VIRTUALIZATION: CPU

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CS 537, Fall 2024

ADMINISTRIVIA

- Project 1 is out! Due on September 13th (Friday)
  - Check handin directory

- Signup for Piazza https://piazza.com/wisc/fall2024/cs537
- Lecture notes at pages.cs.wisc.edu/~shivaram/cs537-fa24/
- 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

```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;
}
```

Program

Process

WHAT IS A PROCESS?

Stream of executing instructions and their "context"

Instruction Pointer

```
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
```

Registers
Memory addrs

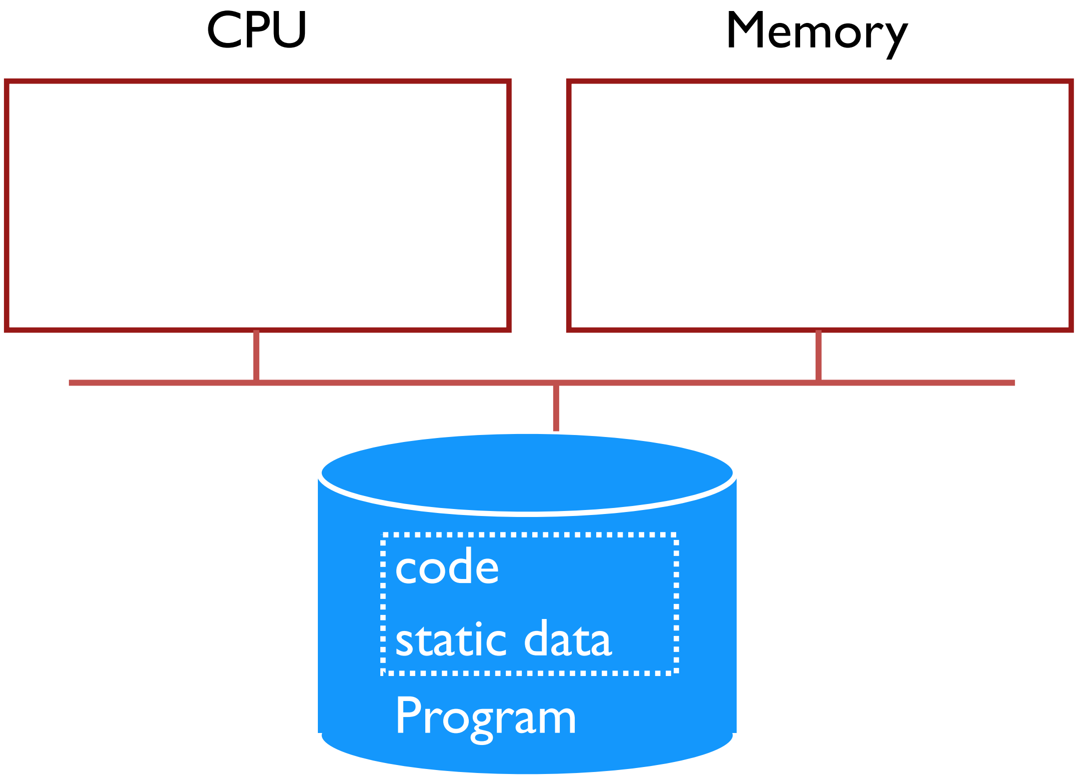
File descriptors

PROCESS IN XV6

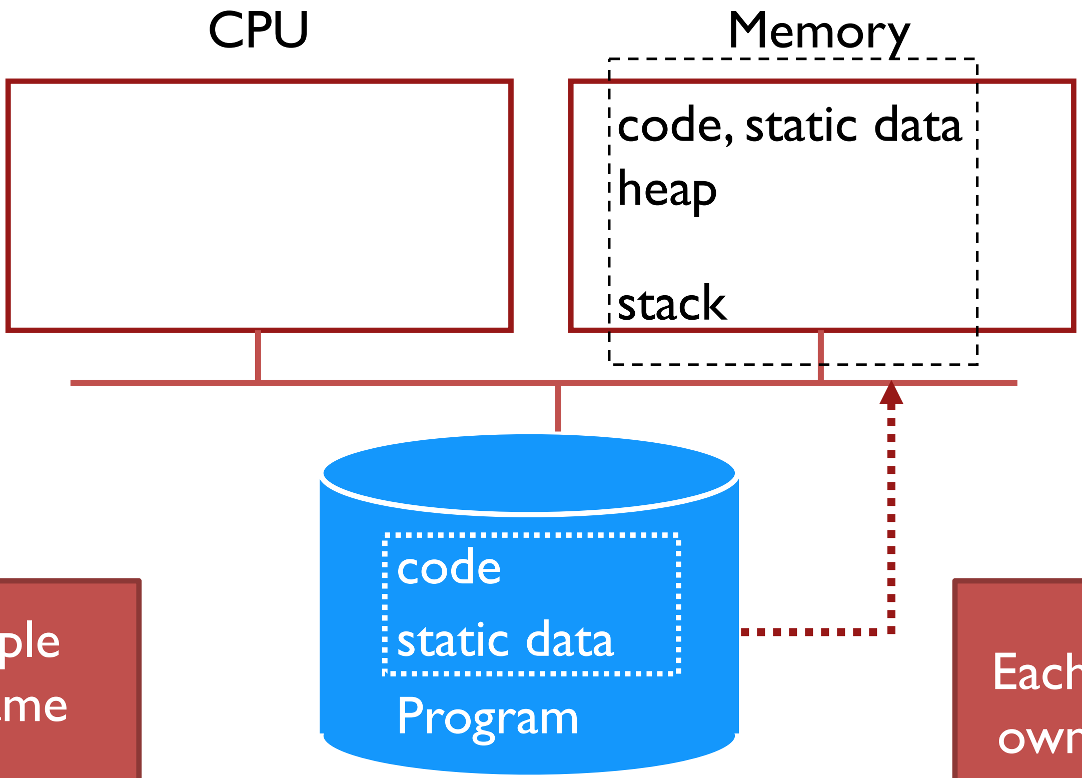
```c
// Per-process state
struct proc {
  uint sz;                     // Size of process memory (bytes)
  pde_t* pgdir;                // Page table
  char *kstack;                // Bottom of kernel stack for this proces
  enum procstate state;        // Process state
  int pid;                     // 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)
};
```

```c
struct context {
  uint edi;
  uint esi;
  uint ebx;
  uint ebp;
  uint eip;
};
```

PROCESS CREATION



PROCESS CREATION



Can run multiple instances of same program

Each program has its own stack, heap etc.

PROCESS VS THREAD

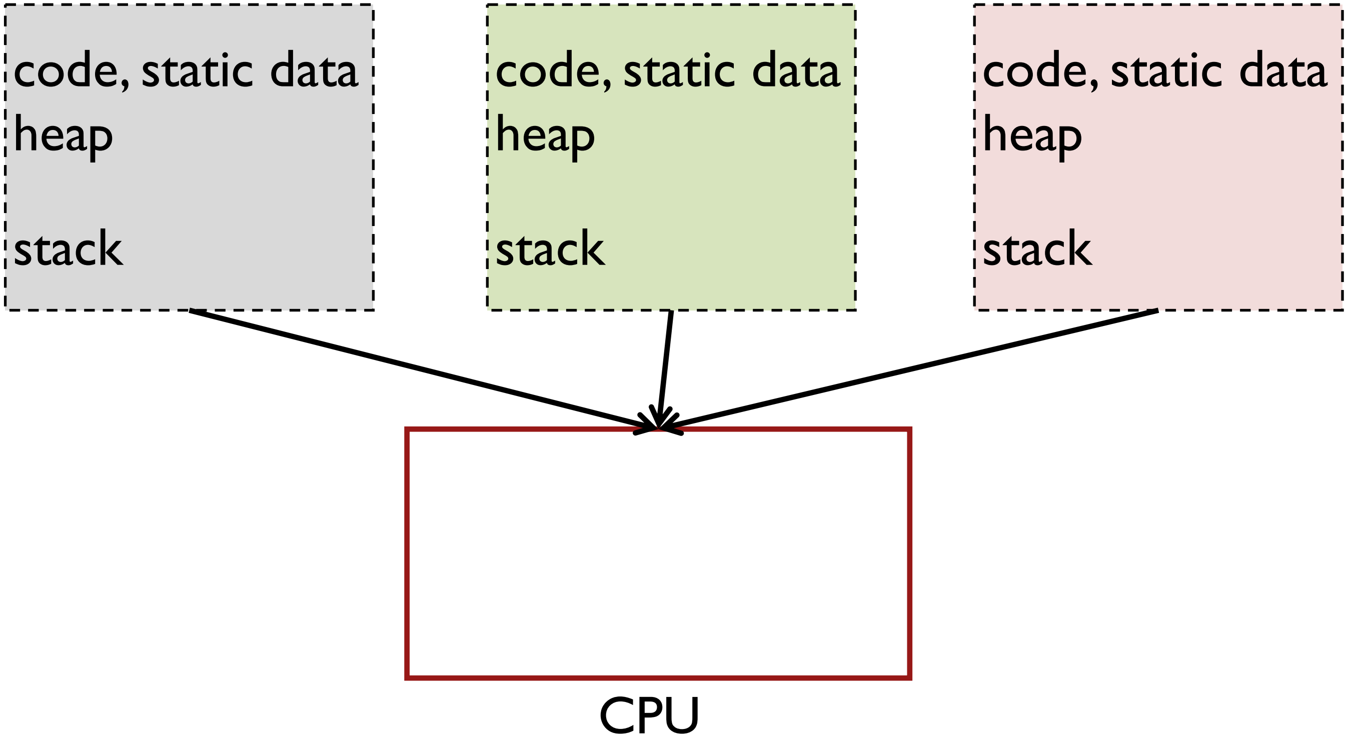
Threads: “Lightweight process”

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

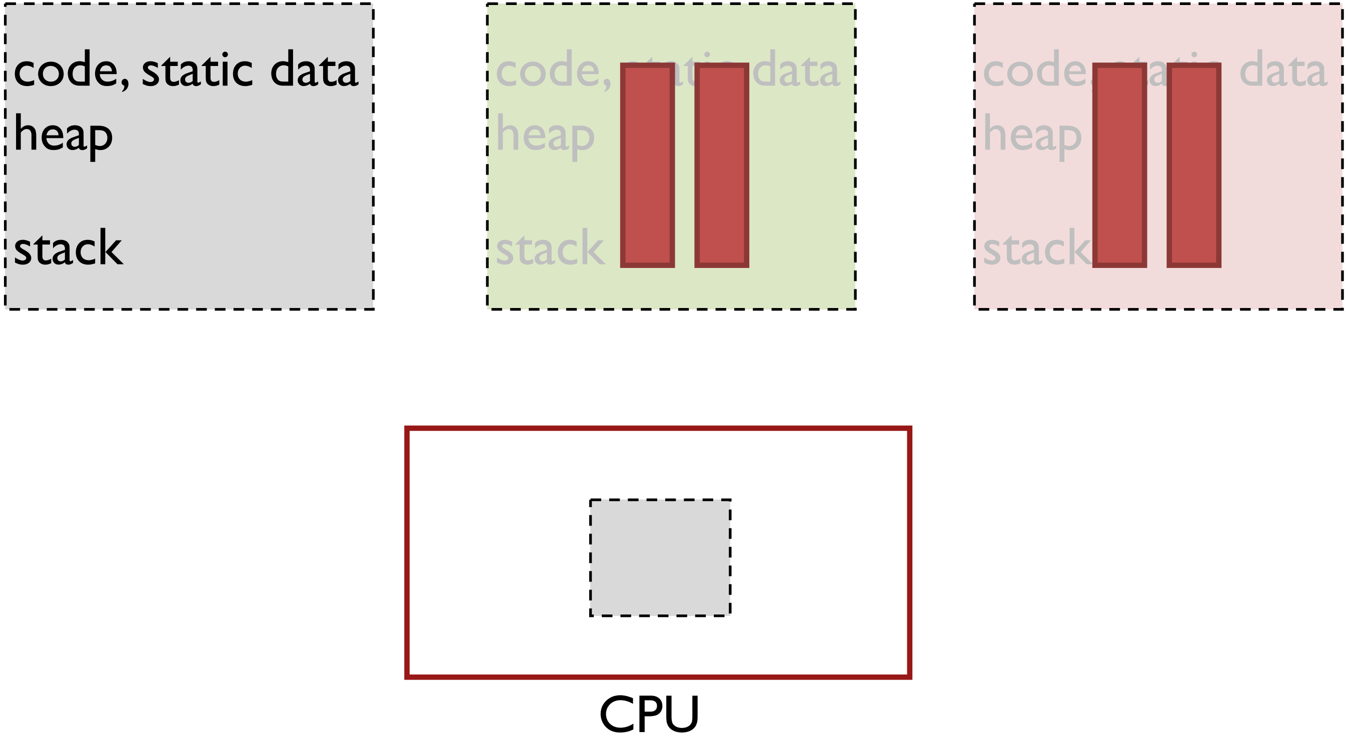
Can have multiple threads within a single process

SHARING THE CPU

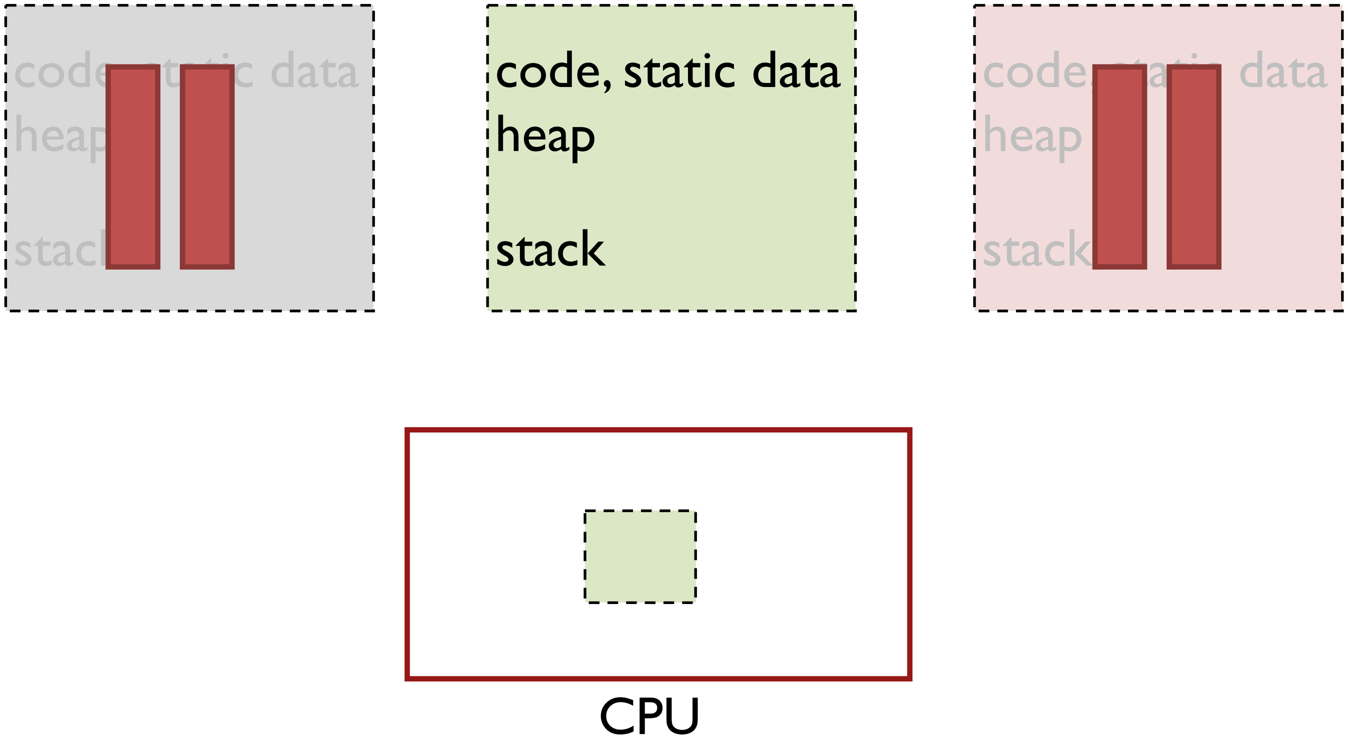
SHARING CPU


code, static data
heap
stack
code, static data
heap
stack
code, static data
heap
stack
CPU

TIME SHARING



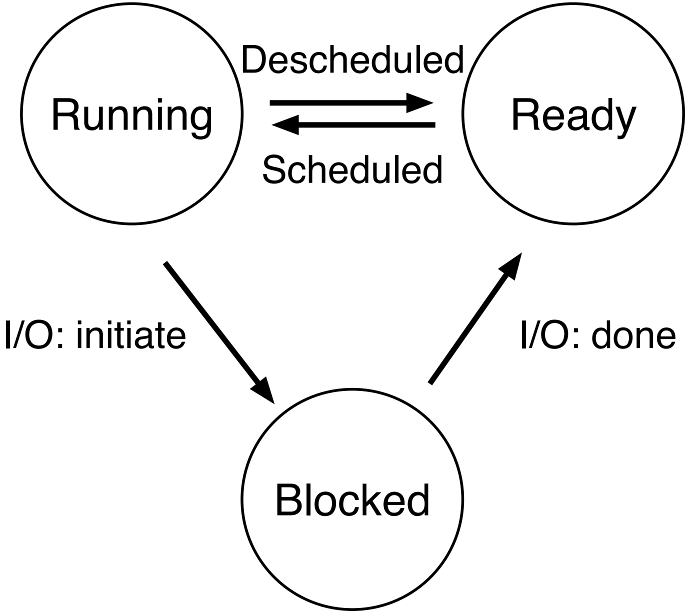
TIME SHARING



WHAT TO DO WITH PROCESSES THAT ARE NOT RUNNING ?

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

STATE TRANSITIONS



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

https://tinyurl.com/cs537-fa24-quiz1a

≥ ./process-run.py -l 3:80,3:50

Time	PID: 0	PID: 1	CPU	IOs
1	RUN:io	READY	1	
2	BLOCKED	RUN:cpu	1	1
3	BLOCKED	RUN:io	1	1
4	BLOCKED	BLOCKED		2
5	BLOCKED	BLOCKED		2
6	BLOCKED	BLOCKED		2
7*	RUN:io_done	BLOCKED	1	1

Each IO takes 5 time units,
3 CPU slices per process

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()

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)

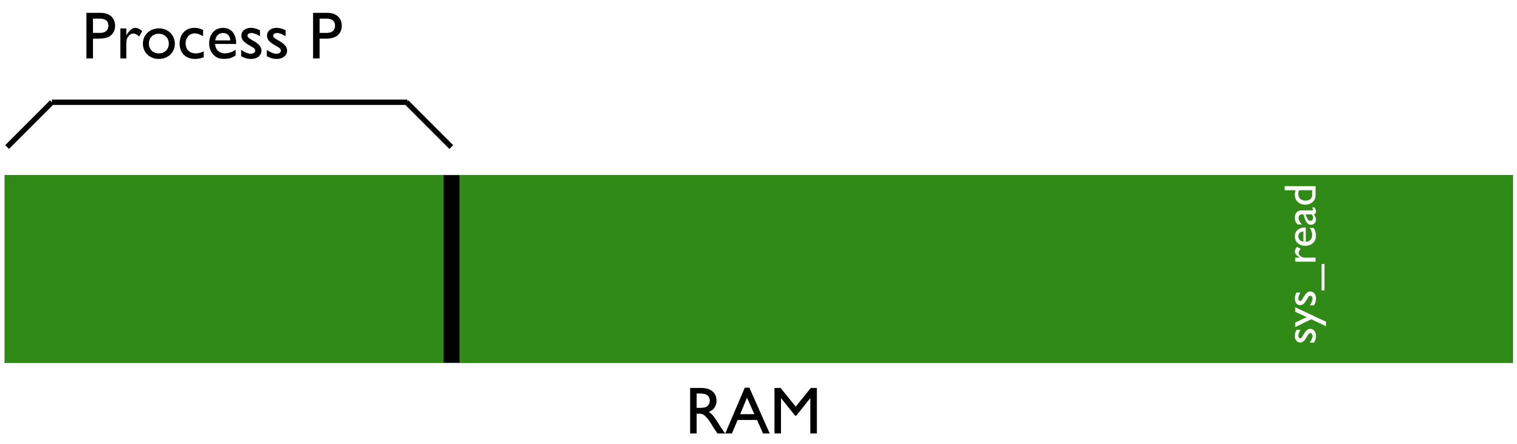
OS runs in kernel mode (not restricted)

How can process access devices?

System calls (function call implemented by OS)

SYSTEM CALL

SYSTEM CALL



P wants to call read()

SYSTEM CALL

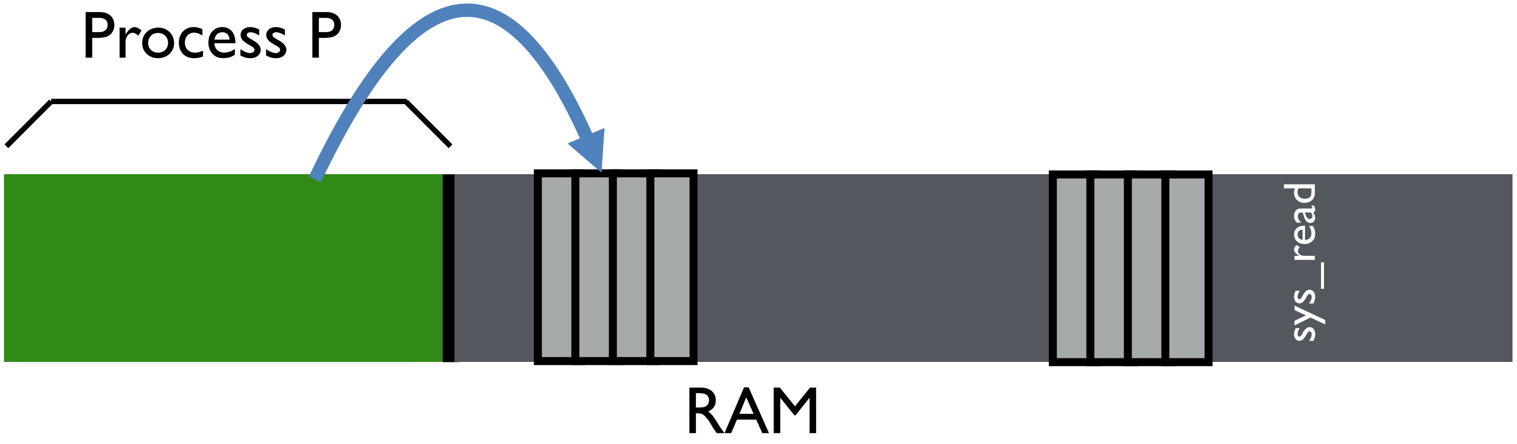
P can only see its own memory because of **user mode**
(other areas, including kernel, are hidden)

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

SYSTEM CALL


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

SYSTEM CALL

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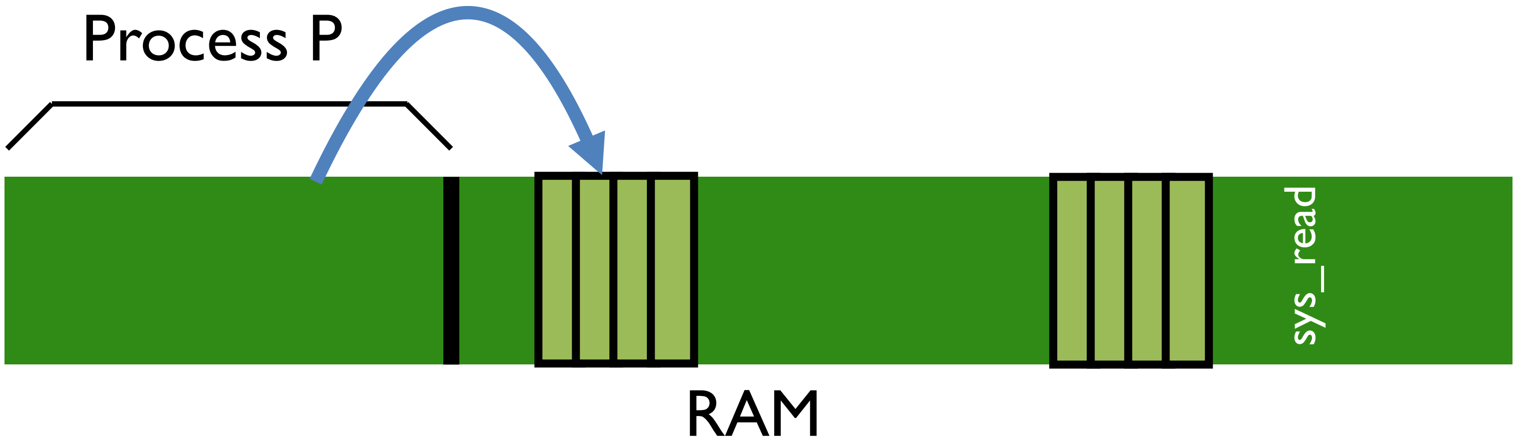
SYSTEM CALL

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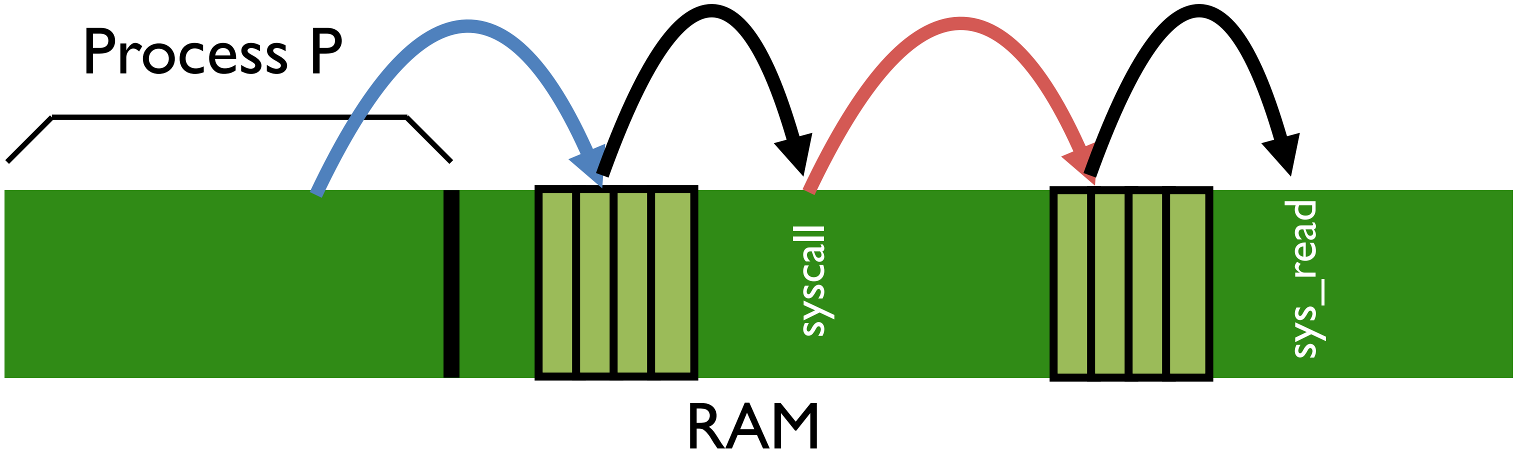
SYSTEM CALL




```
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```
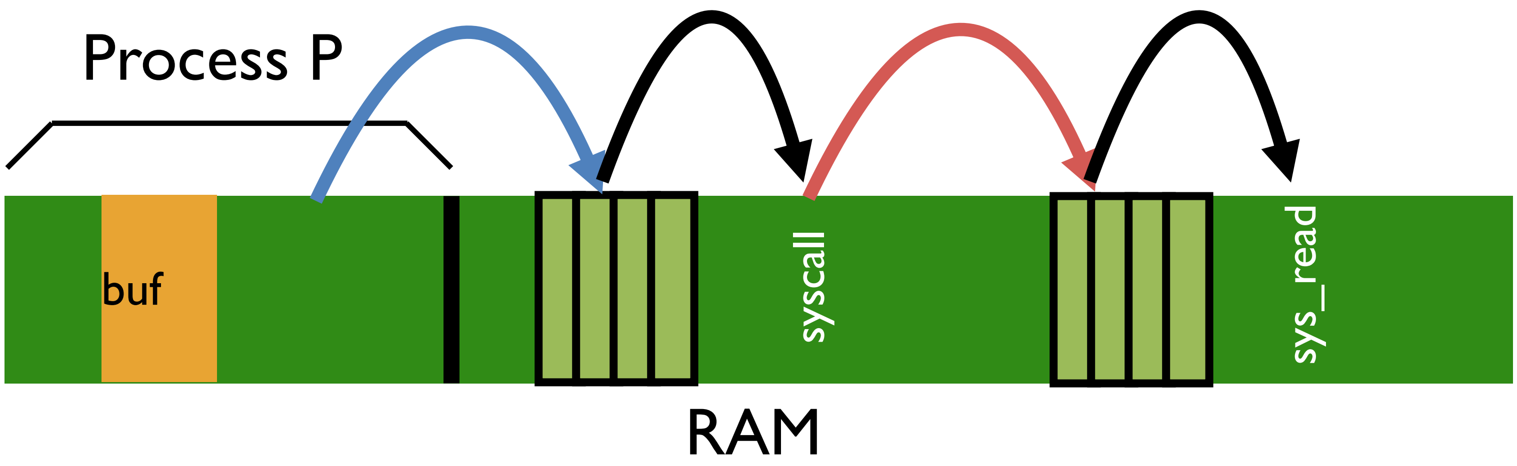

Follow entries to correct system call code

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-fa24-quiz1b

To call SYS_read the instructions we used were

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

To call SYS_exec what will be the instructions?

```
movl _____  %eax
int  _____
```

```
// 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
}
```

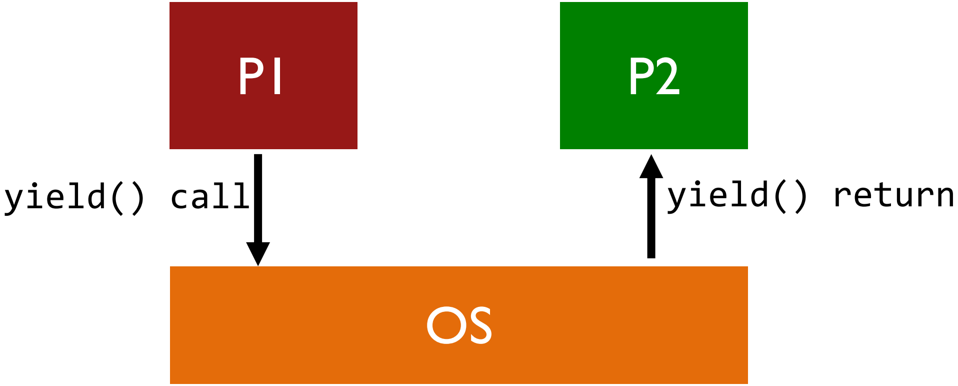
Question 1: How does dispatcher gain control?

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

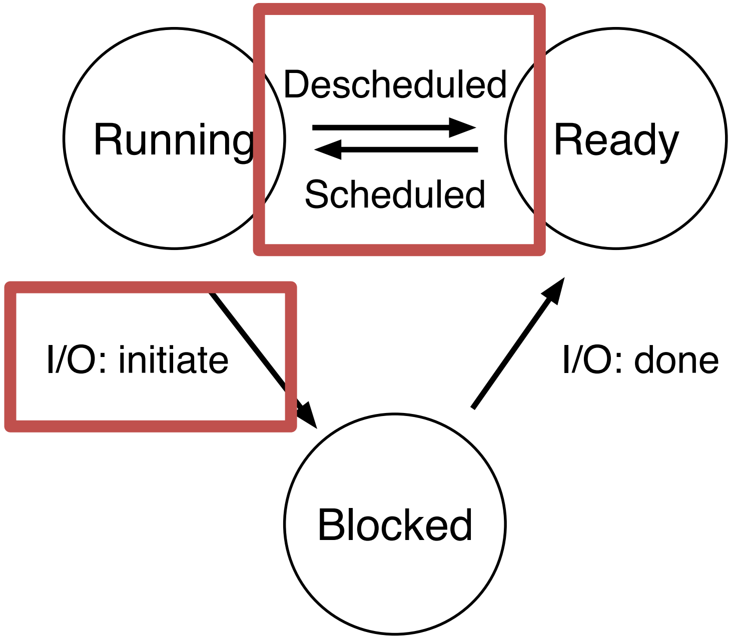
SUMMARY

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 1: Due Friday, Sept 13th

Project 2: Out Friday, Sept 13th

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