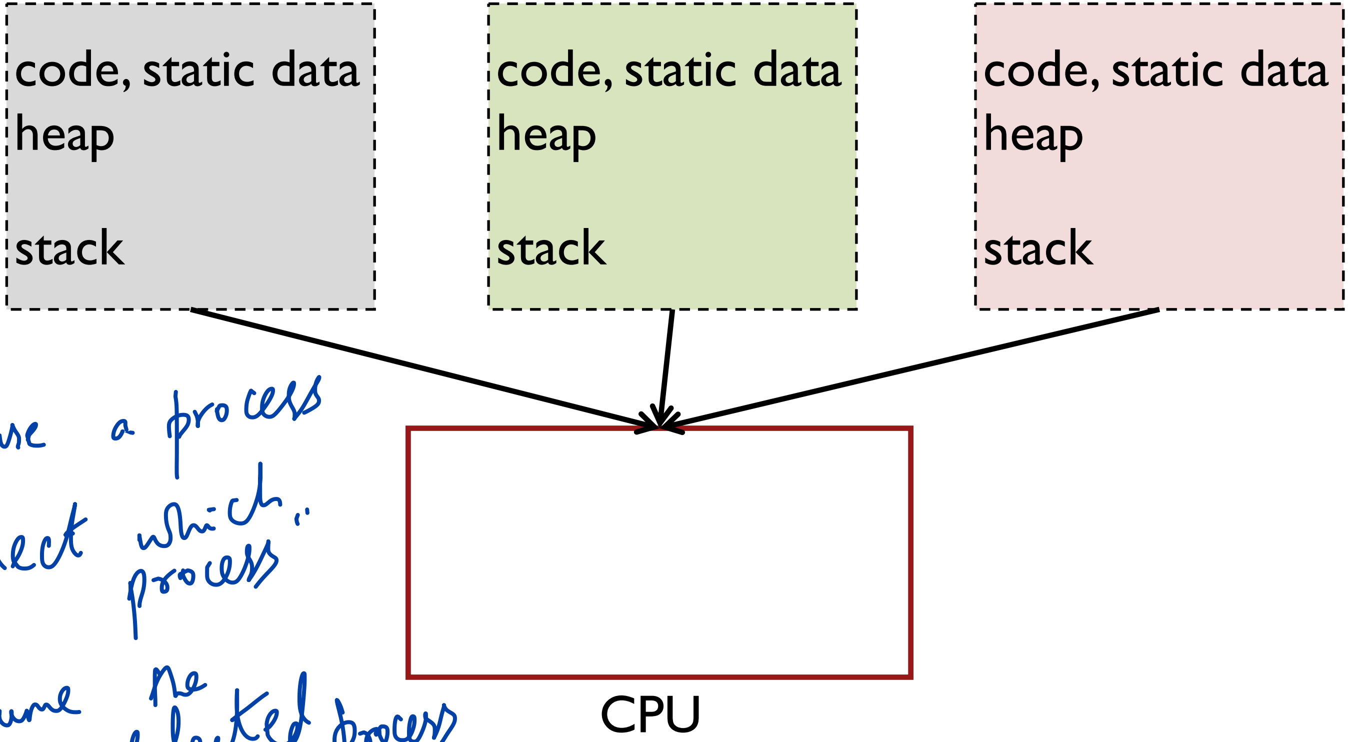
0 to 10 ms P1

10 to 20 ms P2

TIME SHARING



SHARING CPU



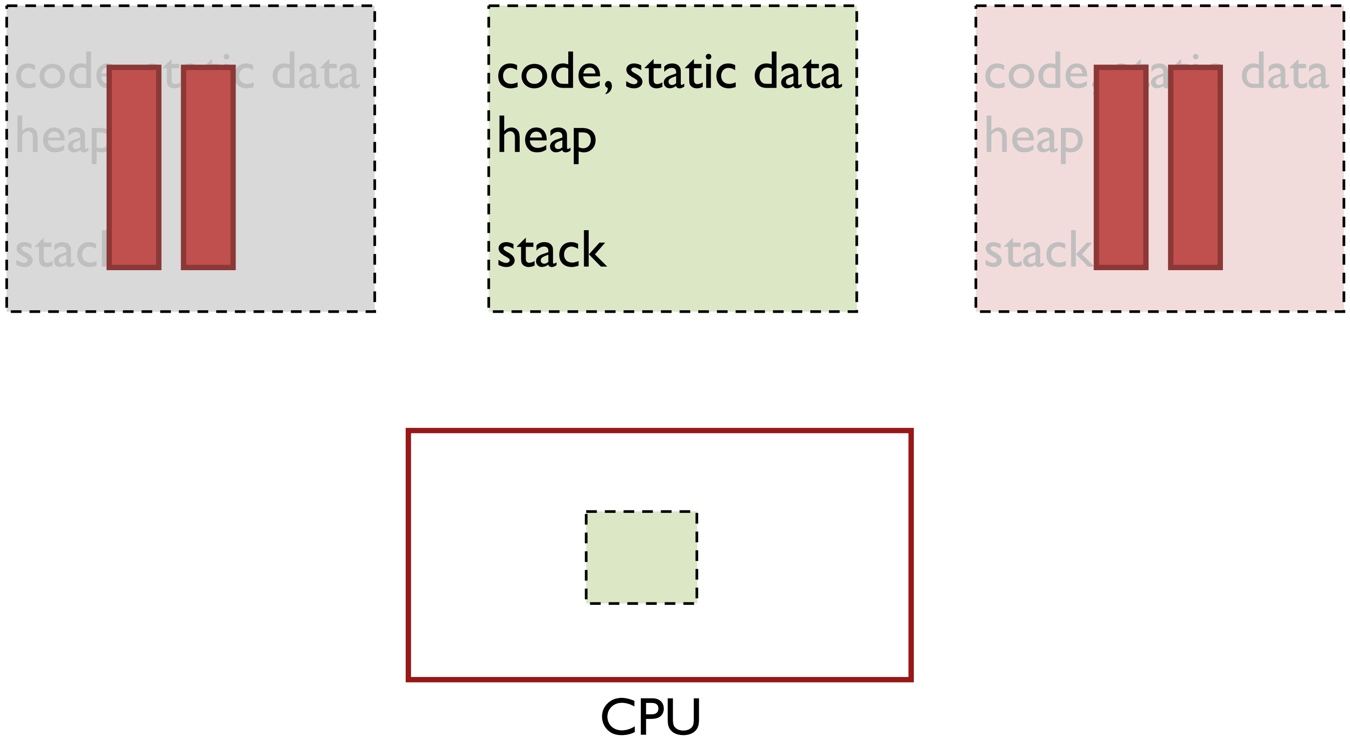
Steps:

mech → Pause a process

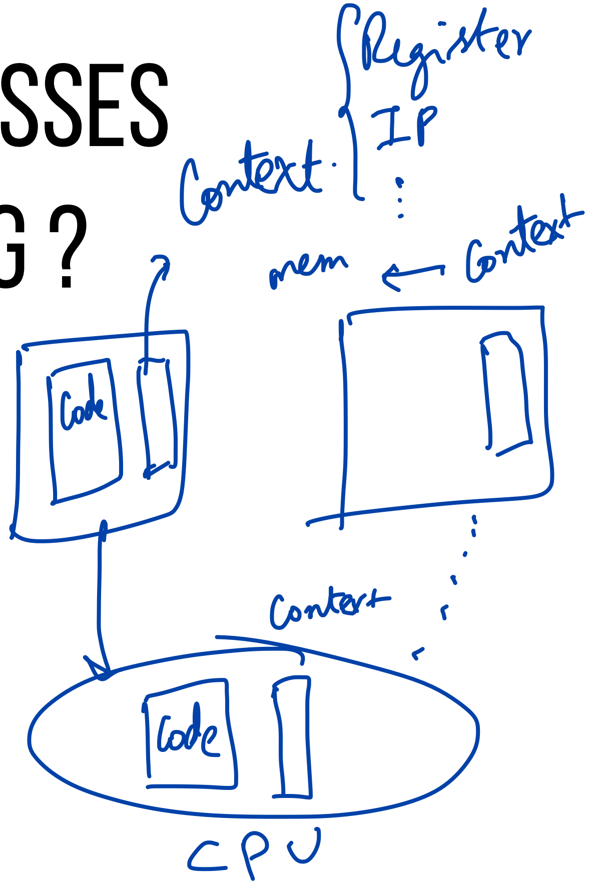
Policy → "Select which process"

→ Resume the selected process

TIME SHARING



WHAT TO DO WITH PROCESSES THAT ARE NOT RUNNING ?



OS Scheduler

- Save context when process is paused
- Restore context on resumption

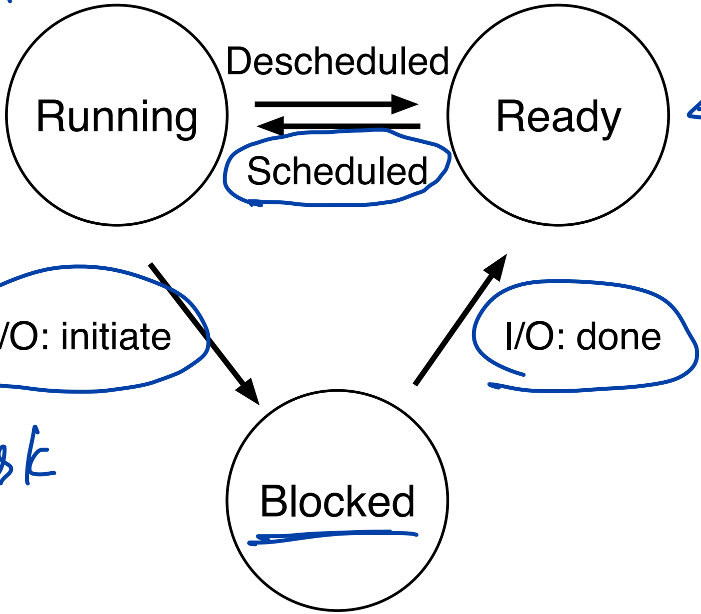
STATE TRANSITIONS

Scheduler

Ready P1 P3

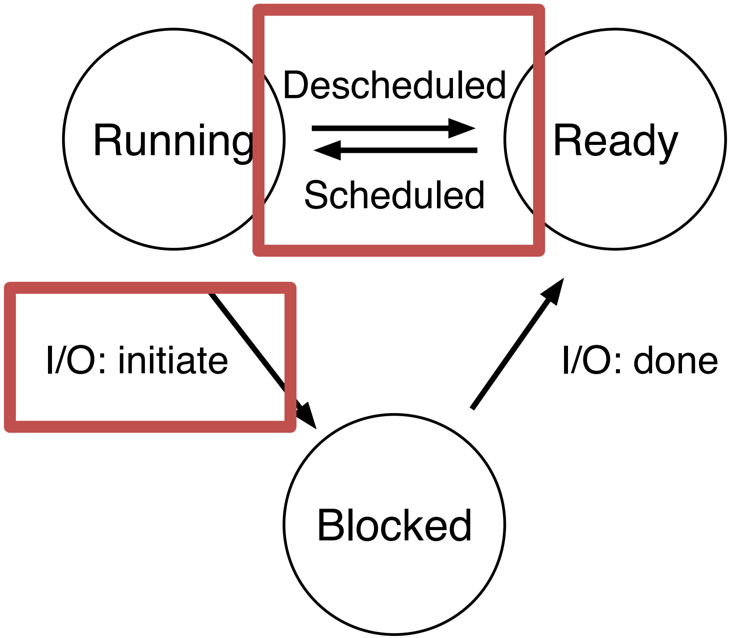
Launch Blocked P2

Using the CPU



e.g., read from disk

STATE TRANSITIONS



ASIDE: OSTEP HOMEWORKS!

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

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

PROCESS HW

Run ./process_run.py –l 2:100,2:0

QUIZ 1

drive.google.com/a/wisc.edu

https://tinyurl.com/cs537-sp20-quiz1

≥ ./process-run.py -l 3:50,3:40

Process 0

io
io
cpu

Process 1

cpu
io
io

Each IO takes 5 time units

Time	PID: 0	PID: 1
1	RUN:io	READY
2	WAITING	RUN:cpu
3	WAITING	RUN:io
4	WAITING	WAITING
5	WAITING	WAITING
6	RUN:io	WAITING
7	WAITING	WAITING
8	WAITING	RUN: io

done with

What happens at time 8?

CPU SHARING

Policy goals

- Virtualize CPU resource using processes
- Reschedule process for fairness? efficiency ?

Mechanism goals

- Efficiency: Sharing should not add overhead
- Control: OS should be able to intervene when required

EFFICIENT EXECUTION

Simple answer !?: Direct Execution

Allow user process to run directly

Create process and transfer control to main()

Access a file

check permissions

disk

Challenges

What if the process wants to do something restricted ? Access disk ?

What if the process runs forever ? Buggy ? Malicious ?

Solution: Limited Direct Execution (LDE)

PROBLEM 1: RESTRICTED OPS

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

Solution: privilege levels supported by hardware (bit of status)

    User processes run in user mode (restricted mode)

    OS runs in kernel mode (not restricted)

How can process access devices?

    System calls (function call implemented by OS)

Process

read a file

OS

read this file

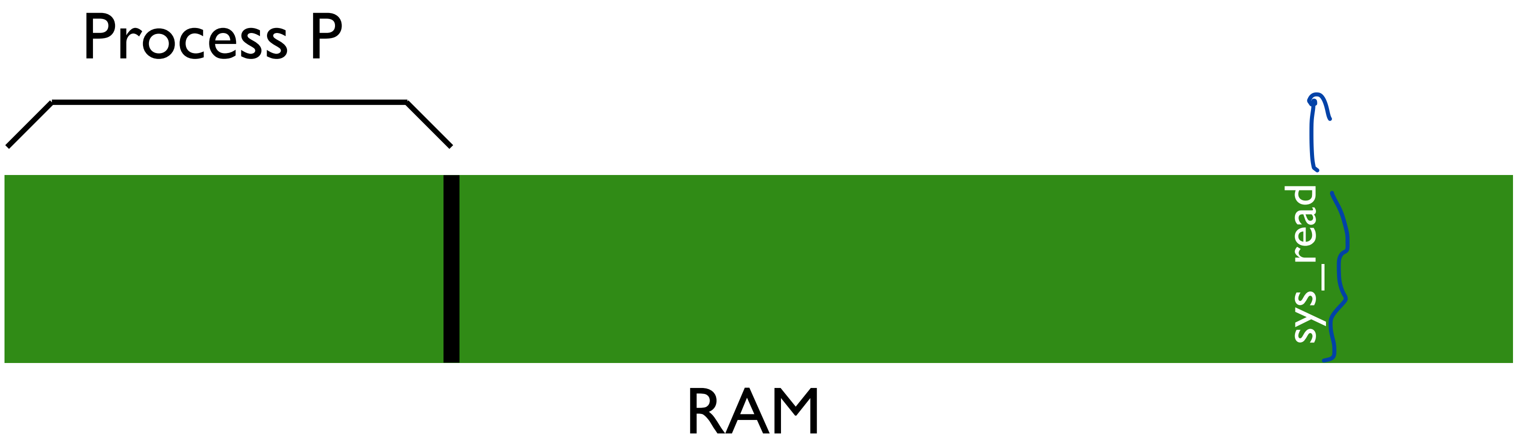
check

disk

SYSTEM CALL

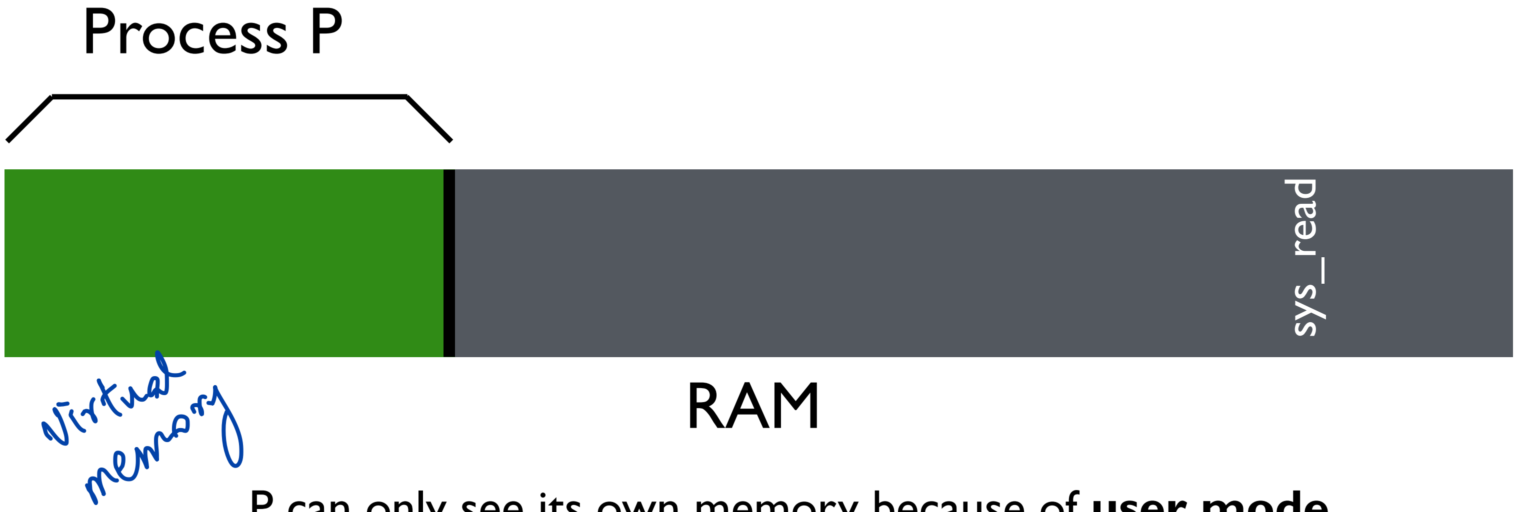
Similar to library call except executed with higher permission level

SYSTEM CALL



P wants to call read()

SYSTEM CALL



P can only see its own memory because of **user mode**
(other areas, including kernel, are hidden)

P wants to call read() but no way to call it directly

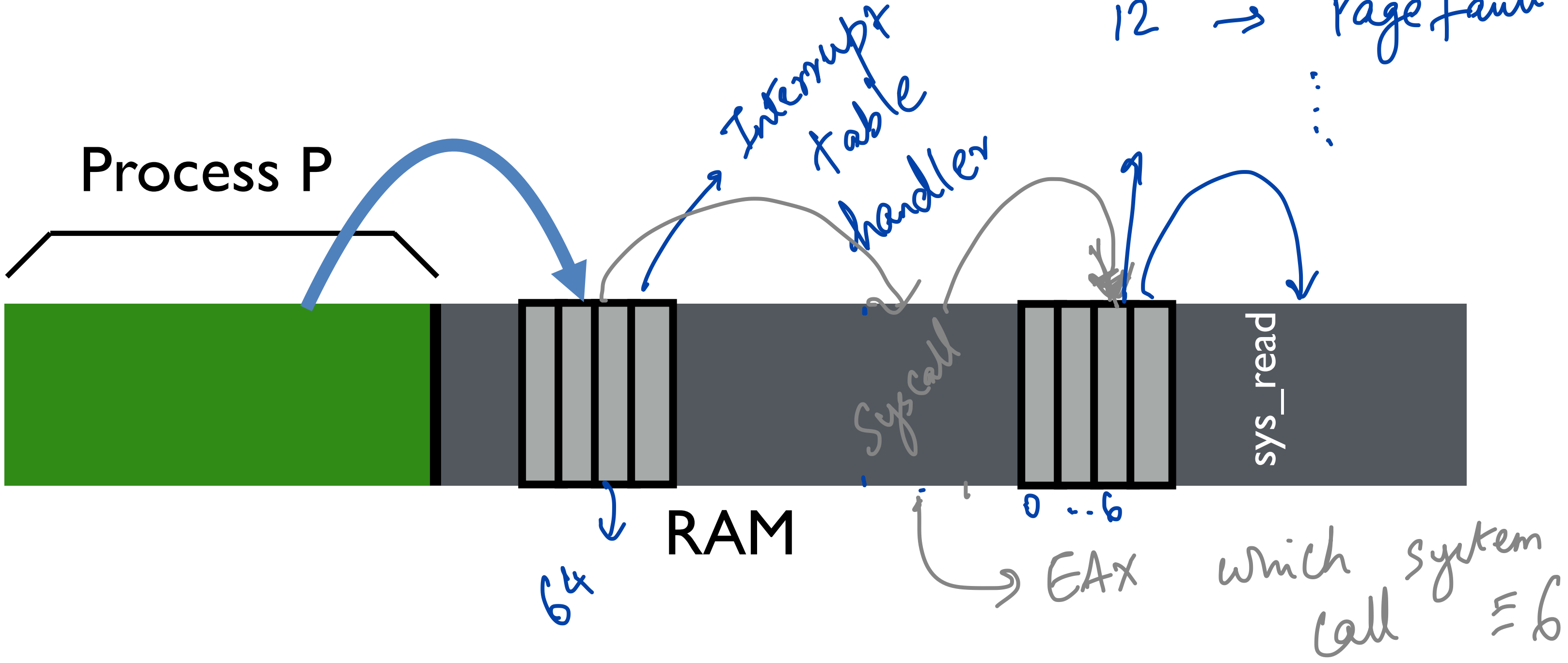
SYSTEM CALL

movl $6, %eax;   int $64

sys_read   register   Interrupt   special instruction

SYSTEM CALL

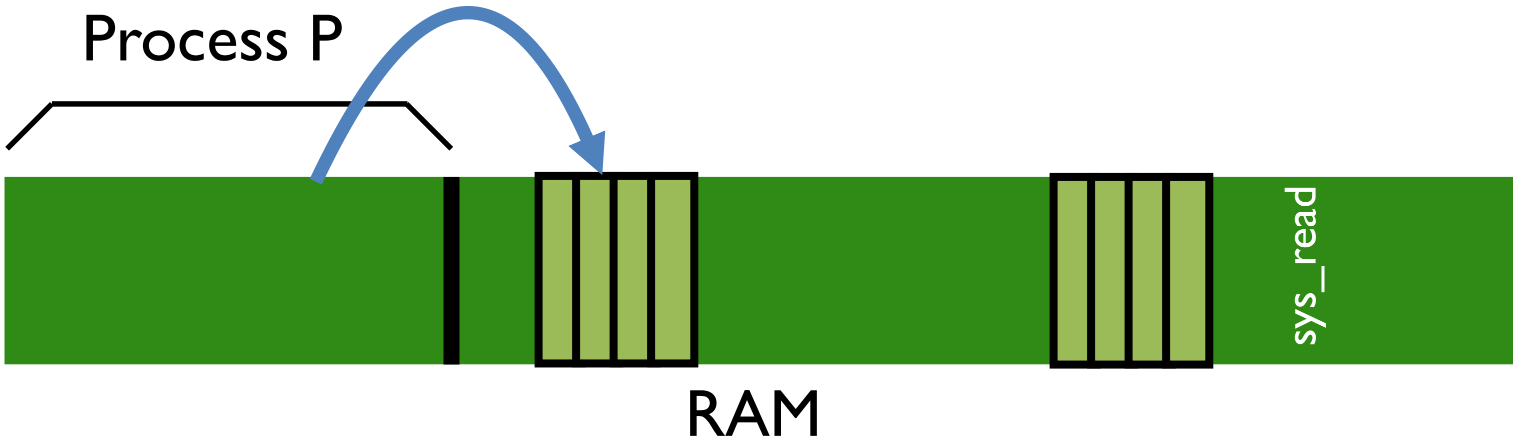
64 -> system call
12 -> Page fault
⋮



`movl $6, %eax;   int $64`

which calls sys_read

SYSTEM CALL

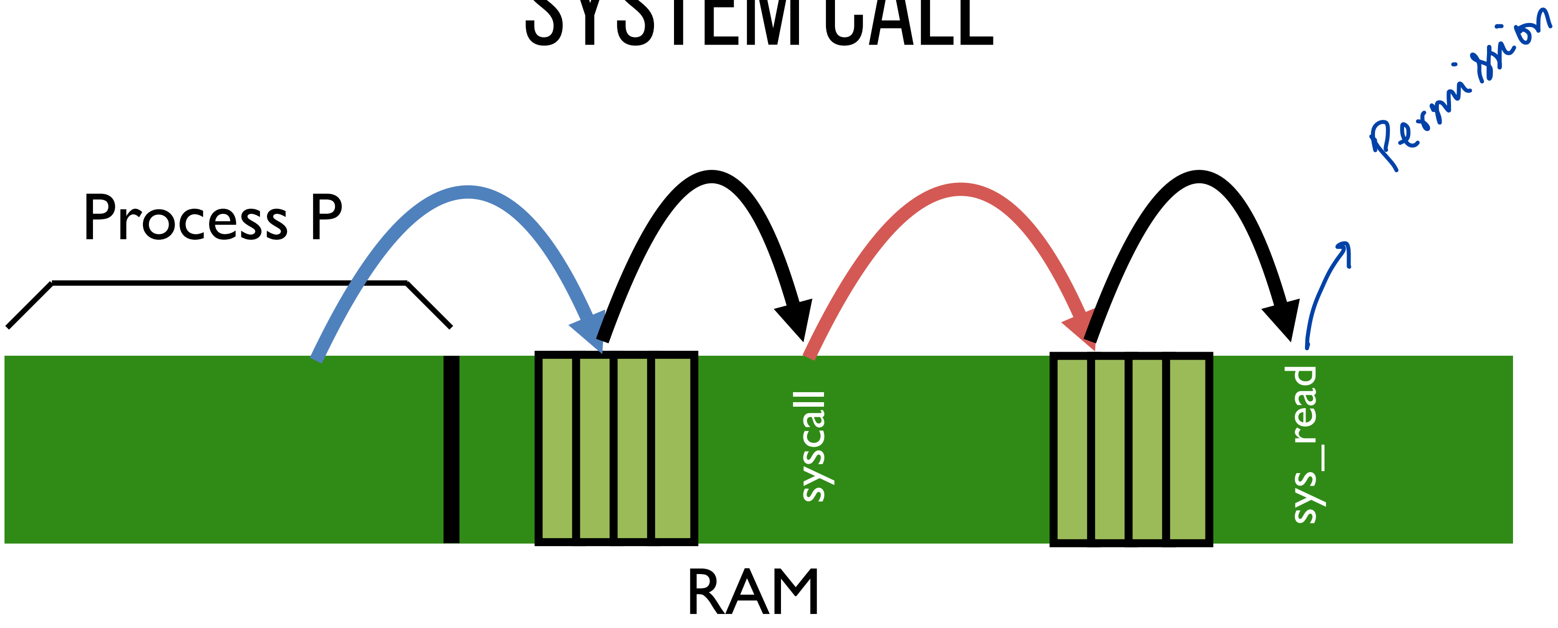


Syscall table index

```
movl $6, %eax;    int $64
```

Trap table index

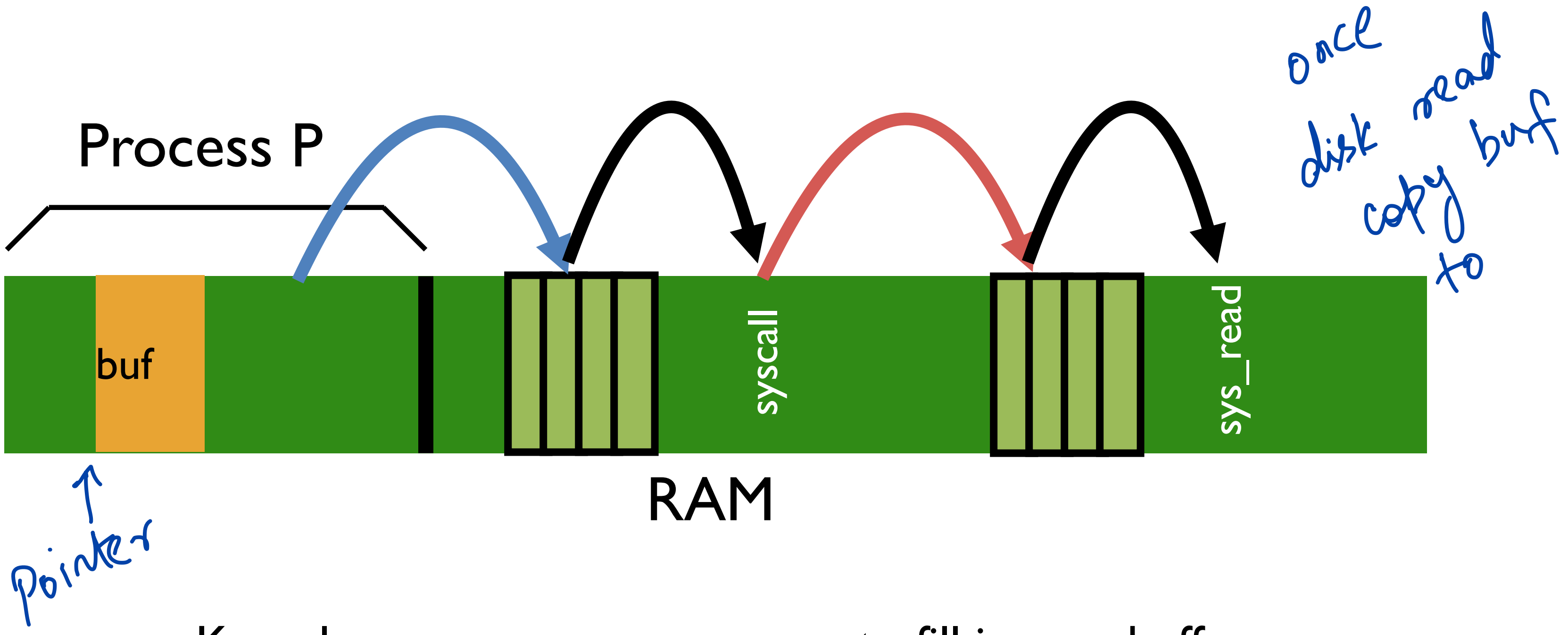
SYSTEM CALL




```
movl $6, %eax;    int $64
```

Follow entries to correct system call code

SYSTEM CALL



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

SYSCALL SUMMMARY

Separate user-mode from kernel mode for security

Syscall: call kernel mode functions

Transfer from user-mode to kernel-mode (trap)

Return from kernel-mode to user-mode (return-from-trap)

QUIZ 2

https://tinyurl.com/cs537-sp20-quiz2

To call SYS_read the instructions we used were

movl $6, %eax
int $64

To call SYS_exec what will be the instructions?

movl __$9__ %eax
int __$64__

```
// System call numbers
#define SYS_fork    1
#define SYS_exit    2
#define SYS_wait    3
#define SYS_pipe    4
#define SYS_write   5
#define SYS_read    6
#define SYS_close   7
#define SYS_kill    8
#define SYS_exec    9
#define SYS_open   10
```

PROBLEM2: HOW TO TAKE CPU AWAY

Policy

- To decide which process to schedule when
- Decision-maker to optimize some workload performance metric

Mechanism

- To switch between processes
- Low-level code that implements the decision

Separation of policy and mechanism: Recurring theme in OS

DISPATCH MECHANISM

OS runs dispatch loop

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

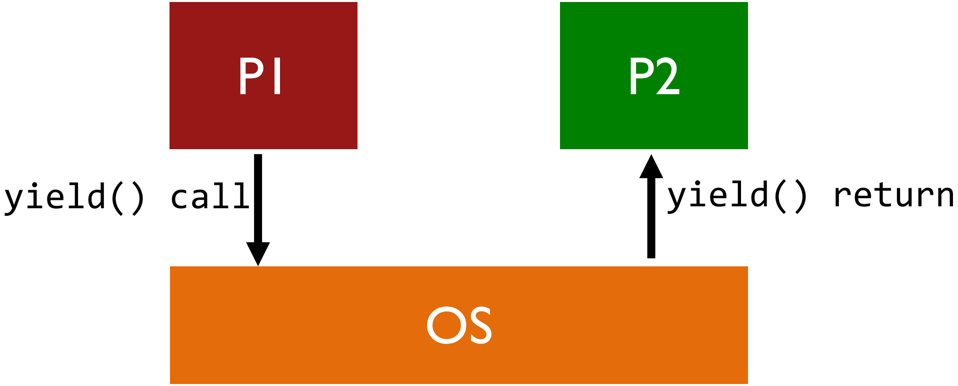
Question 1: How does dispatcher gain control?

Question 2: What must be saved and restored?

HOW DOES DISPATCHER GET CONTROL?

Option 1: Cooperative Multi-tasking: Trust process to relinquish CPU through traps

- Examples: System call, page fault (access page not in main memory), or error (illegal instruction or divide by zero)
- Provide special `yield()` system call



PROBLEMS WITH COOPERATIVE ?

Disadvantages: Processes can misbehave

By avoiding all traps and performing no I/O, can take over entire machine

Only solution: Reboot!

Not performed in modern operating systems

TIMER-BASED INTERRUPTS

Option 2: Timer-based Multi-tasking

Guarantee OS can obtain control periodically

Enter OS by enabling periodic alarm clock

- Hardware generates timer interrupt (CPU or separate chip) Example: Every 10ms
- User must not be able to mask timer interrupt

Operating System | Hardware | Program

Process A

Operating System	Hardware	Program
		Process A
	timer interrupt save regs(A) to k-stack(A) move to kernel mode jump to trap handler	

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Handle the trap Call switch() routine save kernel regs(A) to proc-struct(A) restore kernel regs(B) from proc-struct(B) switch to k-stack(B) return-from-trap (into B)		

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

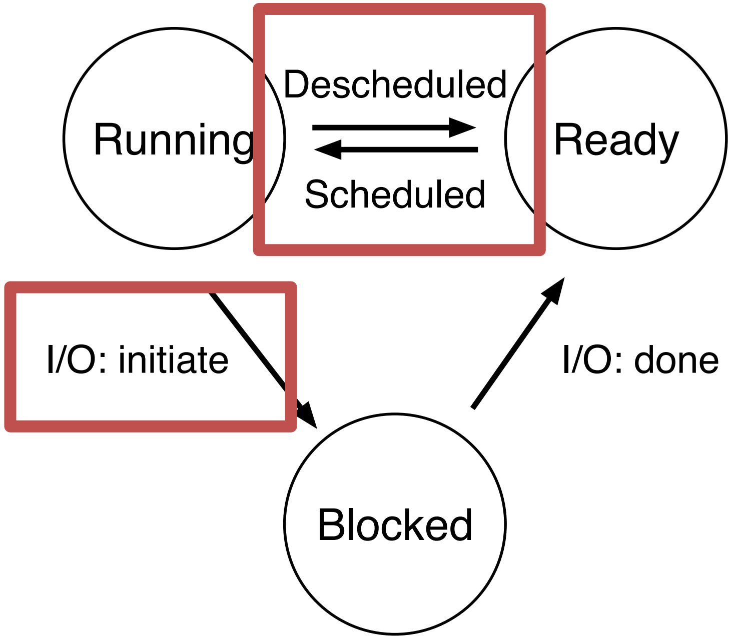
SUMMARY

Process: Abstraction to virtualize CPU

Use time-sharing in OS to switch between processes

Key aspects

- Use system calls to run access devices etc. from user mode
- Context-switch using interrupts for multi-tasking



POLICY ?

NEXT CLASS!

NEXT STEPS

Project 1a: Due Jan 29th (Wednesday) at 10pm

Project 1b: Out on Jan 29th

Discussion section: Thursday 5.30pm-6.30pm at 105 Psychology

Waitlist? Email enrollment@cs.wisc and cc me (will finalize by Monday)