# CS3210: Operating Systems

Lecture 1

Instructors: Dr. Tim Andersen and Mr. Kyle Harrigan

# What is this course about?

- Continues from CS 2200 Operating Systems
- Application and Lab focused. You learn by doing in this class.
- Forces you to understand how OS's actually work in the real world (no convenient abstractions)
- UNIX/Linux focus
- May be some students' first exposure to the full x86 architecture (bootstrapping, MMU, real mode, paging, traps, etc.)

## What is this course about?

## Course Goals

- Gain a detailed knowledge of how an Operating System it built up
- Gain hands-on experience working with a real kernel
- Come away with valuable experience that can be applied to other kernels

# Who should be taking this course?

- Useful for those who want to understand systems and platforms
  - E.g., want to improve Android or contribute to Linux kernel
- Those interested in embedded systems
- Those interested low-level programming
- Those who want to write drivers and hardware abstraction layers
- Not good for students who want to work in Java, Python, or other high level software unless you are curious about what's under the hood

# Prerequisites

- C programming (strict)
- CS 2200: Systems and Networks (strict)
- CS 2110: Computer Organization and Programming (recommended)
- CS 3220: Processor Design (recommended)

```
"I'm doing a (free) operating system (just a hobby, won't be big and
professional like gnu) for 386(486) AT clones." -- Linus Torvalds
```

# What is an operating system?

e.g. OSX, Windows, Linux, FreeBSD, etc.

- What does an OS do for you?
  - **Abstract** the hardware for convenience and portability
  - **Multiplex** the hardware among multiple applications
  - **Isolate** applications to contain bugs
  - Allow **sharing** among applications

## What is an operating system?

## View: layered organization

Layers:

- **User**: applications (e.g., vi and gcc)
- **Kernel**: file system, process, etc.
- **Hardware**: CPU, mem, disk, etc.

-> **Interface** between layers

## What is an operating system?

## View: layered organization

## View: core services

Typical Core Services:

- Processes
- Memory
- File contents
- Directories and file names
- Security
- Many others: users, IPC, network, time, terminals, etc.

-> **Abstraction** for applications

# Example: system calls

- **Interface**: applications talk to an OS via system calls
- **Abstraction**: process and file descriptor

```
fd = open("out", 1);
write(fd, "hello\n", 6);
pid = fork();
```

# Why is designing OS interesting?

- Conflicting design goals and trade-offs
  - Efficient yet portable
  - Powerful yet simple
  - Isolated yet interactable
  - General yet performant
- Open problems: security and multi-core

# General information

- Web: https://tc.gtisc.gatech.edu/cs3210/2017/spring
- Piazza: https://piazza.com/gatech/spring2017/cs3210agr
- GitHub https://github.gatech.edu/cs3210-spring2017
- Text: freely available online
  - xv6: a simple, Unix-like teaching operating system
  - (optional) Linux Kernel Development

# General information

- Two instructors for this course:
  - Dr. Tim Andersen
  - Mr. Kyle Harrigan
  - Office hours: Tuesday and Thursday, 2-3 PM usually in KACB 3100
- Three TAs:
  - Meenal Maheshwari
    - Office hours: Friday, 12-1 PM in KACB 3100
  - Pranit Shah
  - Vivek Iyer
    - Office hours: Monday and Wednesday, 10-11 AM in KACB 1315

# Grading policy

- Preparation and In-Class Assignments (10%)
- 2 Quizzes (10% each = 20%)
- Lab (10% each = 50% + 10% bonus)
- Final project (20%)
    - Proposal presentation (5%)
    - Demo & presentation (10%)
    - Write-up (5%)

# Class structure

- Lecture and Demos
- Tutorial
    - Individual exercises
    - Group meeting
- Both meet in Klaus 1456, 3:05 - 4:25 PM.

Bring your laptop!

# Class structure

https://tc.gtisc.gatech.edu/cs3210/2017/spring/cal.html

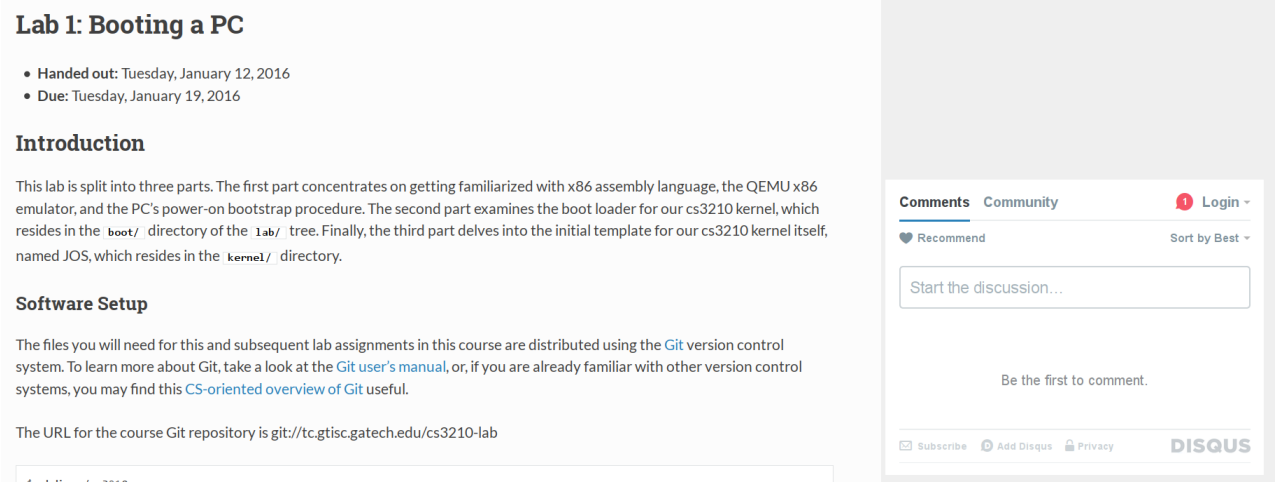
- First week:
  - Lecture: about PC, Booting, and C
  - Tutorial: tools
- NOTE: preparation questions and reading

# About labs

- A toy operating system, called JOS (exokernel)
  - Lab 1: Booting a PC
  - Lab 2: Memory management
  - Lab 3: User environments
  - Lab 4: Preemptive multitasking
  - Lab 5: File system and shell
  - Lab 6: Network driver

# About labs

- "Lab 1: Booting a PC" is out (**DUE: Jan 27**)
- Ask questions via inline comments



## Lab 1: Booting a PC

- **Handed out:** Tuesday, January 12, 2016
- **Due:** Tuesday, January 19, 2016

### Introduction

This lab is split into three parts. The first part concentrates on getting familiarized with x86 assembly language, the QEMU x86 emulator, and the PC's power-on bootstrap procedure. The second part examines the boot loader for our cs3210 kernel, which resides in the `boot/` directory of the `lab/` tree. Finally, the third part delves into the initial template for our cs3210 kernel itself, named JOS, which resides in the `kernel/` directory.

### Software Setup

The files you will need for this and subsequent lab assignments in this course are distributed using the Git version control system. To learn more about Git, take a look at the Git user's manual, or, if you are already familiar with other version control systems, you may find this CS-oriented overview of Git useful.

The URL for the course Git repository is git://tc.gtisc.gatech.edu/cs3210-lab

# Lab Policies

- Labs build on each other. Important to have labs working completely to do later labs.
- Each lab has challenge questions (5%) and regular questions (2%). That need to be written and turned in with code.
- Labs are commited, tagged, and pushed to a GitHub repo for grading. Please don't email labs. If it's not committed, it will not be graded.
- We are using a Vagrant Trusty32-based configuration on VirtualBox as our official configuration.
    - Pull this file from the GitHub
    - Use another VM at your own risk.
- Each student has assigned GATech GitHub repos for turning in labs and other assignments. Only these will be used for grading.
- Best to commit and push daily -- also best way to share code with the instructors and TAs is GitHub.

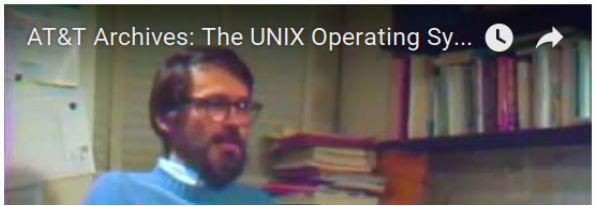
# About quiz, project

- Two "quizzes" (in-class, about lec/tut/lab)
  - 80 minutes
- Final project
  - Team project on a topic of your choosing (with approval of instructors)
  - No more than 4 students per team
  - On scale of Lab 6 (Bonus project only this semester)
  - https://tc.gtisc.gatech.edu/cs3210/2017/spring/proj.html
  - Pre-proposal, Team proposal, Demo day, Write-up

# About preparation questions and in-class assignments

- Every lecture and tutorial ([[DUE: by 3:04 PM on class day]])
- In-class assignments are due a week from the class day at midnight.
- No late prep questions or in-class submissions accepted.
- Must be turned in on the prep GitHub (https://github.gatech.edu/cs3210-spring2017/cs3210-prep-YOUR-USERNAME.git) by the due date/time.

**Question for Lecture 3 (lec3.txt)**



# Class policy

- Late days
  - [[Five]] days of grace period can be used on one lab deadline (except bonus lab)
  - Grace period is for non-official emergencies (job interviews, broken laptops, etc.)
  - Labs incur 10% per day late penalty otherwise
  - Repeat submissions are allowed (can incur late penalties)
- No cheating
  - Cheating vs. collaboration
  - Write the name(s) of your sources

See, https://tc.gtisc.gatech.edu/cs3210/2017/spring/info.html

# Equipment

- A laptop or other computer is required for this course.
    - Must be able to install the necessary software on it (VirtualBox, QEMU, etc.)
- Let us know in advance if this is a problem.

# Today's agenda

- What is an operating system?
  - Design
  - Goal
  - Role
  - Example: xv6 and JOS
  - Lab Overview

# Challenges in operating systems

- Portability
- Performance
- Reliability
- Security

# Challenges in (practical) operating systems

e.g. Mac OSX, Windows, Linux

- Legacy (compatibility)
- Implementation
- Business

# About "compatibility"

- https://lkml.org/lkml/2012/3/8/495

  Seriously. Binary compatibility is *so* important that I do not want to have anything to do with kernel developers who don't understand that importance. If you continue to pooh-pooh the issue, you only show yourself to be unreliable. Don't do it. -- Linus

# CS3210: JOS and xv6

- Micro-kernel: JOS (exokernel)
- Monolithic: xv6 (UNIX-like)
  - Book: Xv6, a simple Unix-like teaching operating system
  - Code: commentary

```
$ git clone git://github.com/mit-pdos/xv6-public.git
```

# xv6

What is xv6?

- A re-implementation of Unix Version 6 (1970's era OS)
- Big enough to illustrate concepts, small enough to digest in one semester
- Used as a reference implementation for studying concrete implementations of core concepts
- Why not study Linux?
  - xv6 - 6000 lines
  - Linux v4 (kernel only) - ~165,000 lines!

xv6

JOS

# What is JOS?

- A basic teaching operating system
- Provides a skeleton for implementing the labs, with key pieces left out for you to implement
- Major parts of operating system you will build in JOS
  - Booting
  - Memory management
  - User environments
  - Preemptive multitasking
  - File system, spawn, and shell
  - Network driver
  - Open-ended project
- Resulting operating system will run under QEMU, or any x86-based personal computer

# Lab 1 - Booting

- Review x86 assembly
- Boot JOS for the first time under QEMU, familiarize with debugger
- Learn / review physical address space during bootup / real mode
- Step through bootup in gdb
- Learn segmentation basics
- Understanding boot loader
- Learn about ELF binary format

- Observe and understand transition from real mode to protected mode
- Become familiar with C calling conventions by implementing your own backtrace

Lab 1

Lab 2

# Lab 2 - Memory Management

- Kernel physical page management
  - Write the physical page allocator (and deallocator…)
- Virtual memory
  - Understand virtual, linear, and physical addresses
  - Implement reference counting, page table management
  - Permissions and fault isolation
  - Initialize kernel address space

Lab 1

Lab 2

Lab 3

# Lab 3 - User Environments

- Basics of getting a "process" running
  - In JOS terminology this is an "environment"
- Allocating, creating, and running environments
- Basic exception and system call handling
  - Interrupt Descriptor Table
  - Task State Segment
  - Trap Frames
  - Page faults, breakpoints, system calls

Lab 1

Lab 2

Lab 3

Lab 4

# Lab 4 - Preemptive Multitasking

- Part A - Add multiprocessor support
  - Round-robin scheduling
  - Environment management
- Part B - Implement fork()
- Part C - Add Inter-Process Communication
  - Also hardware clock interrupts and preemption

Lab 1

Lab 2

Lab 3

Lab 4

Lab 5

# Lab 5 - File system and shell

- Load and run on-disk executables
- Be able to run a shell on the console
- Build a simple read/write file system

Lab 1

Lab 2

Lab 3

Lab 4

Lab 5

Lab 6

# Lab 6 - Network Driver (optional)

- Build a network stack
- Understand QEMU virtual network
- E1000 emulated card
  - PCI Interface
  - Memory-mapped I/O
  - DMA
- Transmitting and receiving packets

# Tools

- The toolchain setup is critical up-front work for this class
  - We will help you in the first tutorial (Thurs)
  - You can develop on whatever you want, and use whatever you want, but our standardized environment and tools will be used for grading. You have been warned (again).

# QEMU - Quick EMUlator

- Performs hardware virtualization
- Can emulate obscure processor architectures
- Does share code with some other projects (VirtualBox)
- Good for working with the kernel (GDB stub)
    - We will use it for this

# git - the stupid content tracker

- Created by Linus Torvalds in 2005 for development of the Linux kernel
- Of course, widely used now
- All of our configuration management, assignment turn-in, etc. will be done using git.
- Commit early, commit often, push often!
  - We can help you better if we can see your code
  - We can grant you partial credit if you miss deadlines
- It is very easy for us to compare work across students
  - Don't cheat!

# gdb - GNU project debugger

- Hopefully you have experience...
- You may be exposed to some new features of gdb
  - Kernel / Remote debugging
  - QEMU
  - Esoteric (but useful) commands
- This isn't an IDE (though the TUI is close)

# Vagrant

"Create and configure lightweight, reproducible, and portable development environments"

- A convenient front-end to provide reproducible virtual machines
- Easily hooks into Virtualbox, Parallels, VMWare, etc.
- Our vagrant instance on github.gatech.edu will be the de-facto machine for grading
    - Test with it before and after tagging your submissions!

# Why using C for OS development?

- Portability
- No runtime
- Direct hardware/memory access
- (decent) Usability

# How are your C skills?

- C is the most important skill to have for this class
- OS programming involves a great deal of pointer arithmetic. The compiler will not save you from these mistakes.
- If your C skills are rusty, you may stuggle with the lab work.
- Labs deadlines come quickly. Little time to build basic skills.

# Prep quiz: the C programming language

- Open your laptop
- https://tc.gtisc.gatech.edu/cs3210/2017/spring/q/prep.txt
- Download the quiz
- Please submit to GitHub by 1 week from today (Jan 17 before midnight).

# Self evaluation

- < 11/21 (50%): shall we meet next year in cs3210?
- < 15/21 (70%): do you have enough time to catch up?

First two tutorials (Jan 12/Jan 19) will cover in-depth Tools and C/gdb!

# Next lecture

- Tutorial: Group, Tools, Lab1
- Register Piazza
- Lab 1: Booting a PC is out ([[DUE: 11:59 PM, Jan 27]])
- Don't forget to submit "preparation question" ([[DUE: 3:04 PM, Jan 12]])

# References


- UW CSE 451
- OSPP
- MIT 6.828
- Wikipedia
- The Internet