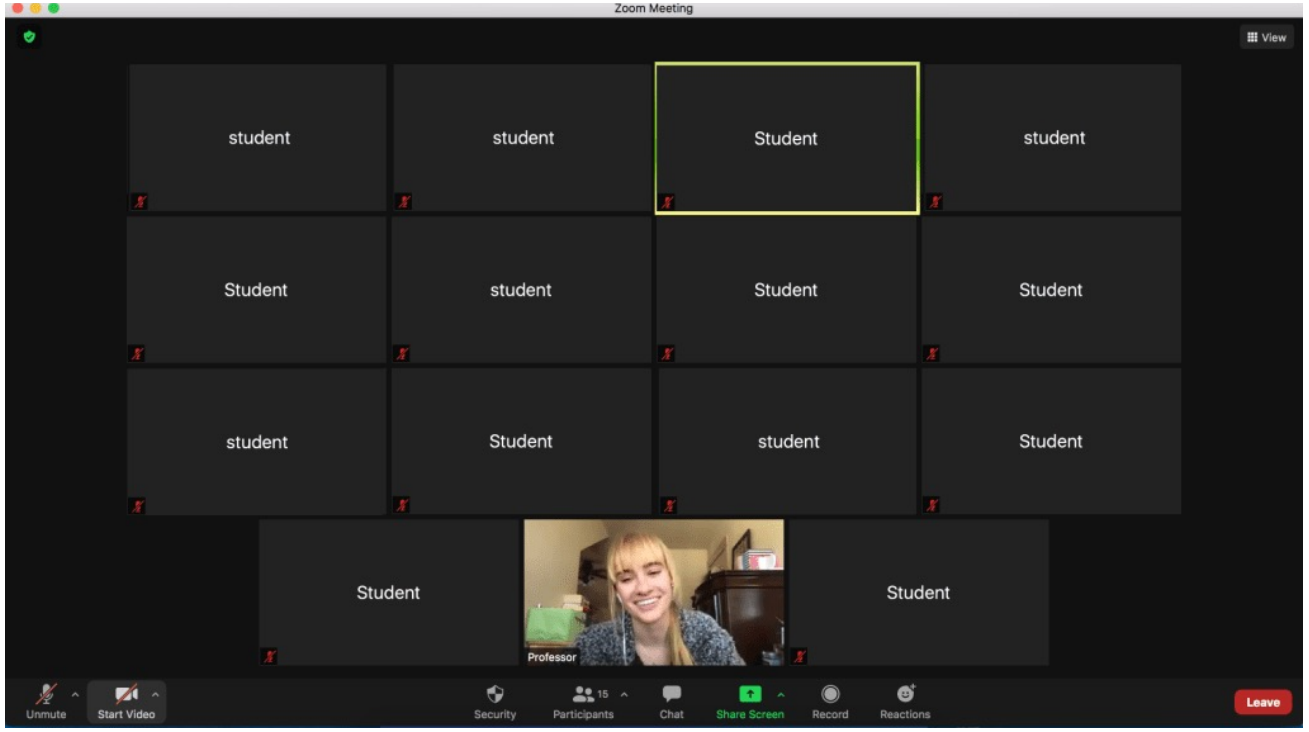
# CS 318 Principles of Operating Systems

Fall 2021

## Lecture 1: Introduction

**Prof. Ryan Huang**

JOHNS HOPKINS
WHITING SCHOOL
*of* ENGINEERING




# It is great to meet in person again…

# Course Instructor

## Prof. Ryan Huang

- Assistant Professor, joined Hopkins in 2017
  - https://cs.jhu.edu/~huang
- Lead the Ordered Systems Lab: https://orderlab.io
  - research on OS, Cloud and Mobile Computing, Systems Reliability
- Office: Malone 231

## Office Hours

- Tue Thu 9:30-10:30 am Eastern Time (or by appointment)
- Default Zoom, in-person if necessary

# Lecture 1 Overview

**COURSE OVERVIEW**

**ADMINISTRATIVE**

**WHAT IS AN OS?**

**WALK-THROUGH OF OS BASICS**

# Staff: Teaching Assistants

## Haoze Wu (TA)

- Office Hours: Thu/Fri 4-5 pm

## Yuzhuo Jing (CA)

- Office Hours: Mon & Wed 3:15-4:15 pm

## Gongqi Huang (CA)

- Office Hours: Tue/Thu 10:30-11:30 am

## Evan Leung (CA)

- Office Hours: Wed & Fri 8:30-9:30 am

# Course Overview

## An introductory course to operating systems

- Classic OS concepts and principles
- Prepare you for advanced OS and distributed system course
- OS concepts often asked in tech interview questions

## A practice course for hands-on experience with OS

- Four large programming assignments on a small but real OS
- Reinforce your understandings about the theories

# Bad News…

**This is a TOUGH course**

**Requires proficiency in systems programming**

- "*Low level (C) programming absolutely necessary.*"
- "*Need to be fearless about breaking code (and then fixing it later).*"
- "*Need to be confident in touching and modifying large systems of code*"

**Requires significant time commitment**

- "*The projects are insanely time consuming*"
- "*The workload is much much heavier than your average CS course…Be prepared to spend entire weeks working on nothing but the material for this course.*"

# Good News

**There aren't many such hardcore courses in CS curriculum ☺**

- Typically the final checkmark for a *solid* CS degree
- You don't have to take it if you are not interested in it

**It's hard, but rewarding in the end**

- "*The project are very hard. But completing them is very rewarding.*"
- "*You learn a lot about operating systems and computers in general.*"

**A highly valued skill after graduation**

**We will try our best to help you**

# Why Study Operating Systems?

## Technology trends

**CPU:** 1.85 GHz dual-core

**memory:** 2 GB

**price:** $329

**size:** 9.4 in × 6.6 in

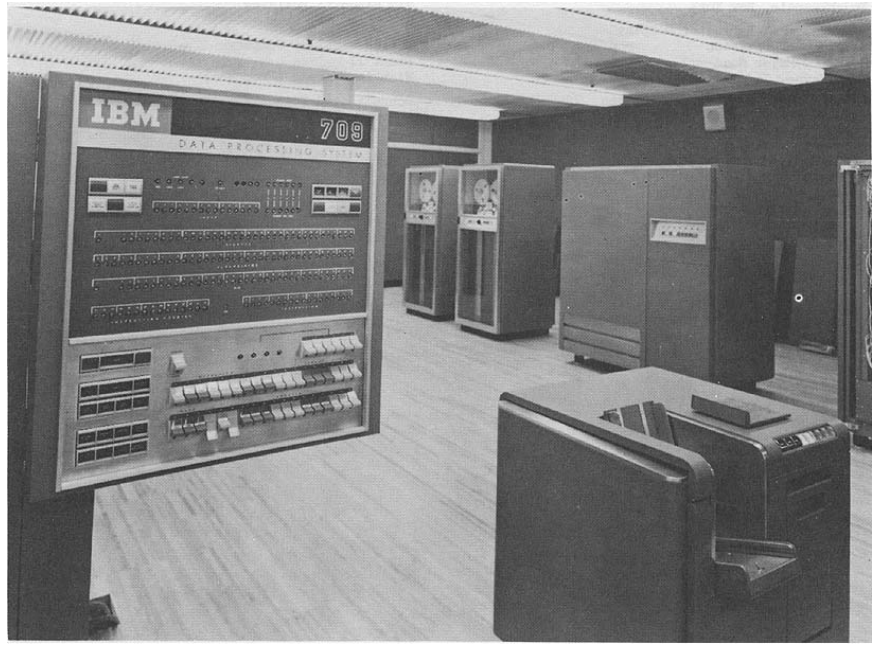
**iPad (2017)**

# Why Study Operating Systems?

## Technology trends

- **CPU:** 1.85 GHz dual-core
- **memory:** 2 GB
- **price:** $329
- **size:** 9.4 in × 6.6 in

**iPad (2017)**




**IBM 709 (c. late 1950~)**

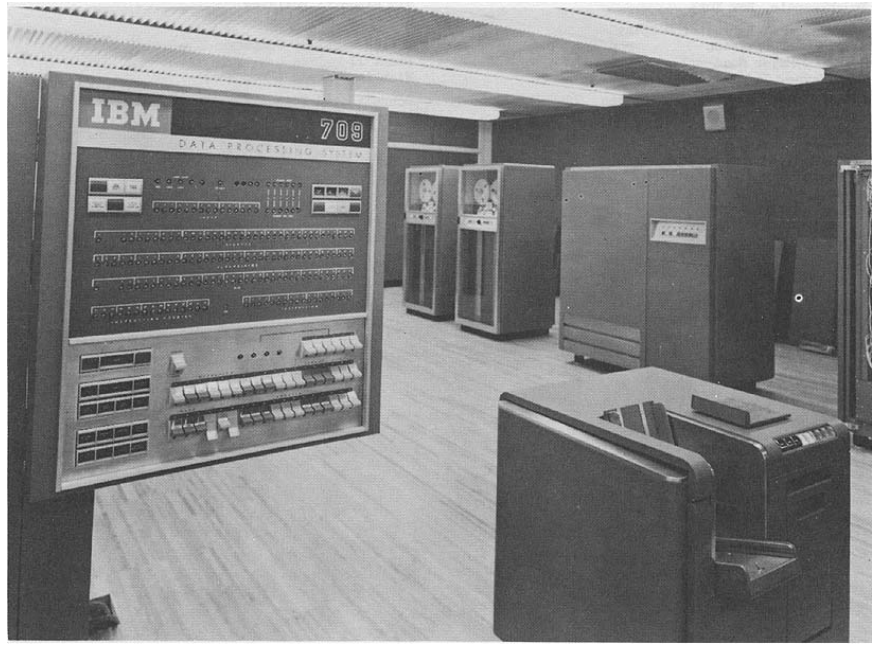
**World's most powerful computer then**

# Why Study Operating Systems?

## Technology trends

| | |
|---|---|
| **CPU:** 1.85 GHz dual-core | **???** mult/div per sec. |
| **memory:** 2 GB | **???** |
| **price:** $329 | **???** |
| **size:** 9.4 in × 6.6 in | **???** |

**iPad (2017)**




**IBM 709 (c. late 1950~)**

**World's most powerful computer then**

# Why Study Operating Systems?

## Technology trends

**CPU:** 1.85 GHz dual-core

**memory:** 2 GB

**price:** $329

**size:** 9.4 in × 6.6 in

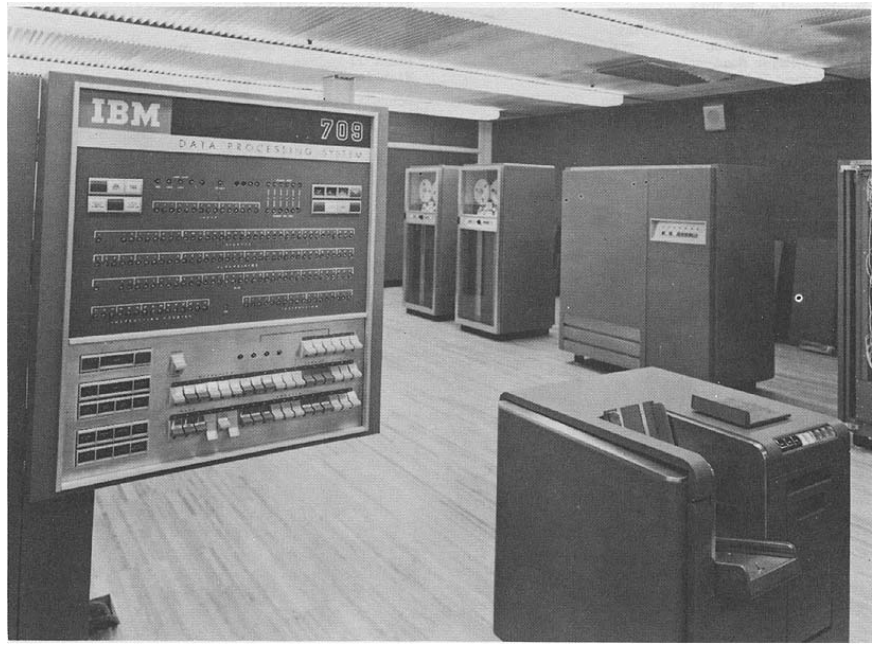
**iPad (2017)**

~4000 mult/div per sec.

32K 36-bit words

$2,630,000+

half room

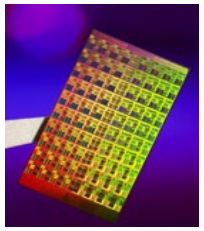



**IBM 709 (c. late 1950~)**

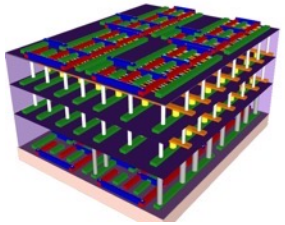
**World's most powerful computer then**

# Why Study Operating Systems?

## Technology trends



manycore



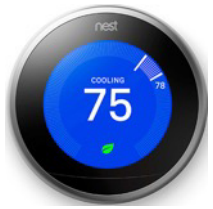
3D stacked chip

persistent memory

accelerators

Tensor Processing Unit

smartphones




IoT device

self-driving cars

robots

data centers

...

# Why Study Operating Systems?

## Technology trends



manycore



3D stacked chip



persistent memory



accelerators



Tensor Processing Unit

**They all need OS support to be useful!**

smartphones




IoT device



self-driving cars

robots

data centers

...

# Why Study Operating Systems?

## An exciting time for OS designs

- New hardware, smart devices, self-driving cars, data centers, etc.
- Existing OSes face issues in performance, battery life, security, isolation

some of you

## Pervasive principles for systems in general

- Caching, concurrency, memory management, I/O, protection

many of you

## Complex software systems

- Many of you will go on to work on large software projects
- OSes serve as examples of an evolution of complex systems

many of you

## Understand what you use

- System software tends to be mysterious
- Understanding OS makes you a more effective programmer

all of you

# Course Materials

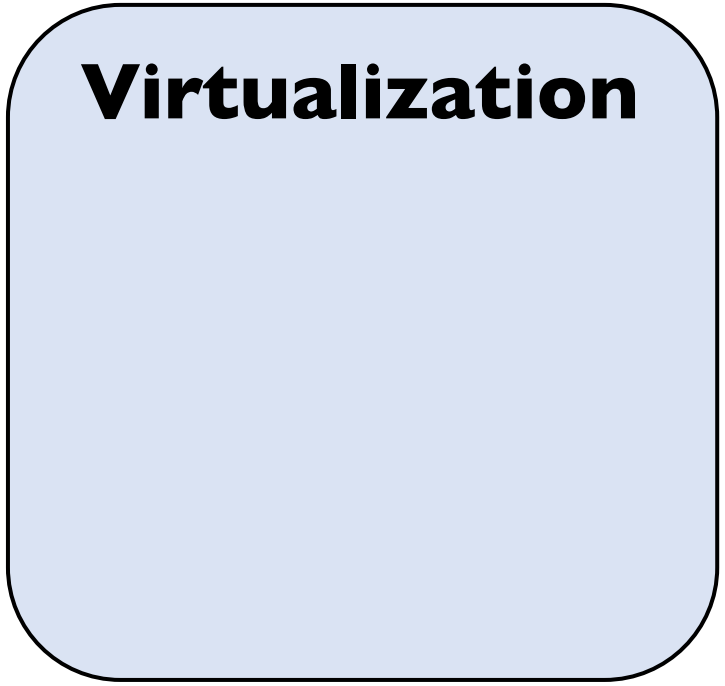
## Course materials

- Lectures are the primary references
- Textbooks are supplementary readings
- Occasionally non-required papers

# Topics Covered

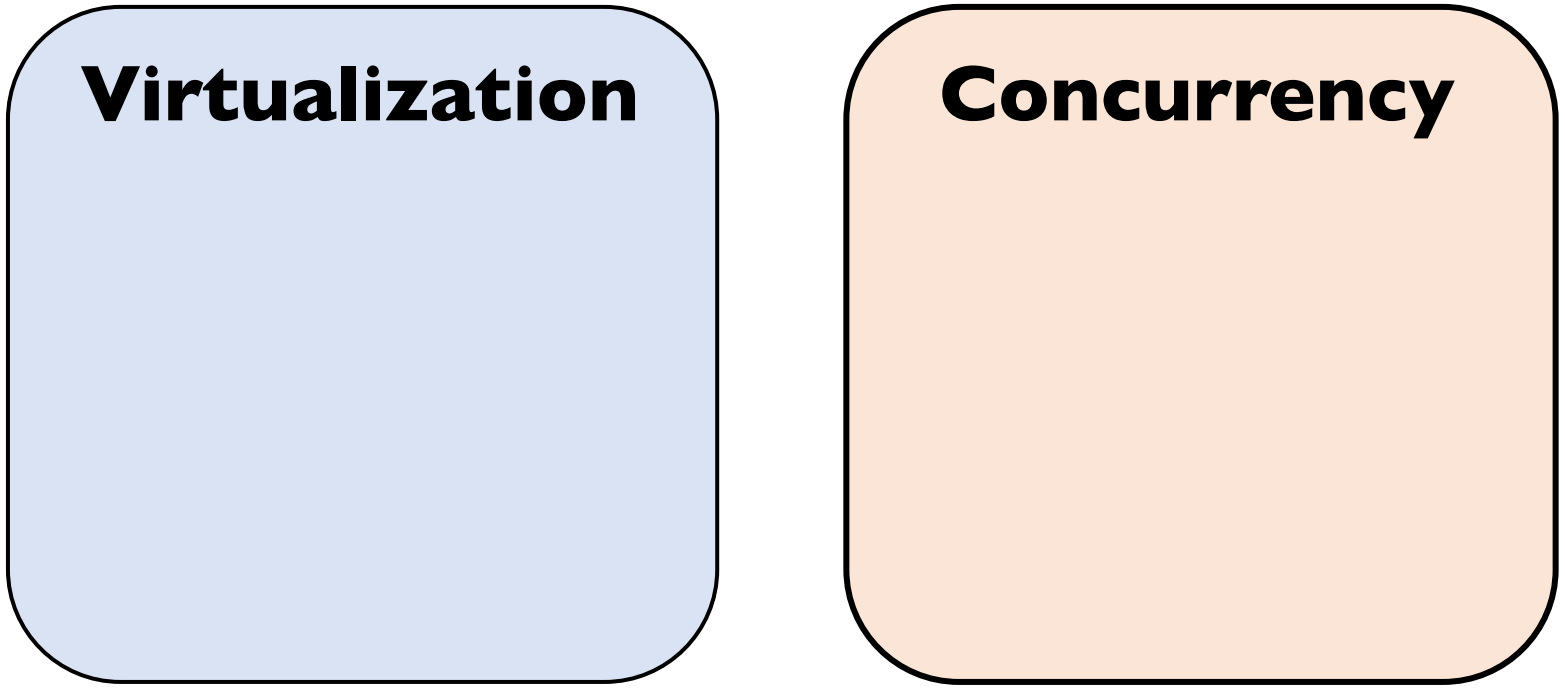
## Three Fundamental Pieces

# Topics Covered



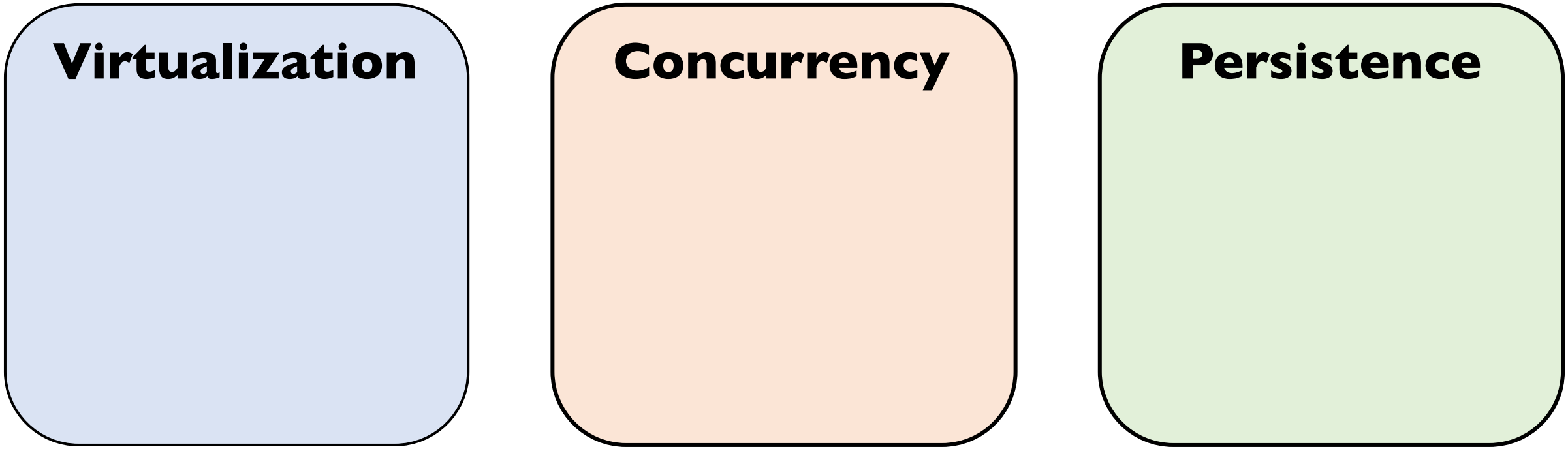

**Three Fundamental Pieces**

# Topics Covered




**Three Fundamental Pieces**

# Topics Covered




**Three Fundamental Pieces**

# Topics Covered

**Virtualization**

Processes

Scheduling

Virtual Memory

**Concurrency**

**Persistence**

**Three Fundamental Pieces**

# Topics Covered

## Virtualization

Processes

Scheduling

Virtual Memory

## Concurrency

Threads

Synchronization

Semaphores and Monitors

## Persistence

**Three Fundamental Pieces**

# Topics Covered

## Virtualization

Processes

Scheduling

Virtual Memory

## Concurrency

Threads

Synchronization

Semaphores and Monitors

## Persistence

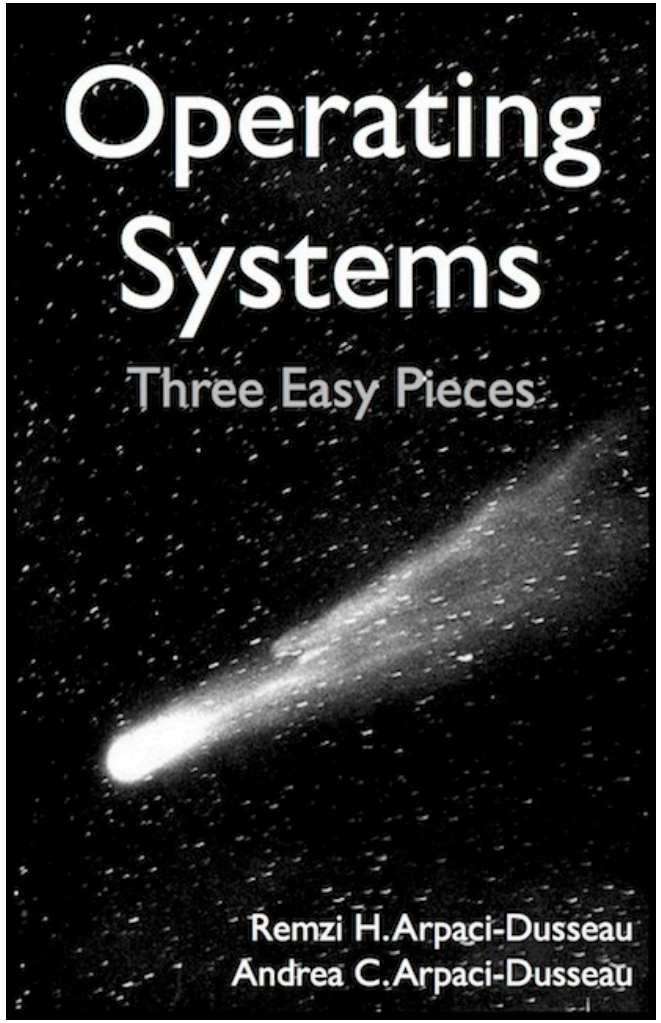
I/O

Disks

File Systems

**Three Fundamental Pieces**

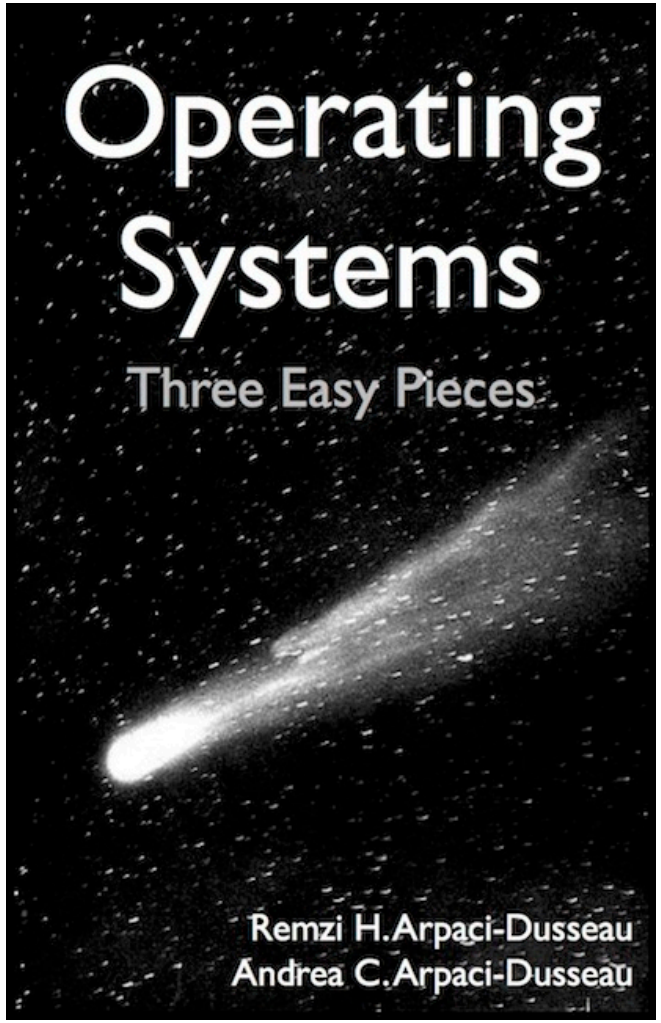
# Textbook




***Operating Systems: Three Easy Pieces***, Version 0.91

By *Remzi Arpaci-Dusseau* and *Andrea Arpaci-Dusseau*

# Textbook

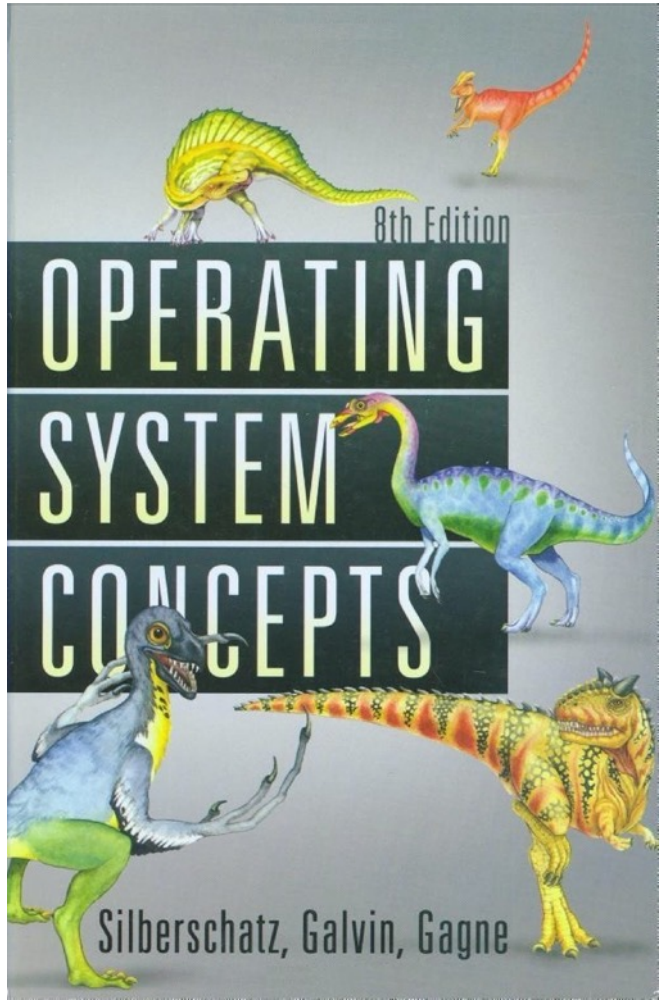




***Operating Systems: Three Easy Pieces***, Version 0.91

By *Remzi Arpaci-Dusseau* and *Andrea Arpaci-Dusseau*

http://from-a-to-remzi.blogspot.com/2014/01/the-case-for-free-online-books-fobs.html

# Textbook

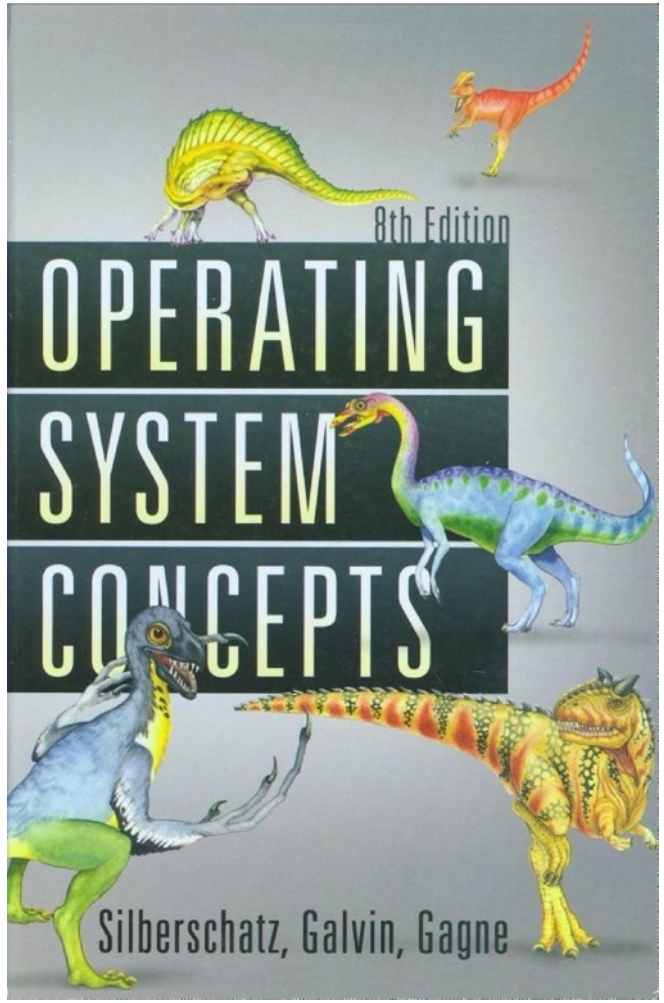



***Operating Systems Concepts***

By *Silberschatz*, *Galvin* and *Gagne*

# Textbook

**What killed the dinosaur?**

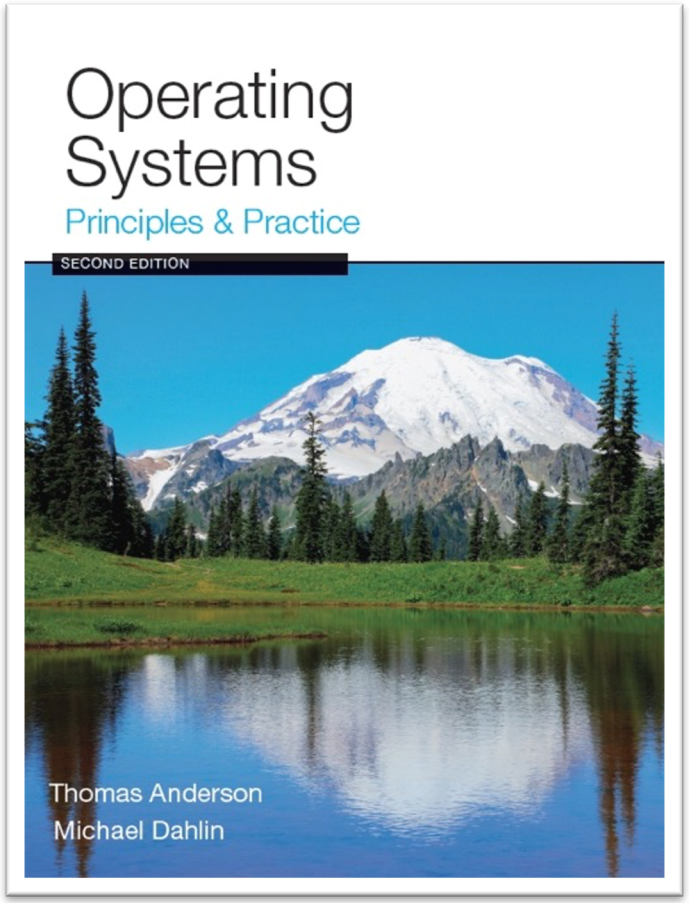


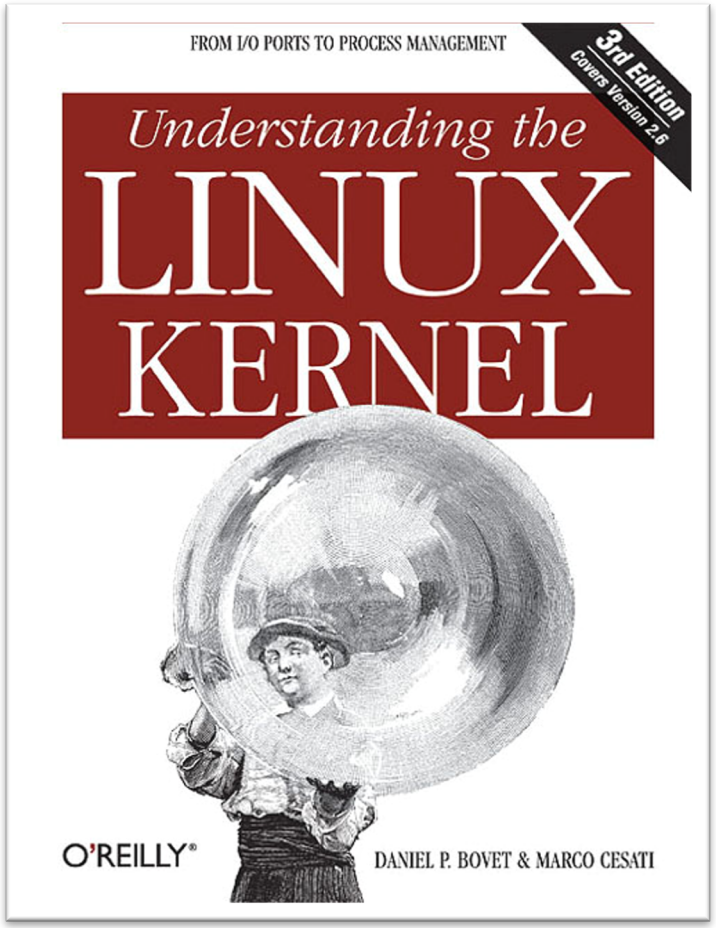

***Operating Systems Concepts***

By *Silberschatz*, *Galvin* and *Gagne*

# Textbook

# Other Recommended Textbooks



# Important Links (1)

## Course Website (check it often)

- https://www.cs.jhu.edu/~huang/cs318/fall21
- Course syllabus and schedule
- Lecture slides
- Homework handouts
- Project descriptions and references

# Important Links (2)

## Discussion Forum: CampusWire

- https://campuswire.com/p/G432AC582
- Access code: 9699
- Questions about project, lecture, exams

## Staff mail list:

- cs318-staff@cs.jhu.edu
- administrative requests, sensitive questions, etc.

# Homework

**Several homework assignments throughout the semester**

- help you check understanding about the lectures
- prepare you for the exams

**The homework assignments will *not* be graded**

- amount learned from doing homework is proportional to effort
- your choice on how much effort

# Project Assignments

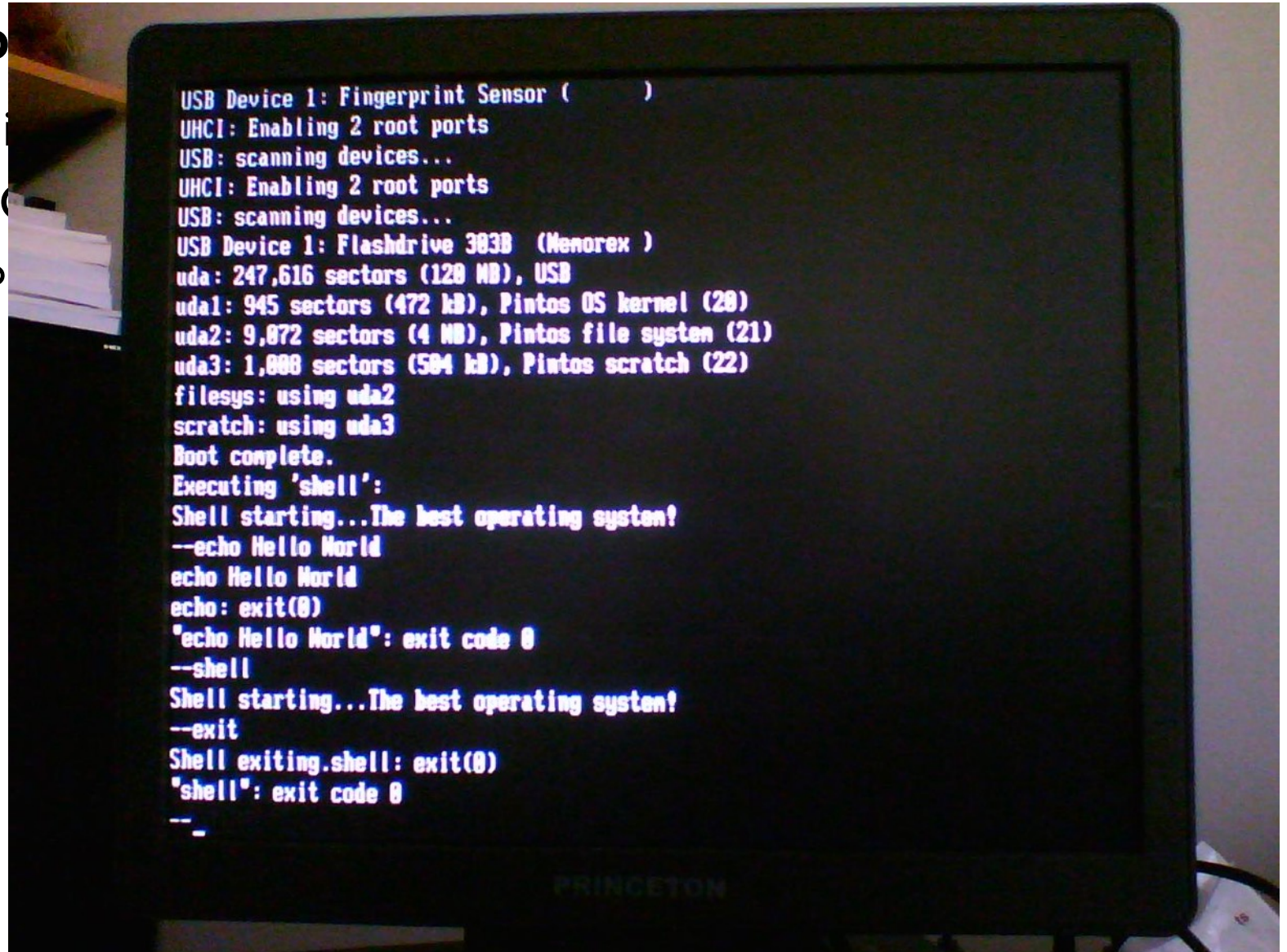
**Implement parts of Pintos operating system**

- Developed in 2005 for Stanford's CS 140 OS class
- Written in C, built for x86 hardware
  - can run on a real machine!

# Project Assignments

**Implement p**

- Developed i
- Written in C
  - can run o



# Project Assignments

## Implement parts of Pintos operating system

- Developed in 2005 for Stanford's CS 140 OS class
- Written in C, built for x86 hardware
  - can run on a real machine!
- Use hardware emulator (QEMU/Bochs) during development


QEMU
SeaBIOS (version rel-1.10.2-0-g5f4c7b1-prebuilt.qemu-project.org)
Booting from Hard Disk...
PiLo hda1
Loading.....
Kernel command line: -q run shell
Pintos booting with 3,968 kB RAM...
367 pages available in kernel pool.
367 pages available in user pool.
Calibrating timer...  523,468,800 loops/s.
hda: 1,008 sectors (504 kB), model "QM00001", serial "QEMU HARDDISK"
hda1: 218 sectors (109 kB), Pintos OS kernel (20)
hdb: 9,072 sectors (4 MB), model "QM00002", serial "QEMU HARDDISK"
hdb1: 8,192 sectors (4 MB), Pintos file system (21)
filesys: using hdb1
no swap device--swap disabled
Boot complete.
Executing 'shell':
Shell starting...
--echo "hello cs318"
echo "hello cs318"
echo: exit(0)
"echo "hello cs318"": exit code 0
--ls /
/:
echo
ls
cat
mkdir
rm
shell
ls: exit(0)
"ls /": exit code 0
--mkdir home
mkdir: exit(0)
"mkdir home": exit code 0
--ls /
/:
echo
ls
cat
mkdir
rm
shell
home
ls: exit(0)
"ls /": exit code 0
--_

# Project Assignments (2)

**One setup lab (lab 0)**

- due next Thursday (done individually)

**Four substantial labs:**

- Required: Threads, User processes, Virtual memory
- Optional: File system

**Implement projects in groups of up to 3 people**

- Start picking your partners today

**Warning: each project requires significant time to complete**

- Don't wait until the last minute to start!!

# Project Assignments (3)

## Automated tests

- All tests are given so you immediately know how well your solution performs
- You either pass a test case or fail, there is *no* partial credit

## Design document

- Answer important questions related to your design for a lab

## Coding style

- Can your group member and TAs understand your code easily?

# Project Design and Style

## Must turn in a design document along with code

- Large software systems not just about producing working code
- We supply you with templates for each project's design doc

## TAs will manually inspect code

- e.g., must actually implement the design
- must handle corner cases (e.g., handle `malloc` failure)
- will deduct points for error-prone code

## Code must be easy to read

- Indent code, keep lines and functions short
- Use a consistent coding style
- Comment important structure members, globals, functions

# Project Lab Environment

## The CS department ugrad and grad lab machines

- Running Linux on x86
- The toolchain already setup

## You may also use your own machine

- We have written detailed instructions for setting up the environment
  - https://cs.jhu.edu/~huang/cs318/fall21/project/setup.html
- Unix and Mac OS preferred. Windows needs VMs
- Pre-built VM image provided

# Quizzes & Exam

## Quizzes

- In class, bring your laptop or other computer devices
- Mainly cover topics in first half of class

## Final Exam

- Mainly covers second half of class + selected materials from first part
  - I will be explicit about the material covered
- Include project questions

# Grading

**Quizzes: 15%**

**Final Exam: 25%**

**Project: 60%**

- Lab 3b is optional for 318-section students
- Lab 4 is optional for all students
  - Completing it receives a max 6% extra credits
- For each project
  - 60% based on passing test cases
  - 40% based on design document and style

# Late Policies

## Late submissions receive penalties as follows

- 1 day late, 15% deduction
- 2 days late, 30% deduction
- 3 days late, 60% deduction
- after 4 days, no credit

## Each team will have a total of 6-day grace period

- can spread into 4 projects
- for interview, attending conference, errands, etc., no questions asked
- use it wisely, strongly suggest to reserve it for later labs (lab3, 4)

# Collaboration and Cheating Policies (A)

## Collaboration

- Explaining a concept to someone in another group
- Discussing algorithms/testing strategies with other groups
- Helping someone else (in another group) debug

# Collaboration and Cheating Policies (B)

## Do not look at other people's solutions

- Including solutions online
  - This means copying code from GitHub will get you into big trouble
- We will run comprehensive tools to check for potential cheating

## Do not publish your own solutions

- online (e.g., on GitHub) or share with other teams

## Cite any code that inspired your code

- If you cite what you used, it won't be treated as cheating
  - in worst case, we deduct points if it undermines the assignment

# Do Not Cheat

It *will* be caught

The consequence is very high

Truth: you can always get better outcome by not cheating

# How *Not* to Pass CS 318?

## Do not come to lecture

- The slides are online and the material is in the book anyway
- Lecture walks you through difficult materials and tells you the context

## Do not do the homework

- It's not part of the grade
- Concepts seem straightforward...until you apply them
- Excellent practice for the exams, and project

# How *Not* to Pass CS 318?

**Do not ask questions in lecture, office hours or online**

- It's scary, I don't want to embarrass myself
- Asking questions is the best way to clarify lecture material
- Office hours and email will help with homework, projects

**Wait until the last couple of days to start a project**

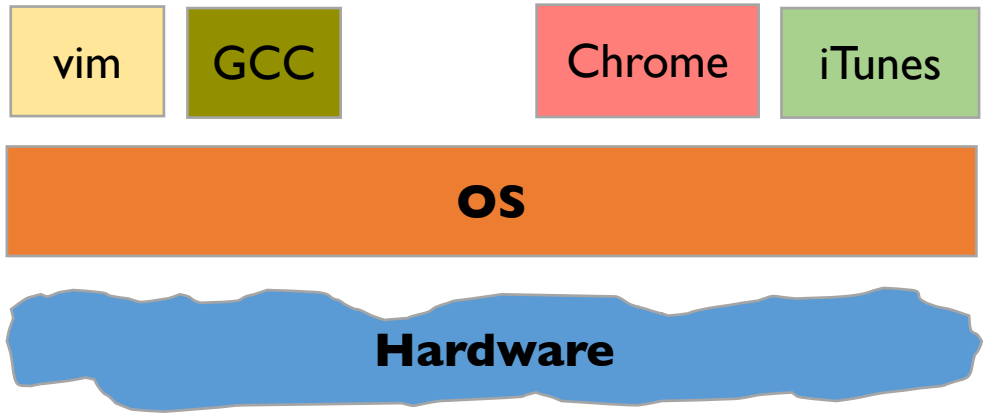
- We'll have to do the crunch anyways, why do it early?
- The projects cannot be done in the last few days
- Repeat: **The projects cannot be done in the last few days**
- (p.s. The projects cannot be done in the last few days)

# Questions

**Before we start, any questions?**

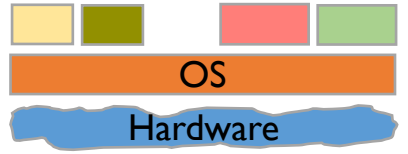
# What Is An Operating System?

**Layer between applications and hardware**

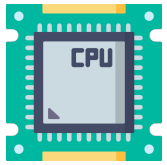



**All the code that you didn't have to write to implement your app :)**

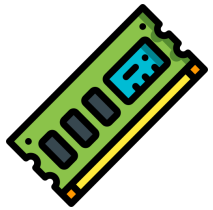
# OS and Hardware




## Manage hardware resources

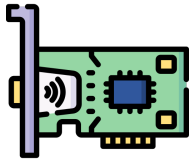



Computation

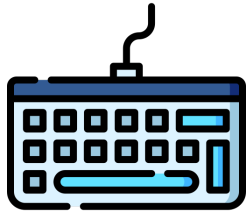


Volatile storage

Persistent storage



Communication

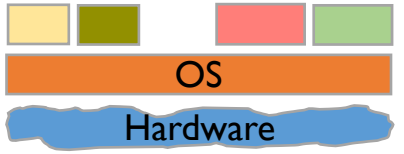


I/O

## Provides abstractions to hide details of hardware from applications

- Processes, threads
- Virtual memory
- File systems
- …

# OS and Hardware (2)



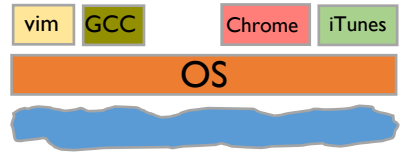

**Mediate accesses from different applications**

- Who has access at what point for how much/long

**Why? Benefits to applications:**

- Simpler (no tweaking device registers)
- Device independent (all network cards look the same)
- Portable (across Win95/98/ME/NT/2000/XP/Vista/7/8/10)

# OS and Applications




## Virtual machine interface

- Each program *thinks* it owns the computer

## Provides protection

- Prevents one process/user from clobbering another

## Provides sharing

- Concurrent execution of multiple programs (time slicing)
- Communication among multiple programs (pipes, cut & paste)
- Shared implementations of common facilities, e.g., file system

# Questions to Ponder

## What is part of an OS? What is not?

- Is the windowing system part of an OS?
- Is the Web browser part of an OS?
- This very question leads to different OS designs

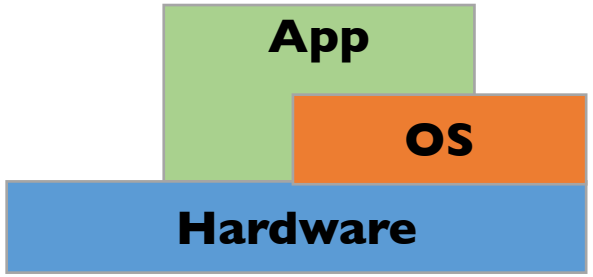
## How different are popular OSes today?




# Walk-through of OS basics

# A Primitive Operating System

**Just a library of standard services**



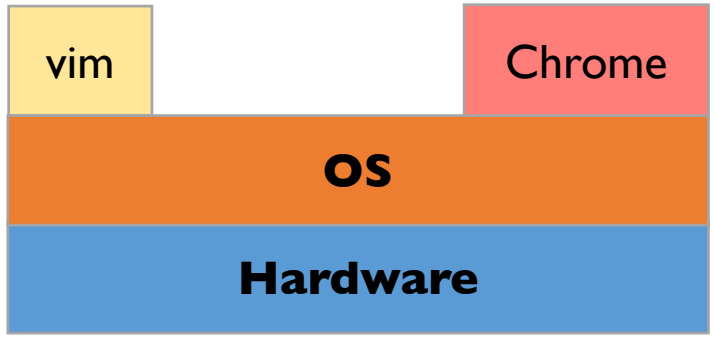

**Simplifying assumptions**

- System runs one program at a time
- No bad users or programs

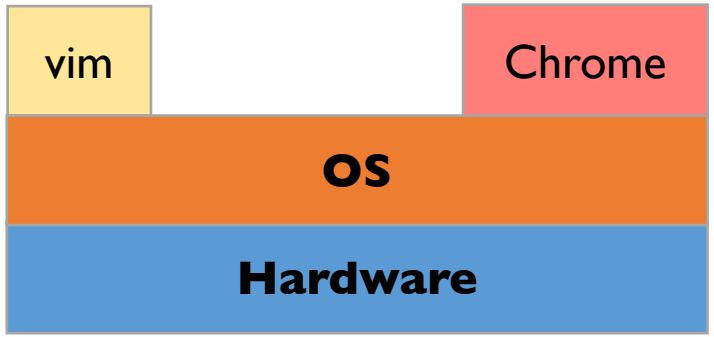
**Problems: poor utilization**

- ...of hardware (e.g., CPU idle while waiting for disk)
- ...of human user (must wait for each program to finish)

# Multitasking



# Multitasking



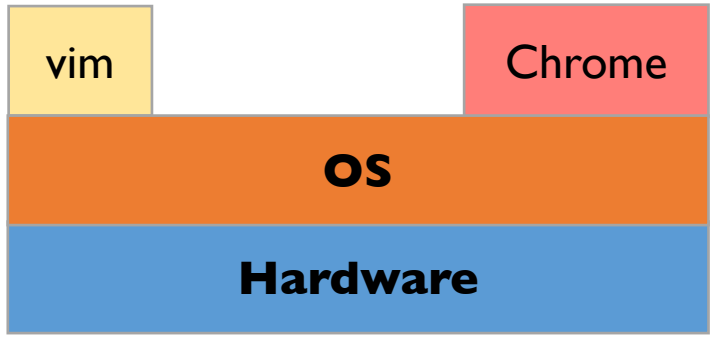

**Idea: more than one process can be running at once**

- When one process blocks (waiting for disk, network, input, etc.) run another process

**How? mechanism: context-switch**

- When one process resumes, it can continue from last execution point

# Multitasking



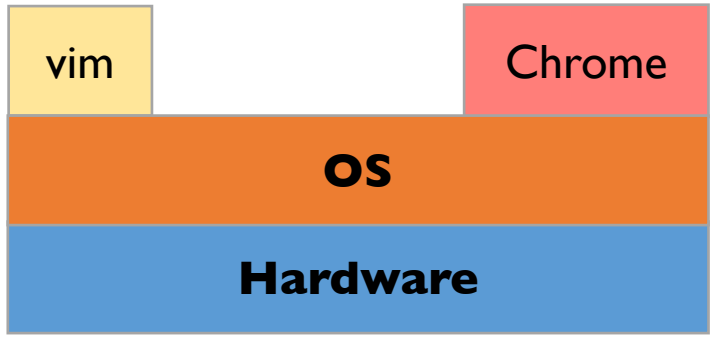

**Idea:** more than one process can be running at once

**Mechanism:** context-switch

**Problems:** ill-behaved process

- go into infinite loop and never relinquish CPU
- scribble over other processes' memory to make them fail

# Multitasking



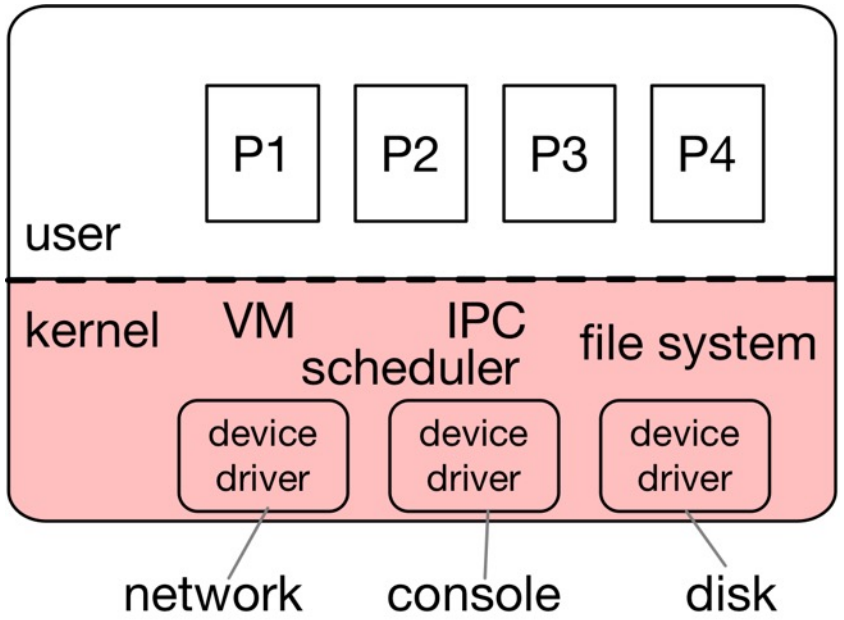

**Problems: ill-behaved process**

- go into infinite loop and never relinquish CPU
- scribble over other processes' memory to make them fail

**Solutions:**

- **scheduling**: fair sharing, take CPU away from looping process
- **virtual memory**: protect process's memory from one another

# Typical OS Structure

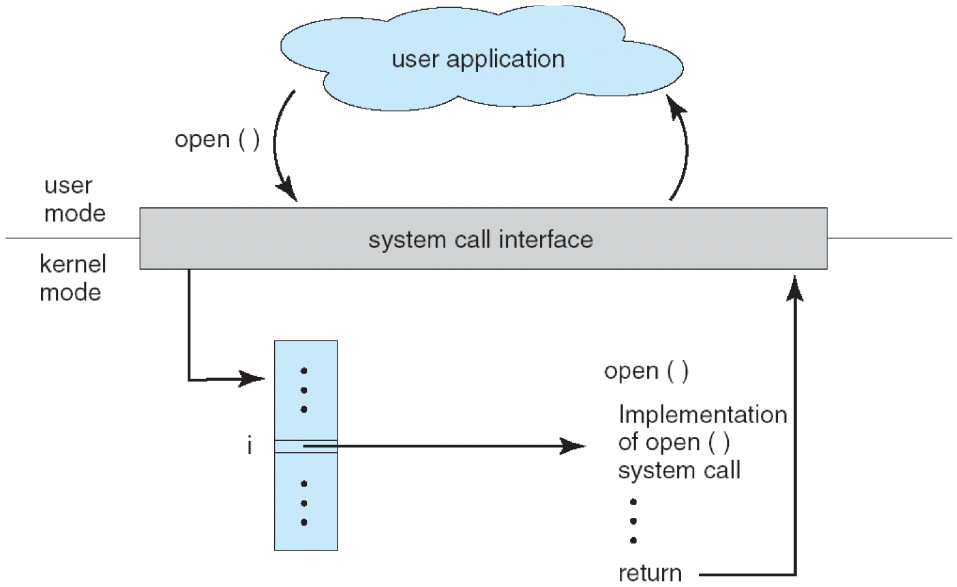



**Most software runs as user-level processes (P[1-4])**

**OS kernel runs in privileged mode (shaded)**

# System Calls

```c
#include <fcntl.h>
#include <unistd.h>
int main()
{
  int fd = open("cs318.txt", O_WRONLY | O_CREAT | O_TRUNC, 0644);
  if (fd < 0) {
    write(2, "Failed to open cs318.txt\n", 25);
    _exit(1);
  }
  write(fd, "Hello, OS!\n", 11);
  close(fd);
  return 0;
}
```




## Applications can invoke kernel through system calls

- Special instruction transfers control to kernel
- ...which dispatches to one of few hundred syscall handlers

# System Calls (continued)

**The *only* way for an application to invoke OS services**

**Goal: Do things application can't do in unprivileged mode**

- Like a library call, but into more privileged kernel code

**Kernel supplies well-defined system call interface**

- Applications set up syscall arguments and trap to kernel
- Kernel performs operation and returns result

# System Calls (continued)

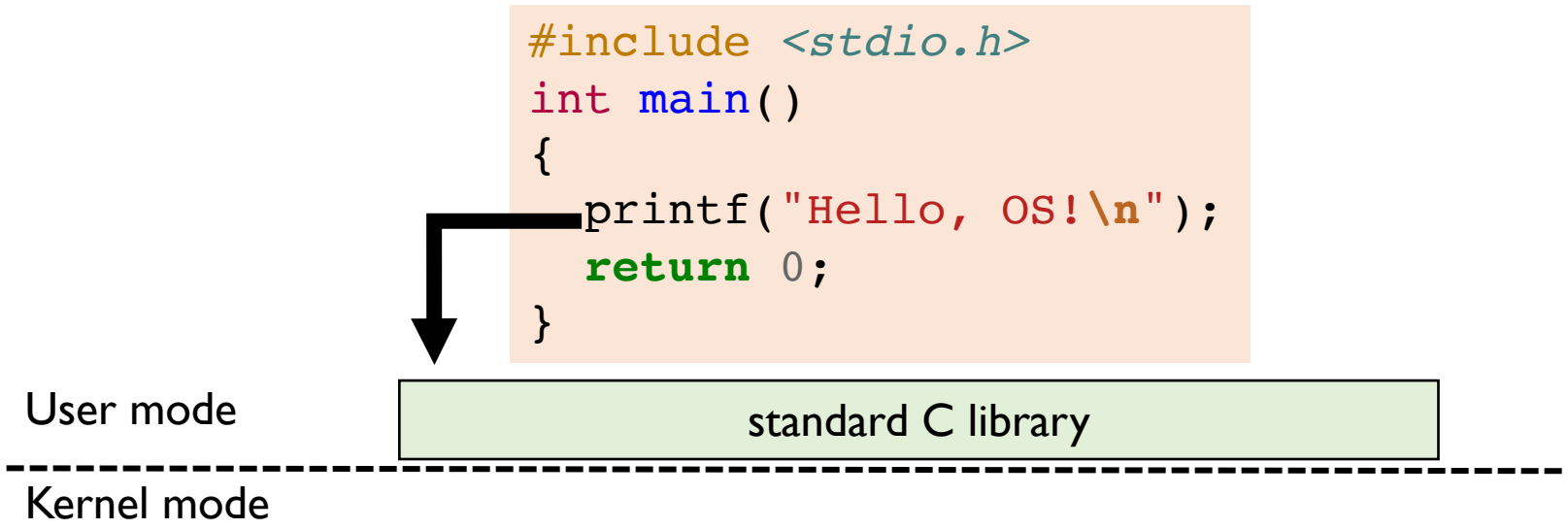
```c
#include <stdio.h>
int main()
{
  printf("Hello, OS!\n");
  return 0;
}
```

# System Calls (continued)

# System Calls (continued)

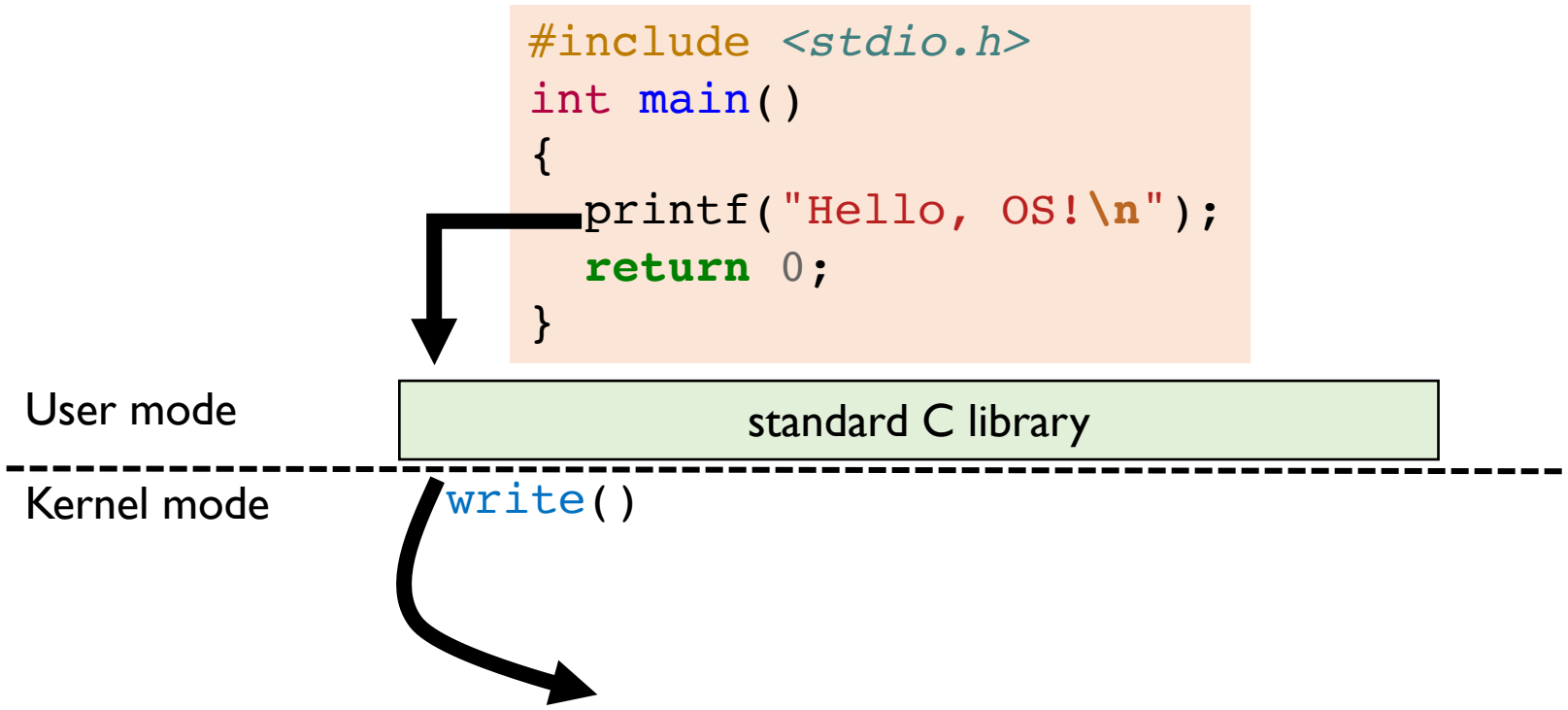

**Standard library calls are built on syscalls**

# System Calls (continued)



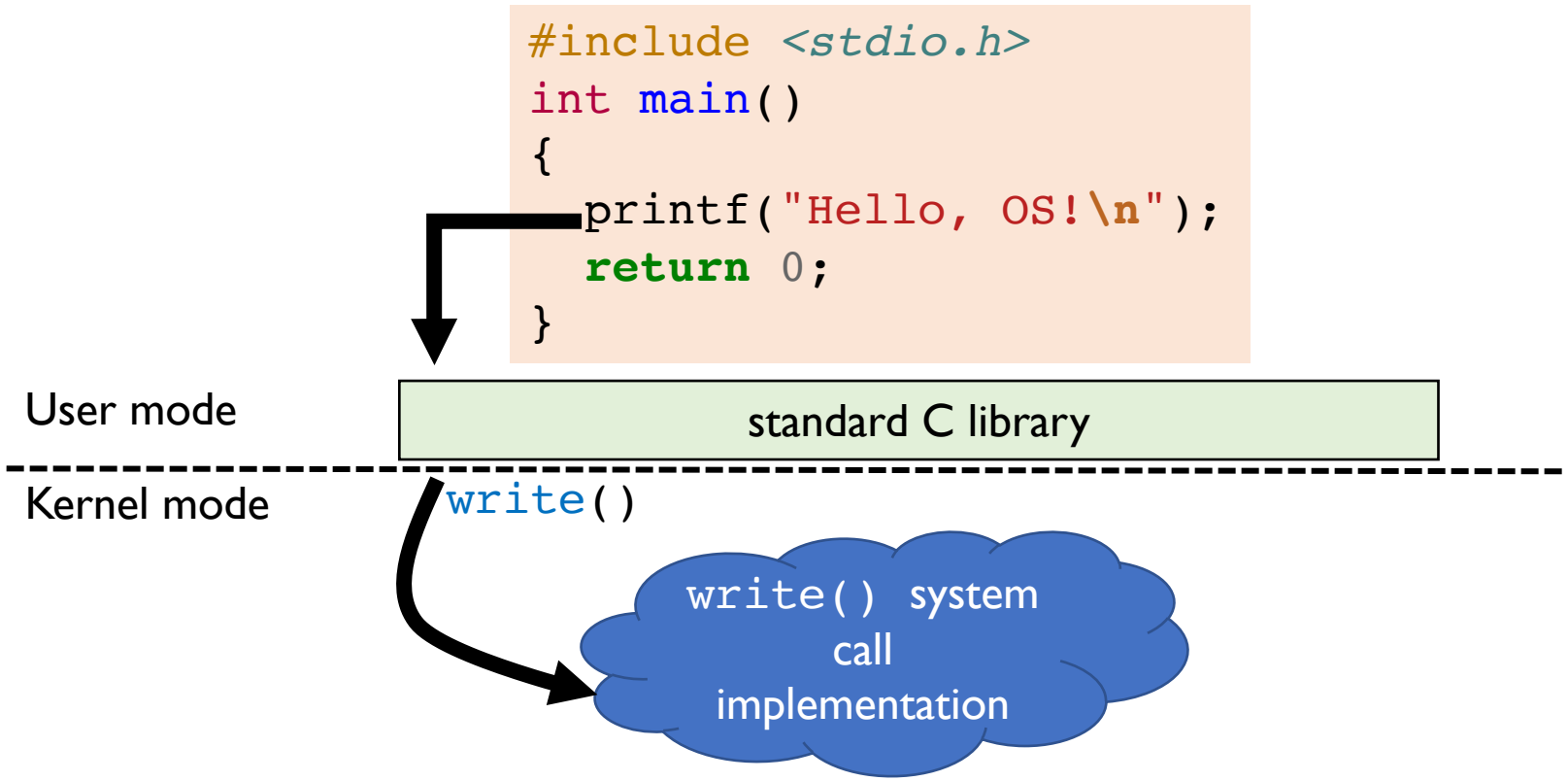

**Standard library calls are built on syscalls**

# System Calls (continued)



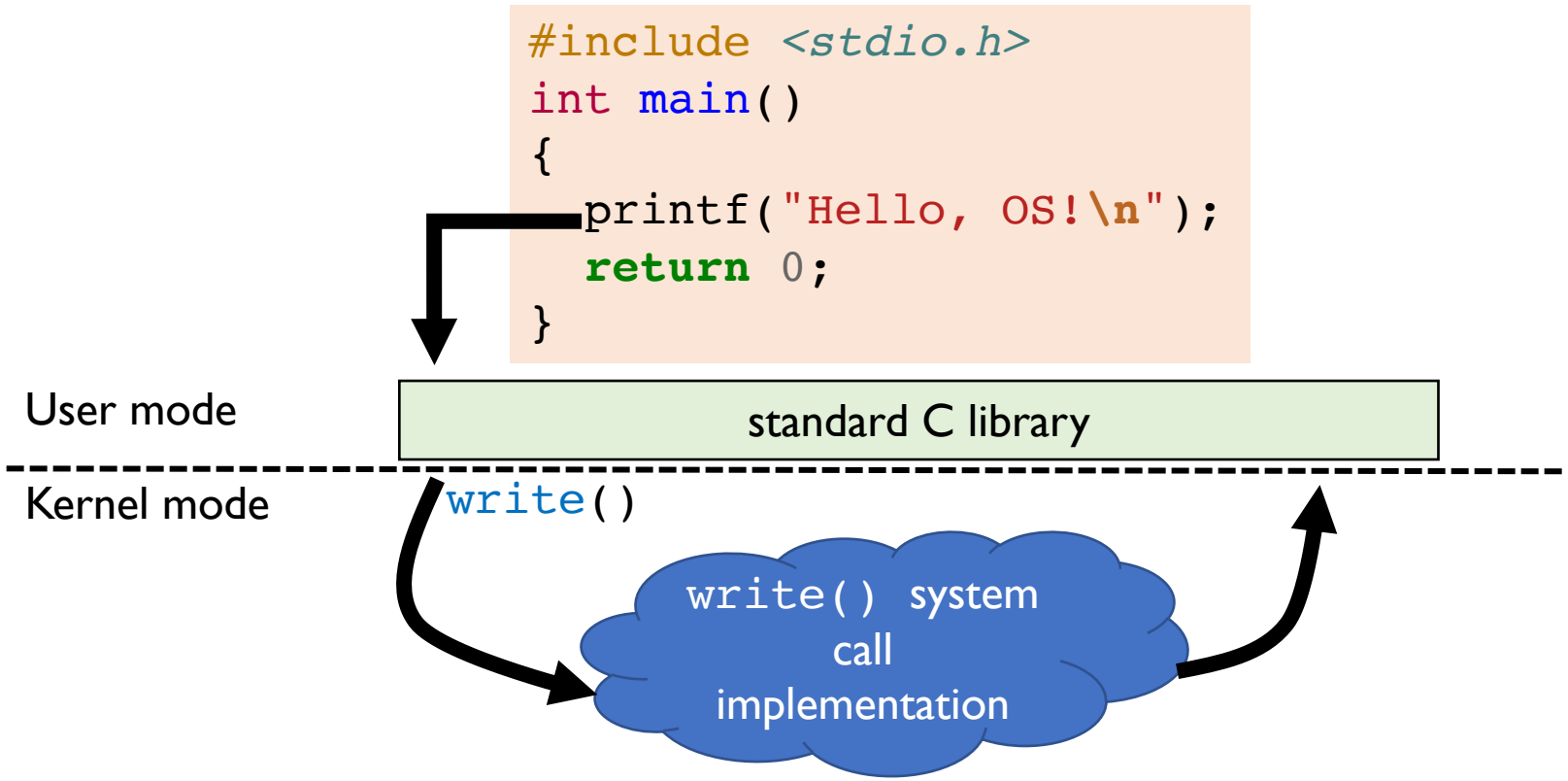

**Standard library calls are built on syscalls**

# System Calls (continued)



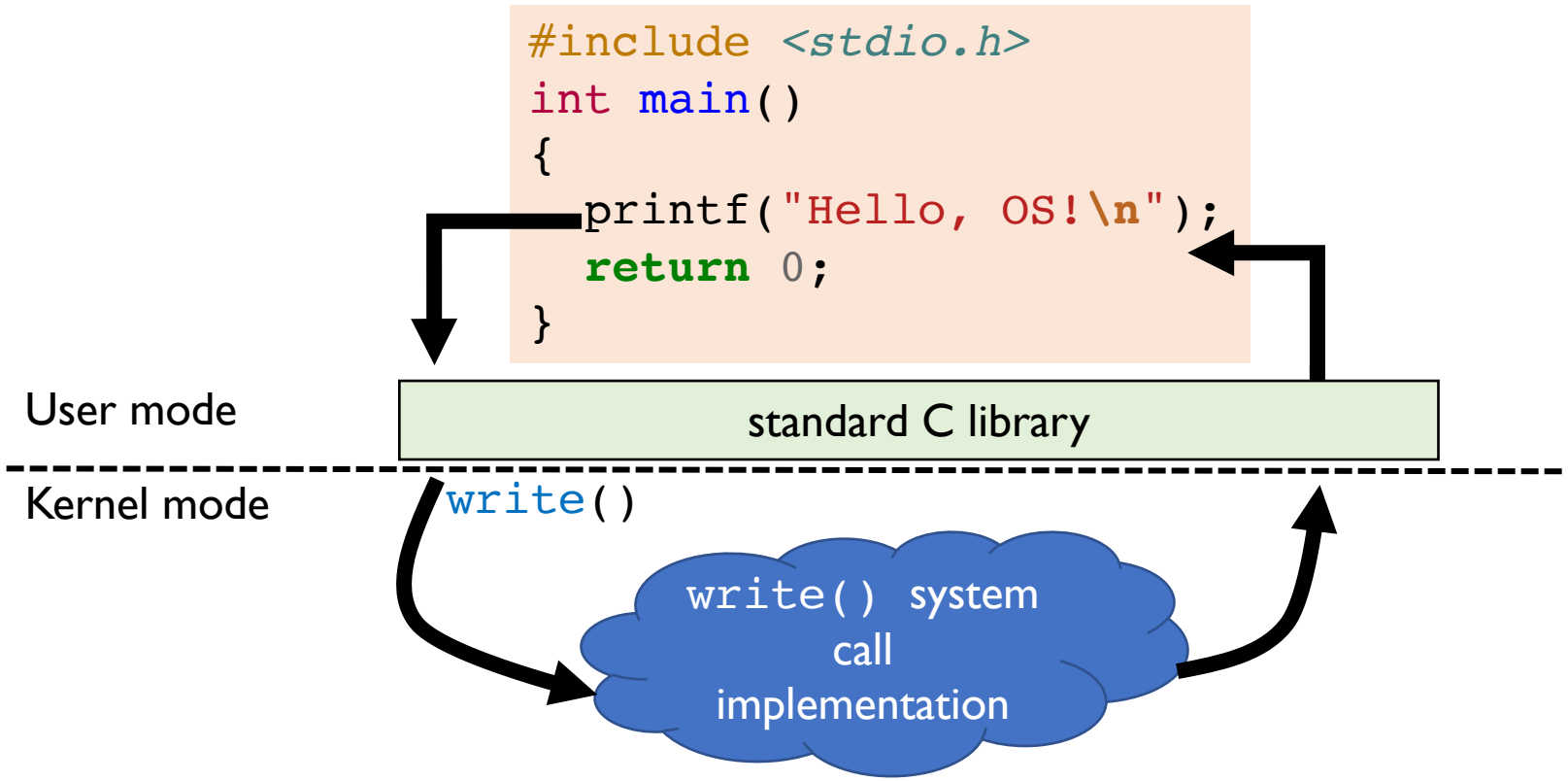

**Standard library calls are built on syscalls**

# System Calls (continued)




**Standard library calls are built on syscalls**

# System Calls (continued)




**Standard library calls are built on syscalls**

# For Next Class...

**Browse the course web**

- https://cs.jhu.edu/~huang/cs318/fall21

**Sign up on Campuswire**

**Read Chapters 1 and 2**

**Setup Pintos and read its documentation**

- **Work on Lab 0**

**Looking for project partners**

# For Next Class...

**Browse the course web**

- https://cs.jhu.edu/~huang/cs318/fall21

**Sign up on Camp**

**Read Chapters 1**

**Setup Pintos and**

- **Work on Lab**

**Looking for proje**