VIRTUALIZATION: THE CPU

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CS 537, Spring 2019

ADMINISTRIVIA

- Project 1a is out! Due Jan 29 at 11.59pm
- Signup for Piazza https://piazza.com/wisc/spring2019/cs537
- Lecture notes at pages.cs.wisc.edu/~shivaram/cs537-sp19/
- Drop? Waitlist? Email enrollment@cs.wisc.edu 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 ?

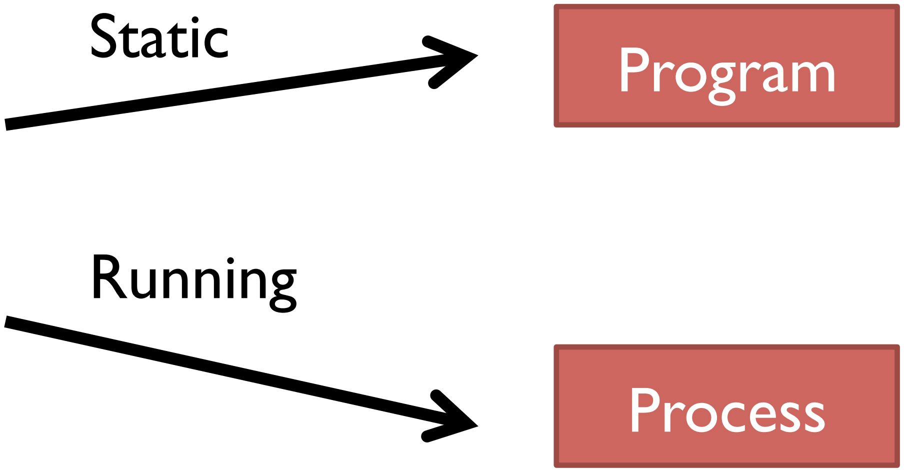
ABSTRACTION: PROCESS

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;
}
```



WHAT IS A PROCESS?

Stream of executing instructions and their "context"

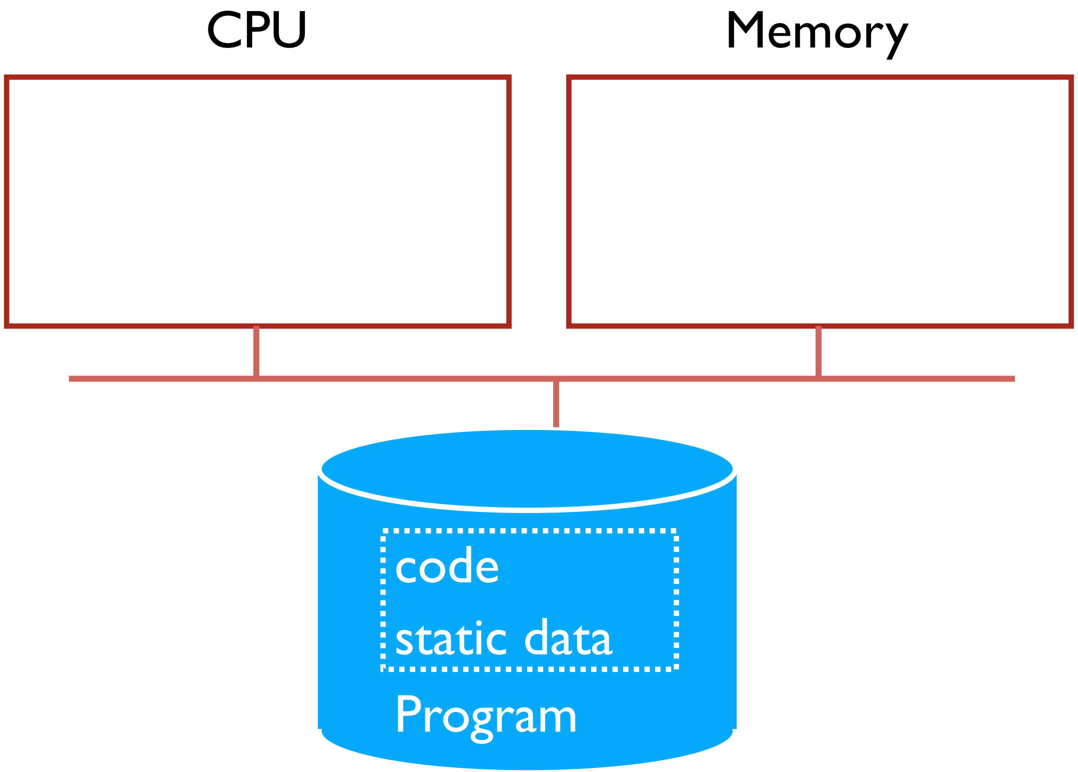
Instruction Pointer →

```
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
```

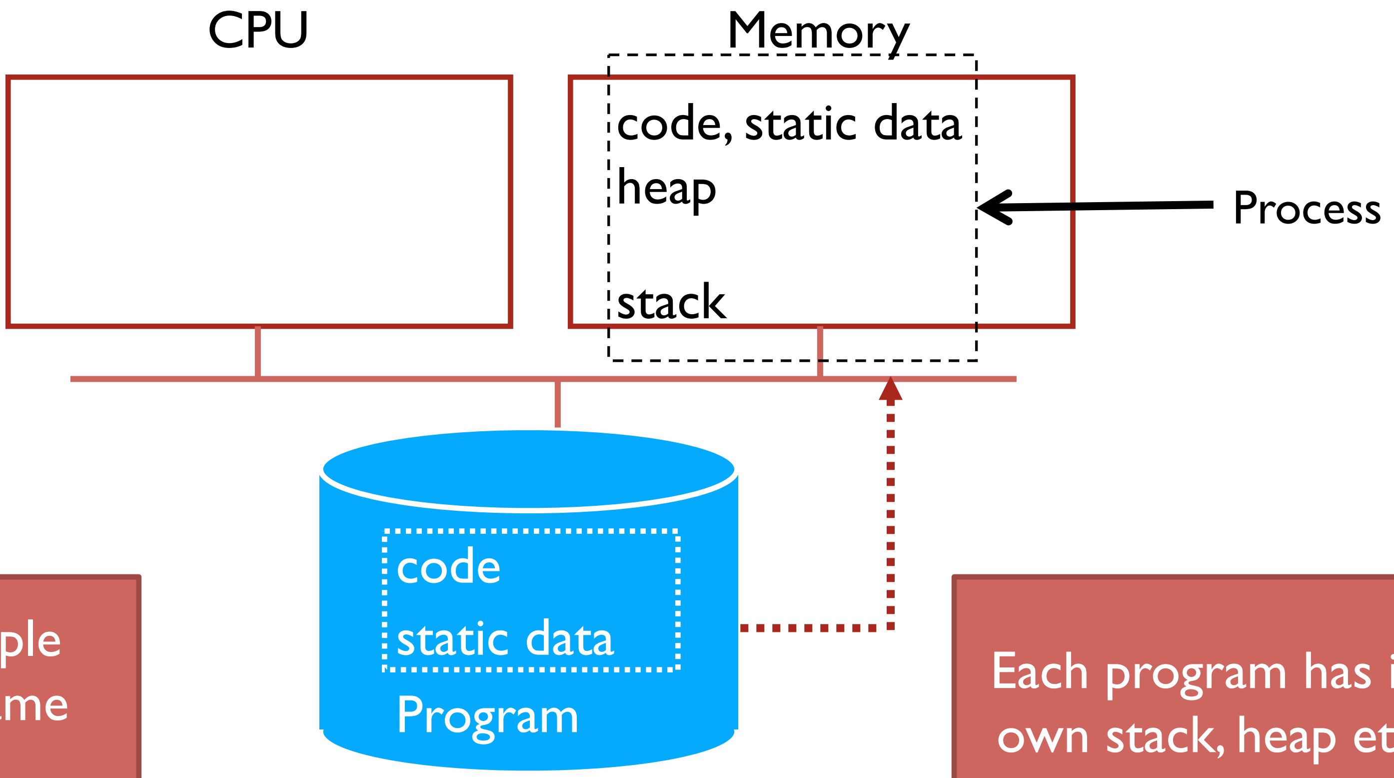
Registers
Memory addrs

File descriptors

PROCESS CREATION



PROCESS CREATION



Can run multiple instances of same program

Each program has its own stack, heap etc.

PROCESS VS THREAD DEMO

PROCESS VS THREAD

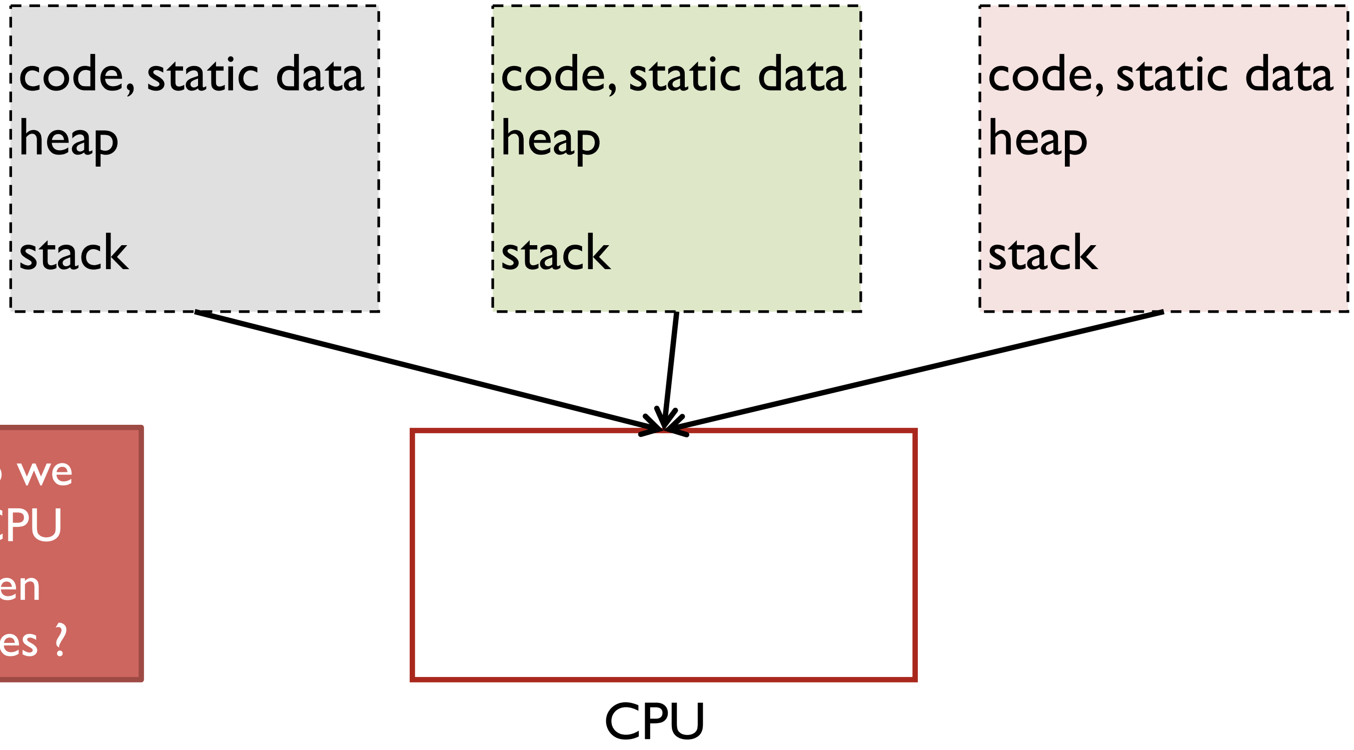
Threads: "Lightweight process"

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

Can have multiple threads within a single process

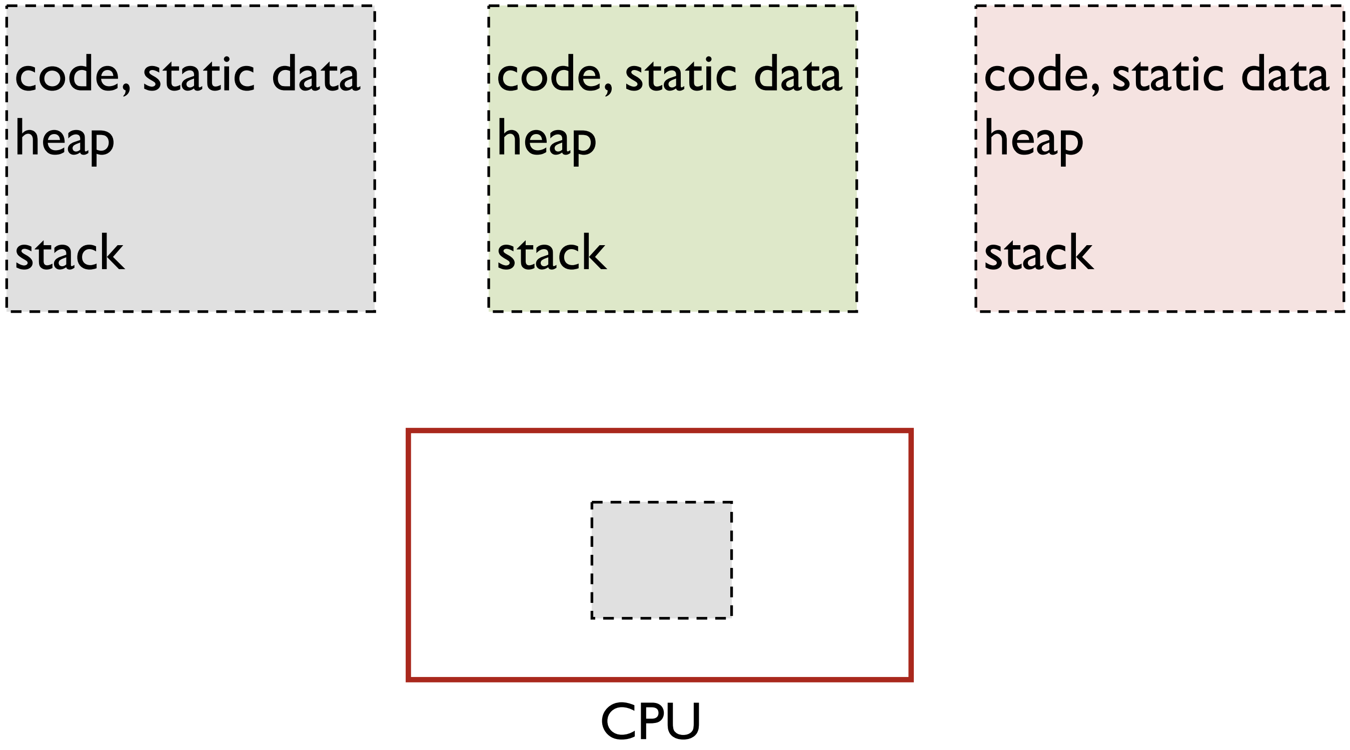
WHY DO WE NEED PROCESSES ?

SHARING CPU

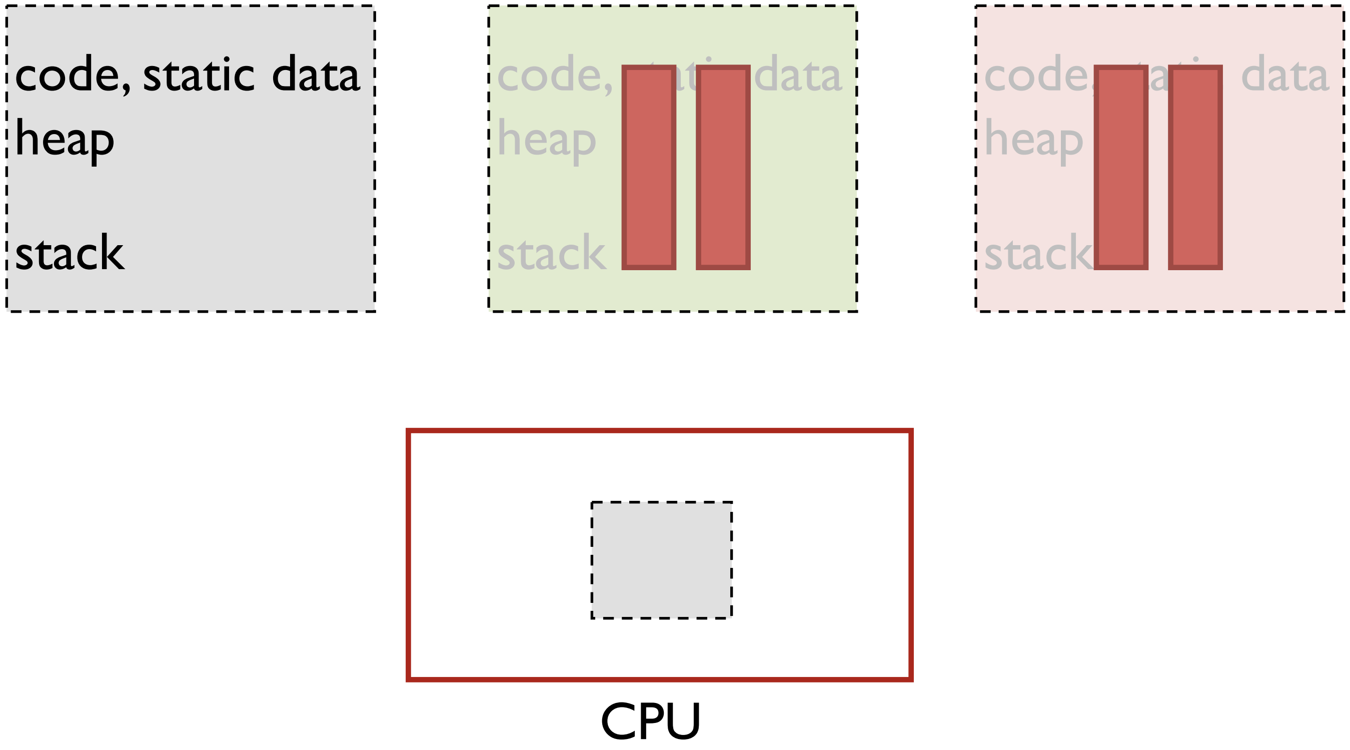


How do we share CPU between processes ?

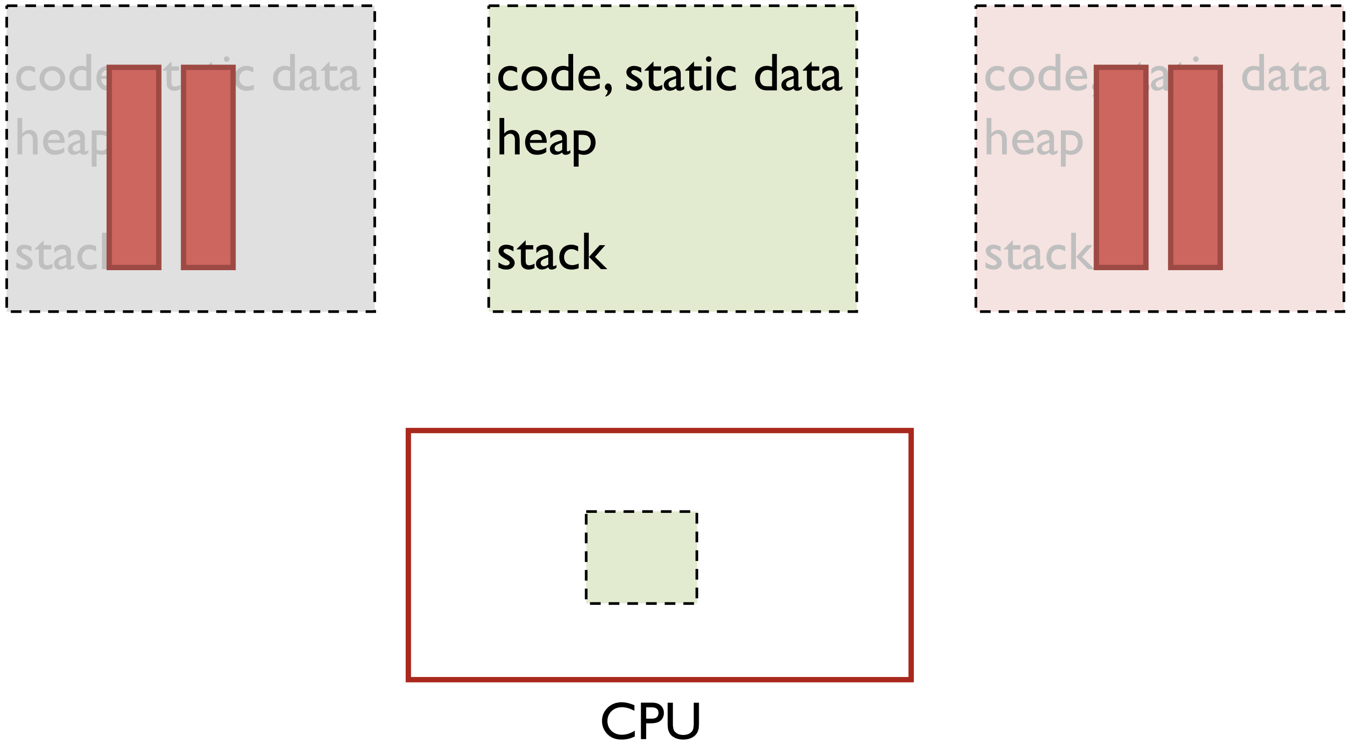
TIME SHARING



TIME SHARING



TIME SHARING

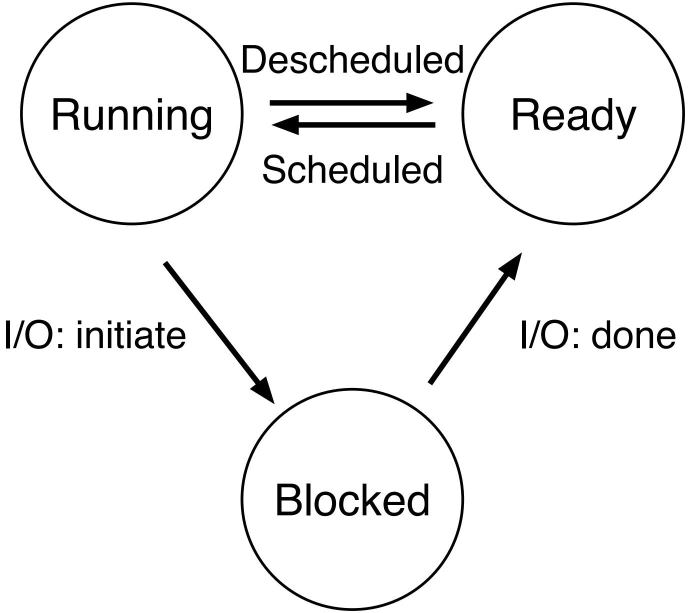


WHAT TO DO WITH PROCESSES THAT ARE NOT RUNNING ?

OS Scheduler

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

STATE TRANSITIONS



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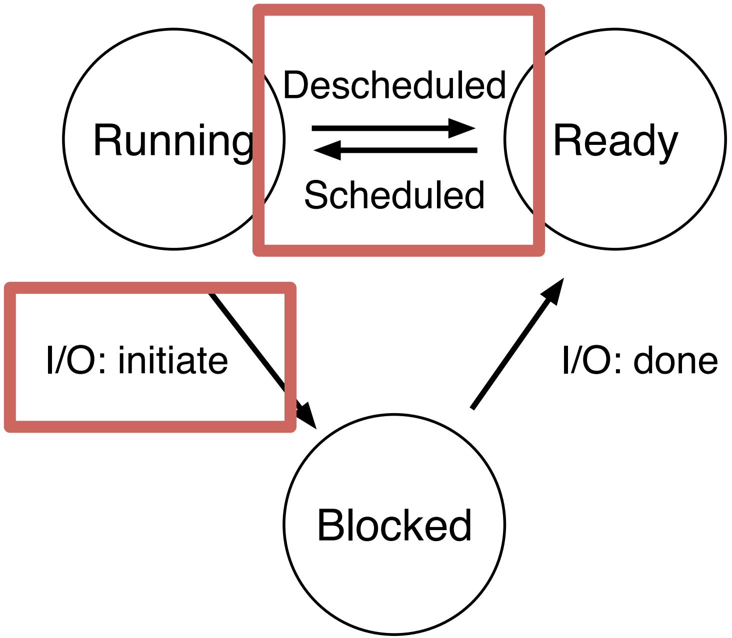


ASIDE: OSTEP HOMEWORKS!

- 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

```
≥ ./process-run.py -l 3:50,3:40
Process 0
  io
  io
  cpu

Process 1
  cpu
  io
  io
```

CPU TIME SHARING

Policy goals

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

Mechanism goals

- Efficiency: Time 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)

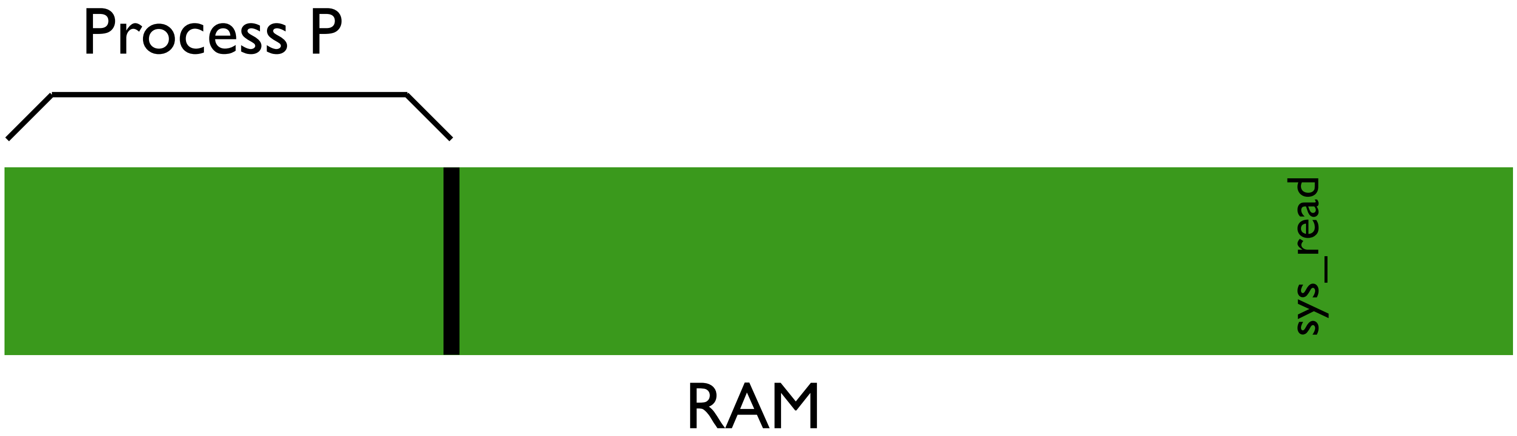
OS runs in kernel mode (not restricted)

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)

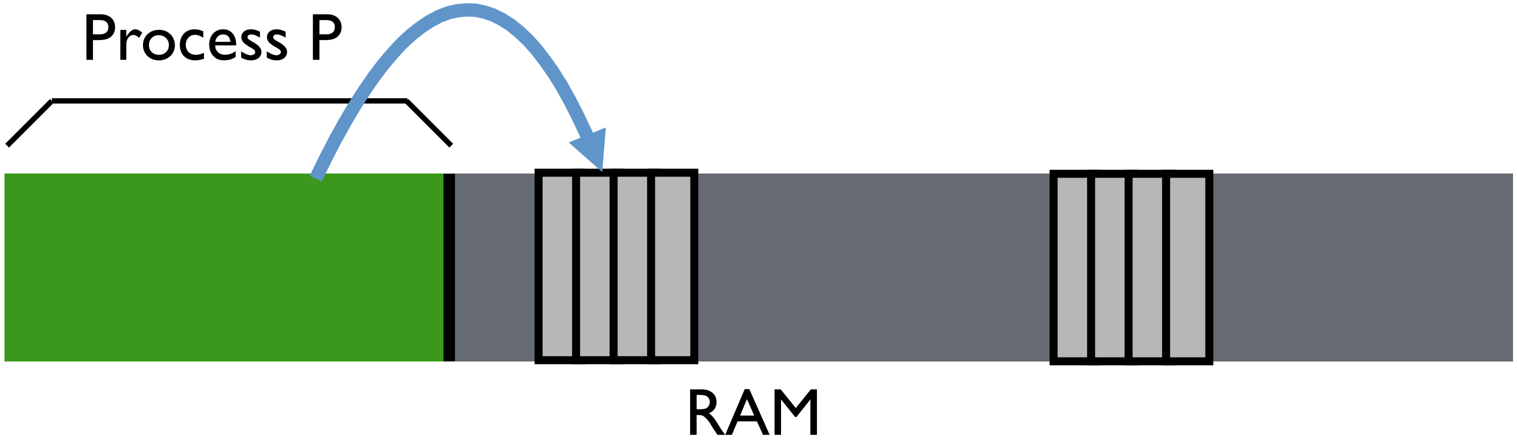
SYSTEM CALL

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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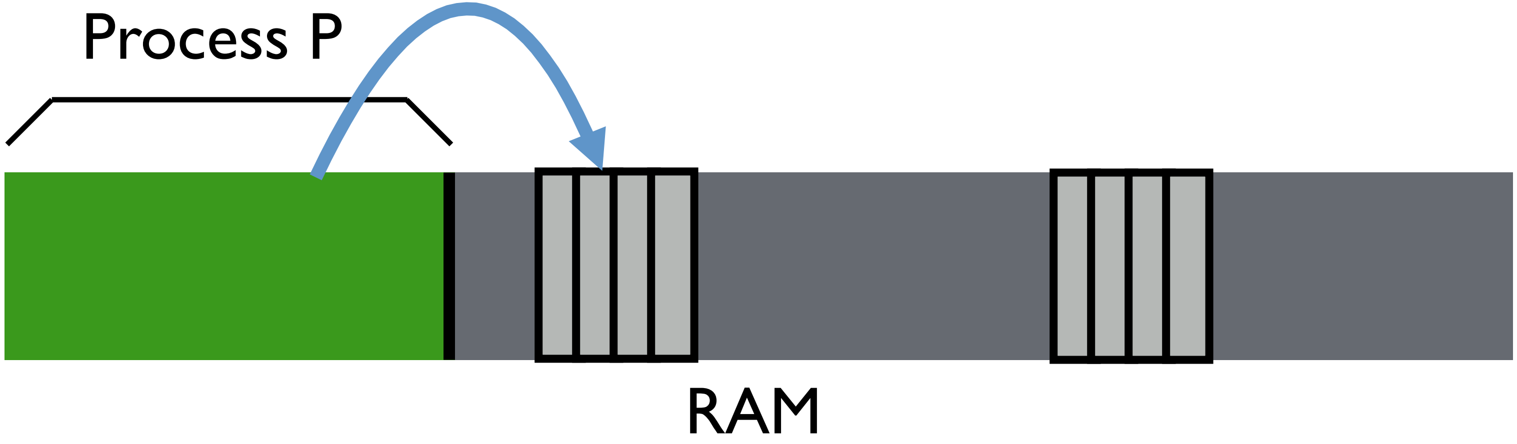


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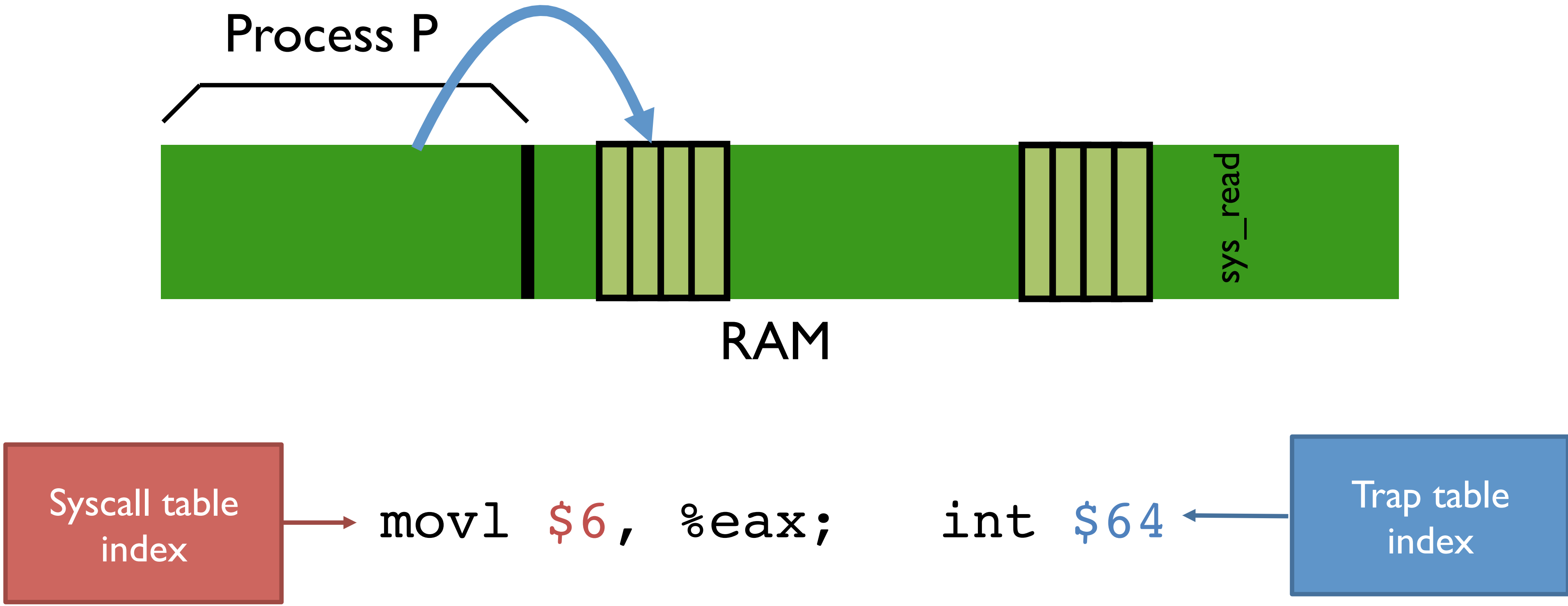


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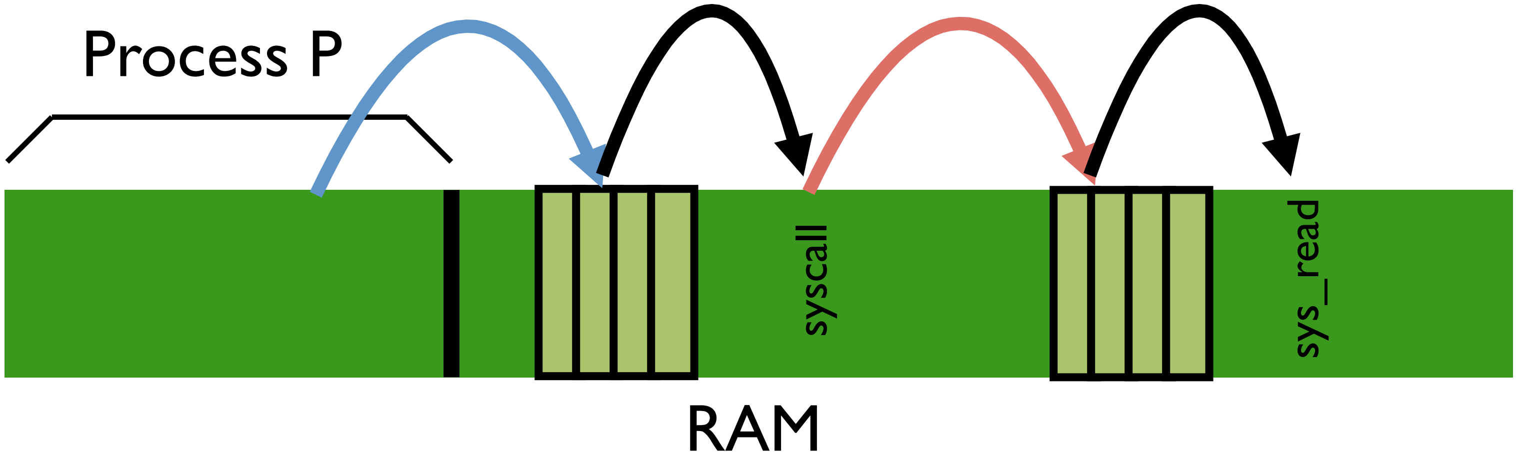


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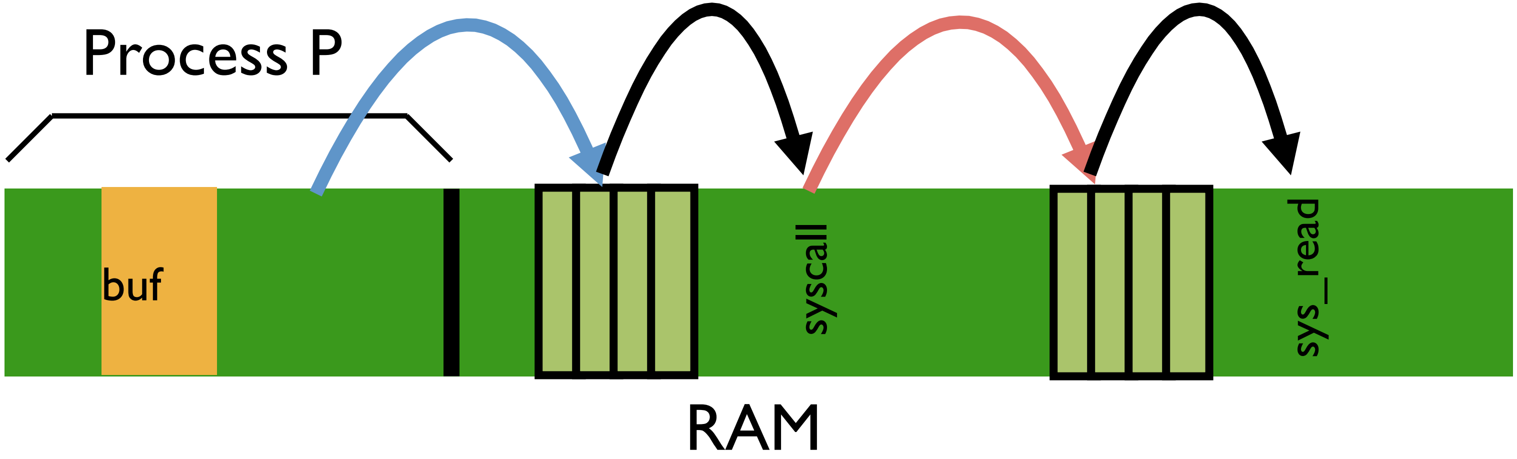
```

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

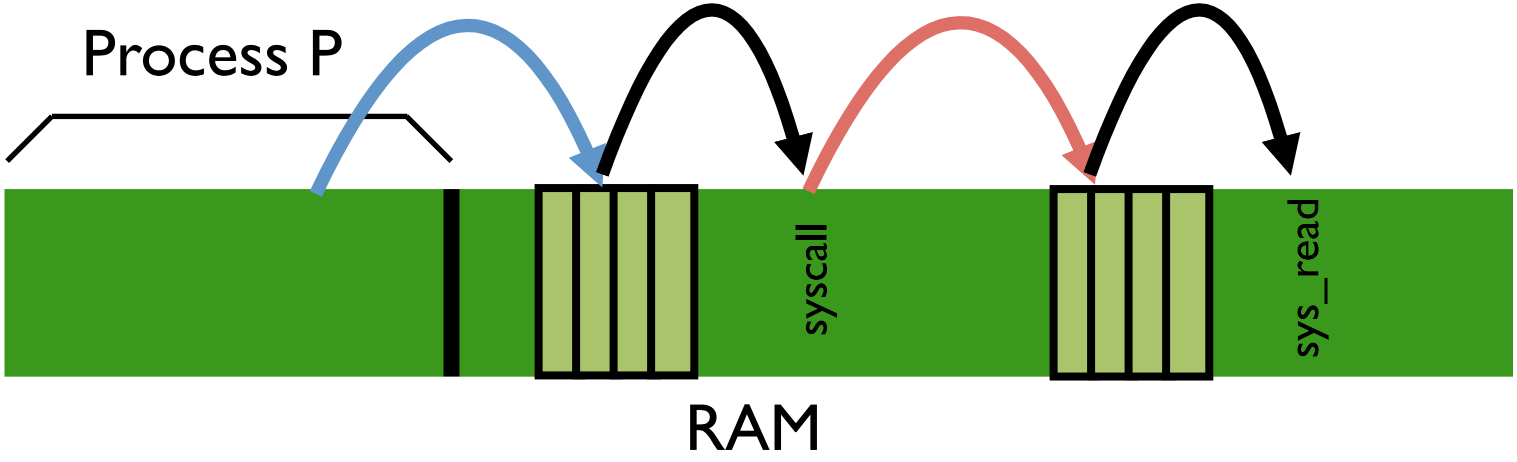
SYSCALL SUMMMARY

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)




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

Why not directly specify sys_read address from user-mode ?

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
}
```

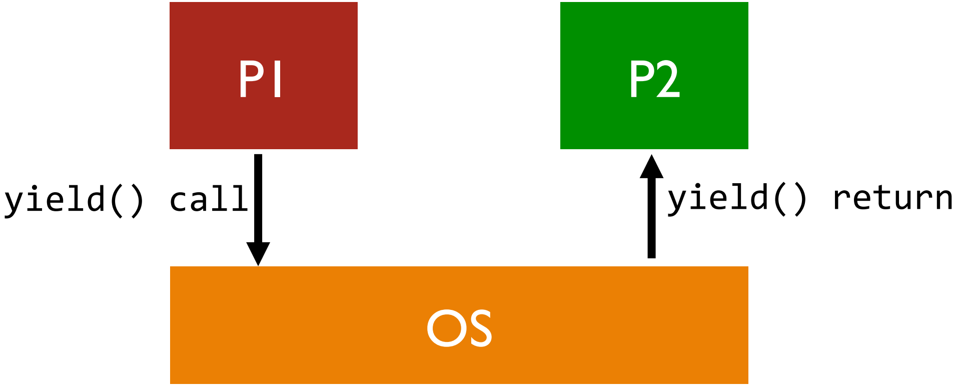
Question 1: How does dispatcher gain control?

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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		Process B

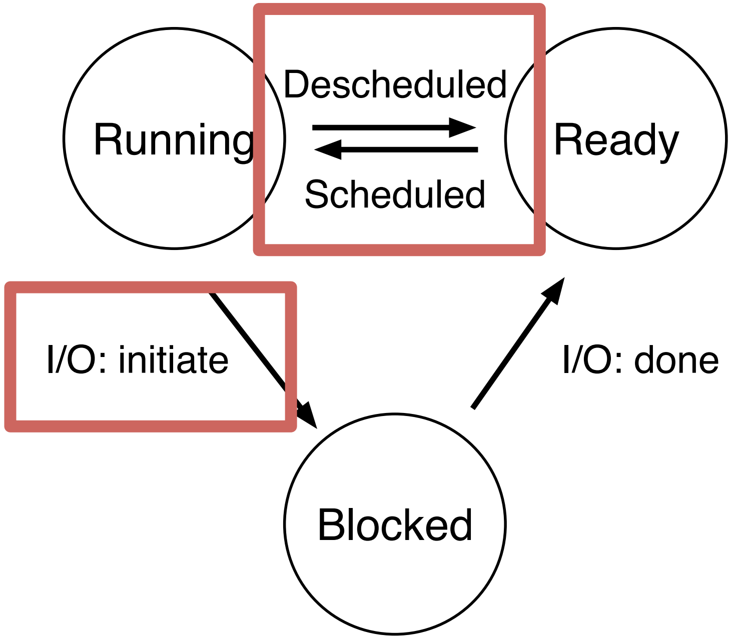
SUMMARY

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 (Tuesday) at 11.59pm

Project 1b: Out on Jan 29th

Discussion section: Thursday 5.30pm-6.30pm

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