CS-3013 — Operating Systems

Professor Hugh C. Lauer
CS-3013 — Operating Systems

(Slides include copyright materials from *Operating Systems: Three Easy Step*, by Remzi and Andrea Arpaci-Dusseau, from *Modern Operating Systems*, by Andrew S. Tanenbaum, 3rd edition, and from other sources)

Outline for Today

- **Details and logistics of this course**
- **Discussion**
  - What is an Operating System?
  - What every student should know about them
- **Project Assignment**
    - Virtual machines
    - Building Linux kernel
    - Adding a system call
- **Introduction to Concurrency**

This course

- **Two sections:–**
  - Section C01 meets at 9:00-11:00 AM Tuesdays and Fridays — Prof. Walls
  - Section C02 (this section) meets at noon-2:00 PM Tuesdays and Fridays — Prof. Lauer
- **Different Lectures and quizzes!**
- **Identical programming projects and schedules**
  - Shared website on *InstructAssist*
  - Same textbook, etc.

This Course & Section (continued)

- **Two 2-hour classes per week**
    - noon – 2:00 PM, Tuesdays and Fridays
    - January 12 – March 2, 2018
  - No class on Friday, February 23, 2018
    - “Reading Day” (or make-up day for closures)
- **Very similar to first half of CS-502**
    - First graduate course in Operating Systems
- **Concentrated reading and project work**

Concentrated reading and project work

- **Students often report that this is their hardest CS course at WPI (so far).**
  - The programming is demanding (even though not many lines of code)
  - *C* language is unforgiving (costing you many hours of frustration)
  - If you wait till a day or two before an assignment is due, you have *very* little chance to complete it

This Course & Section

Parts of course web site are protected in order to comply with copyright regulations

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- **Very similar to first half of CS-502**
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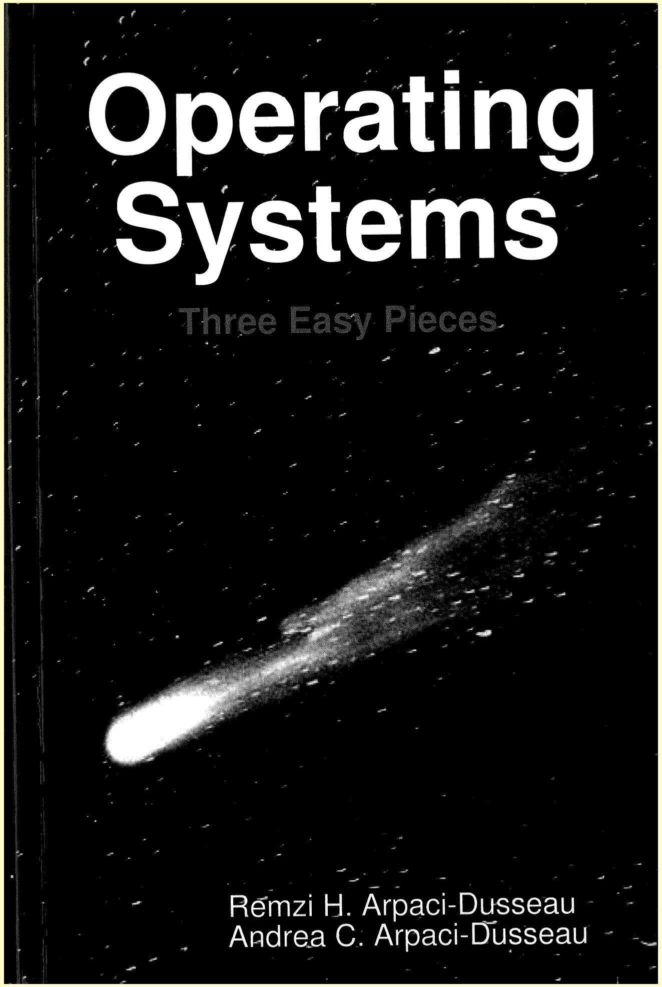
- **Course web site — on *InstructAssist***
  - *https://ia.wpi.edu/cs3013/*

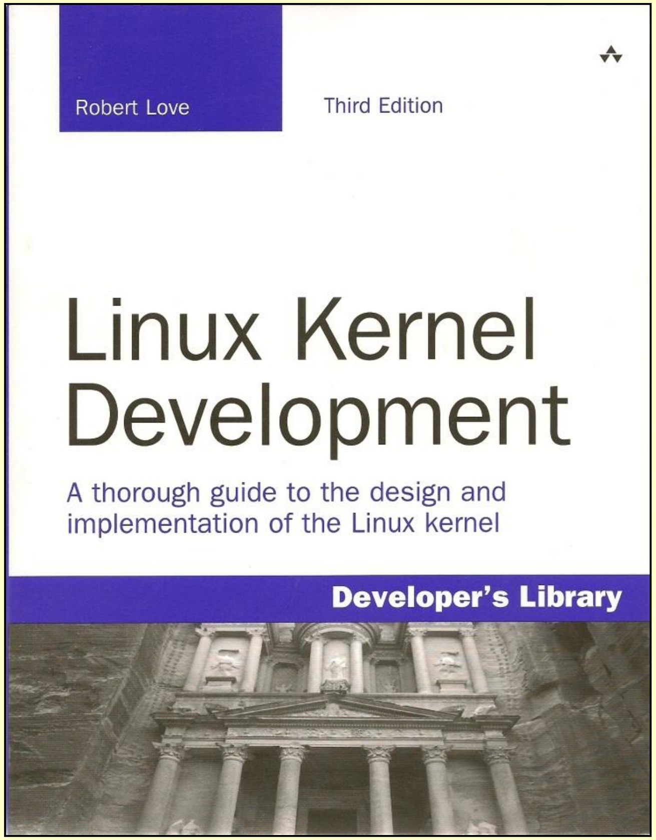
Textbooks

Free (or cheap) online
Printed copy for about $21

Very useful if you plan to do serious work in Linux

A.k.a OSTEP




Robert Love
Third Edition
Linux Kernel Development
A thorough guide to the design and implementation of the Linux kernel
Developer's Library

Recommended Background

- **Computer Programming:–**
  - *C*/*C*++ programming
    - Especially a low-level language such as *C*
    - *CS-2301* or *CS-2303*
  - Data structures
    - Linked lists
  - Computer Organization and Assembly Language
    - CS-2011 (Useful)
  - Unix/Linux user experience
    - Very Useful

C Programming Language

- **Almost *all* difficulties that students have in this course go back to the *C* language**
  - Insufficient preparation and understanding
  - Especially modules and include files
  - **`printf()`** formats of data types
  - **`static`** versus global variables

  - Lack of experience with debugger

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- **Computer Programming:–**
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    - Especially a low-level language such as *C*
    - *CS-2301* or *CS-2303*
  - Data structures
    - Linked lists

- ***Reading assignment***
  - OSTEP Chapters 1&2
  - Quiz on Friday, January 19!

Schedule & Logistics — Section C02

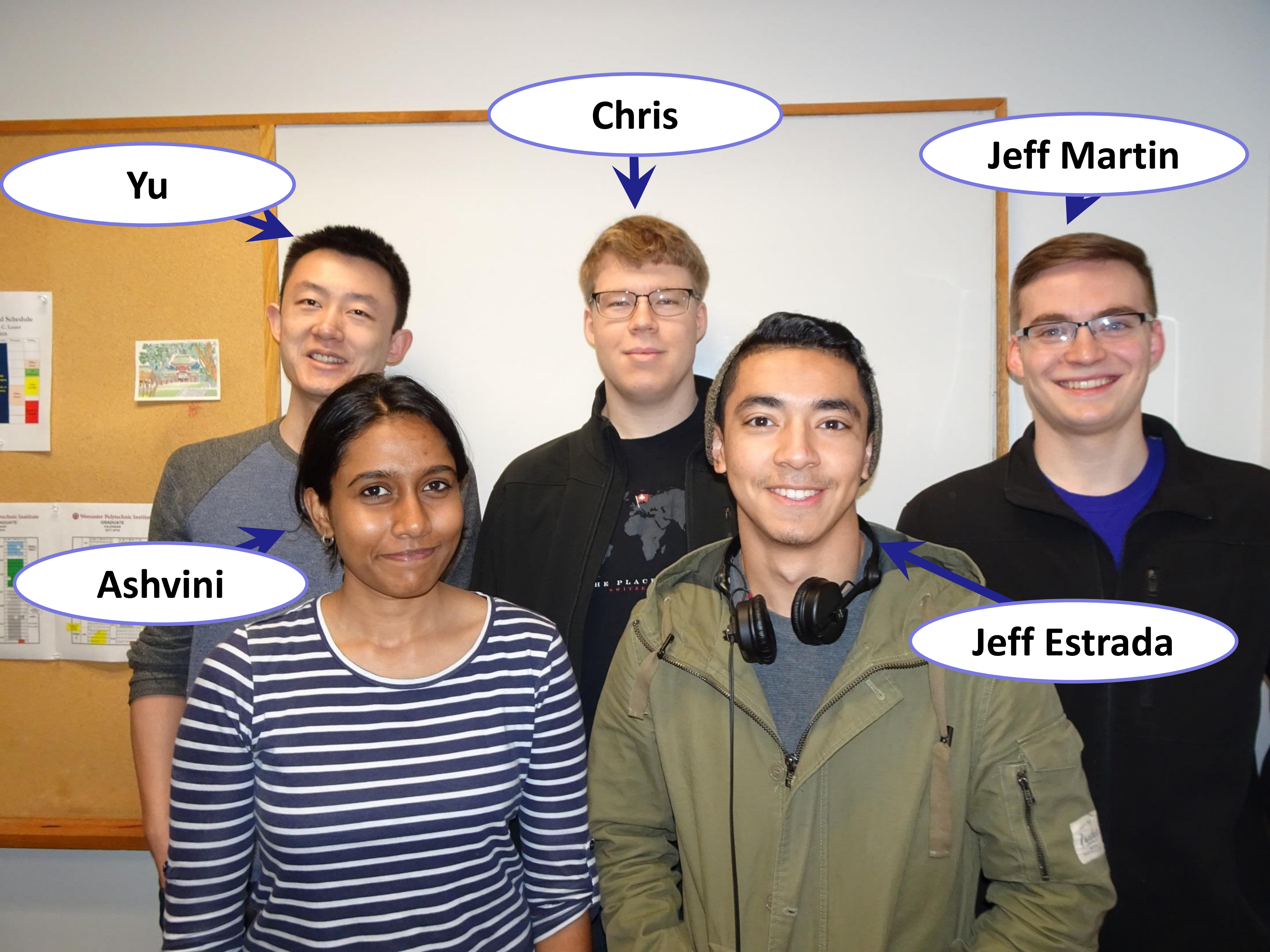
- **Schedule**
  - Classroom:– Kaven 116
  - noon – 2:00 PM, Tuesdays and Fridays
  - One 5 minute break
  - 14 classes
- **~ 4.5 Programming Projects**
  - 1-1.5 weeks each
- **Weekly quizzes**
  - Friday's at start of class

- **Mobile Phones, pagers and other similar devices SILENT during class**
- **Prof's Office Hours**
  - By appointment, *or*
  - See IA or chart by door
  - Office:– Fuller 144
- **Contact**
  - **lauer in the domain wpi.edu**
- **Course e-mail list**
  - **cs3013-all (in domain cs.wpi.edu)**
  - **cs3013-staff (Prof & TAs)**

Assistants

- **Graduate TAs**
  - Yu Liu
  - Ashvini Varatharaj
- **Undergraduate SAs**
  - Jeffrey Estrada
  - Jeffrey Martin
  - Christopher Myers

Office hours in Zoo Lab – i.e., Fuller A21


Yu
Chris
Jeff Martin
Ashvini
Jeff Estrada

Lecture Capture – Section C02

- **Lectures (voice and slides) will be captured automatically**

- **Can be viewed at**

https://echo360.org/section/99afb70b-f55c-41d2-9266-ed069c280ba2/public

- **Link is also on InstructAssist**
  - Lessons > Lecture Capture

Please remind me *every class* to turn on microphone!

Weekly Quizzes

Quiz portion of grade based on sum of four highest numerical quiz grades out of 100

- **One quiz each week in Section C02**

Friday, Jan 19	Friday, Feb 9
Friday, Jan 26	Friday, Feb 16
Friday, Feb 2	Friday, Mar 2

No makeup quizzes!

No quiz Feb 23 unless it is a make-up day due to WPI closure

- **20 minutes each**
  - Except 50 minutes on March 2
- **No final exam!**
  - *Must take March 2 quiz to pass course*
  - *Skipping March2 is equivalent to asking for an NR*

Open book, open notes

May use electronic books

May *not* access the Web or any online site!

Projects

- Install Virtual Machine, build Linux kernel, add Linux Kernel Module

1. *Midday commander* — learn how to create and manage processes
2. Adding functionality to Linux Kernel
3. Serious multithreaded application
4. Virtual Memory simulation

Grading

- **Grading**
  - Quizzes ~ 45%
  - Projects ~ 45%
  - Class participation ~ 10%

- **Good-faith attempt & submission of all projects *required* to pass this course!**

WPI Academic Honesty Policy

http://www.wpi.edu/Pubs/Policies/Honesty/policy.html

More on Prerequisites

- **C programming is essential**
  - Java-only programmers will find it very challenging
- **Time required**
  - 17+ hours per week, 7 weeks total
- **Computing resources required**
  - Modern PC or Mac with > 20 gigabytes of free disk space
  - Preferably dual- or quad-core
  - Ability to install Virtual Box

OR

  - Zoo Lab (with do-it-yourself storage)

Ground Rule

- There are no “stupid” questions.
- It is a waste of your time and the class’s time to proceed when you don’t understand the basic terms.
- If you don’t understand it, someone else probably doesn’t, either.

Ground Rule #2

- **Help each other!**
- **Even if a project or assignment is specified as *individual*, ask your colleagues about stuff you don’t understand.**
- **It is a waste of your time try to figure out some obscure detail on your own when there are lots of resources around.**
- **When you have the answer, *write it in your own words* (or own coding style)**

A Proverb

Lesson:– We don’t have a lot of patience with students who come to us on the day before a project is due and look for help in getting started!

Questions?

Teaching staff

My third career!

Hugh C. Lauer
Teaching Professor

Office hours:–	Tue 10:00 – 11:00 AM
	Thurs 1:00 – 3:00 PM
	Fri 10:00 – 11:00 AM

- Ph. D. Carnegie-Mellon, 1972-73
  - Dissertation “Correctness in Operating Systems”
- Faculty at University of Newcastle upon Tyne, UK
- Approximately 30 years in industry in USA
- WPI since 2006
- 21 US patents issued
- 2 seminal contributions to Computer Science

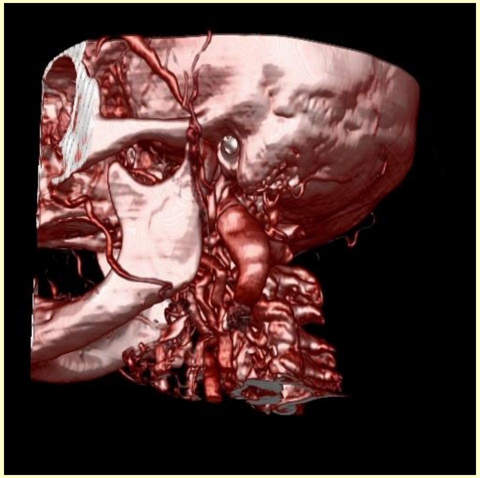
Systems Experience

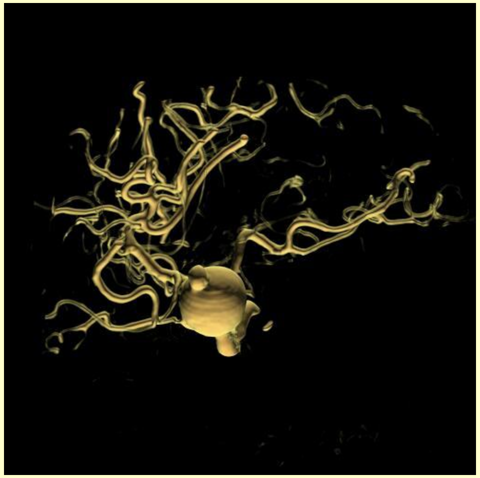
- IBM Corporation
- University of Newcastle
- Systems Development Corporation
- Xerox Corporation (Palo Alto)
- Software Arts, Inc.
- Apollo Computer
- Eastman Kodak Company
- Mitsubishi Electric Research Labs (MERL)
- Real-Time Visualization
    - Founded and spun out from MERL
    - Acquired by TeraRecon, Inc.
- SensAble Technologies, Inc.
- Dimensions Imaging, Inc. (recent start-up, now defunct)

VolumePro™

- **Interactive volume rendering of 3D data such as**
  - MRI scans
  - CT scans
  - Seismic scans
- **Two generations of ASICs, boards, software**
  - VolumePro 500 – 1999
  - VolumePro 1000 – 2001
- **CTO, Chief Architect of VolumePro 1000**
  - 7.5-million gate, high-performance ASIC
  - 10^9 Phong-illuminated samples per second
  - Install in all Siemens CT scanners worldwide!

Sample images from VolumePro™





Operating Systems I Have Known

- IBSYS (IBM 7090)
- OS/360 (IBM 360)
- TSS/360 (360 mod 67)
- Michigan Terminal System (MTS)
- CP/CMS & VM 370
- MULTICS (GE 645)
- Alto (Xerox PARC)
- *Pilot (Xerox STAR)*
- CP/M
- MACH
- *Apollo DOMAIN*
- Unix (System V & BSD)
- Apple Mac (v.1 – v.9)
- MS-DOS
- Windows NT, 2000, XP, Vista, 7, etc.
- various embedded systems
- Linux
- …

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- Discussion
  - What is an Operating System?
  - What every student should know about them
- Project Assignment
    - Virtual Machines
- Introduction to Concurrency

Class Photos

Class Discussion

What is an Operating System?

(Laptops closed, please!)

What is an Operating System?

- **Characteristics**
  - Large, complex set of programs
  - Long-lived, evolutionary
  - Worked on by many people over many years

- **Functions**
  - Creates *abstractions*
  - Multiplexes concurrent activities
  - Manages resources
  - Mediates access to hardware devices
  - Provides a variety of services to users and applications
  - …

Definition – *Abstraction*

- The distillation of a complex mechanism into a simple, conceptual model
- *User* of abstraction does not need to worry about details
- *Implementer* of abstraction does not need to worry about how user will use it (within limits)

Abstraction

The most important word in this course!

The textbook uses *Virtualization* to mean approximately what we mean by *Abstraction*

What is an operating system? (continued)

- ***Abstractions:–***
  - *Processes, threads*, and concurrent computation
  - *Virtual memory.* For managing memory
  - *Files*. Persistent storage of information
  - *Sockets & connections* for network communication
- **Controls I/O & peripherals**
- **Implements security and accessibility**

- **See §1.1 of Tanenbaum**
- **Definition — Same as judicial definition of pornography**
- **“I cannot define it, but I sure can recognize one when I see it!”**

OS and Hardware

- **OS mediates programs' access to hardware**
  - Computation – CPU
  - Storage – volatile (memory) and persistent (disk)
  - Networks – NIC, protocols
  - I/O devices – sound cards, keyboards, displays
- **OS creates uniform abstractions**
  - Processes
  - Files
  - Sockets
  - Streams

Operating Systems – a Study of Evolution

- Simple managing of time of expensive computers
- Managing concurrency between I/O and computation

  … and users

  … and applications
- Managing memory
- Managing files, communication, GUIs
- Creating abstractions for all of the above
- … and more!

What should every student of the Computational Sciences know about Operating Systems?

- Processes, threads, concurrent computation, & how to use them
- Memory Management, fragmentation, allocation, and virtual memory
- Files, persistent storage, and what they can do for you
- Protection, authentication, and what are those silly little keys they ask us about
- Different kinds of operating systems and what they are good for

All of these are embodied in the Course Outcomes

http://web.cs.wpi.edu/~cs3013/c18/Outcomes.htm

Questions or Comments?

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  - What is an Operating System?
  - What every student should know about them
- **Project Assignment**
  - Virtual Machines
- Introduction to Concurrency

More about Programming Projects

- **Project work based on *Ubuntu 16.04.3 LTS***
  - *"LTS" = Long-Term Support*

- **Each student will use a "virtual machine"**
  - What is a virtual machine?
  - A:– a program with enough power and performance to mimic a physical computer
  - See *Setting up your Virtual Machine* (docx, pdf)

- **Build, modify, install Linux kernel on your virtual machine**
  - Debug, analyze, crash
  - Restore, try again

Using a Virtual Machine

- Use *VirtualBox* on your own PC or Macintosh

- Any other virtualization platform
  - You are on your own for support!

- Zoo Lab
  - See Professor if you need it!

What is a *Virtual Machine?*

- **An application that simulates a computer system with enough performance and fidelity to mimic actual hardware**

- **Concept originated in 1960s, and had been used occasionally in large systems**

- **Established in mainstream of enterprise systems by *VMware* in early 2000s**
  - By 2012, a many high quality virtualization systems were available
  - VirtualBox is virtualization system of choice at WPI

Virtual Machine Definitions

- ***Host* system:– The hardware and operating system that supports the virtualization application**
  - E.g., your own or company PC or Mac
  - E.g., a departmental server

- ***Guest* system:– The virtual hardware and the operating system that is being simulated**
  - E.g., *Ubuntu 16.04.3* LTS for this course

Questions?

Before the Break

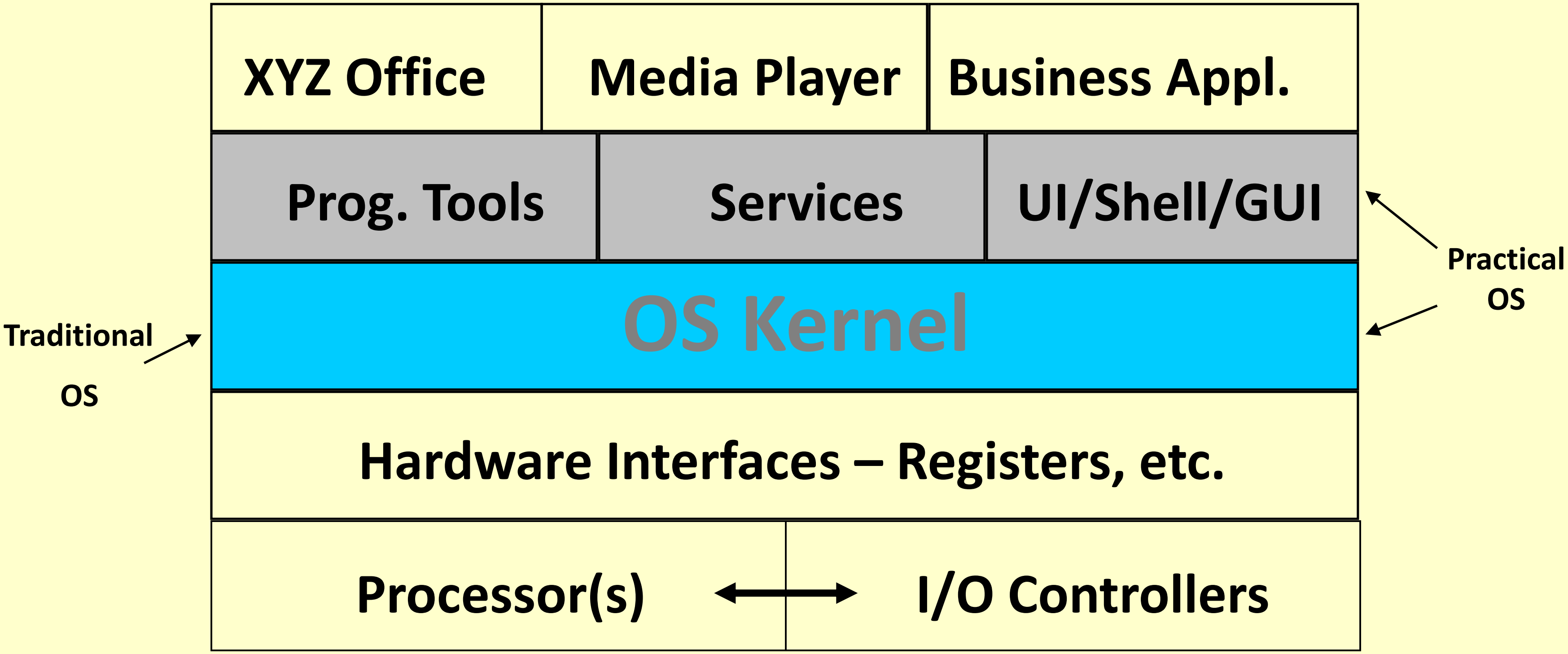
- **Photos**
  - To help me learn your names!

- **Survey**
  - To help me understand your background

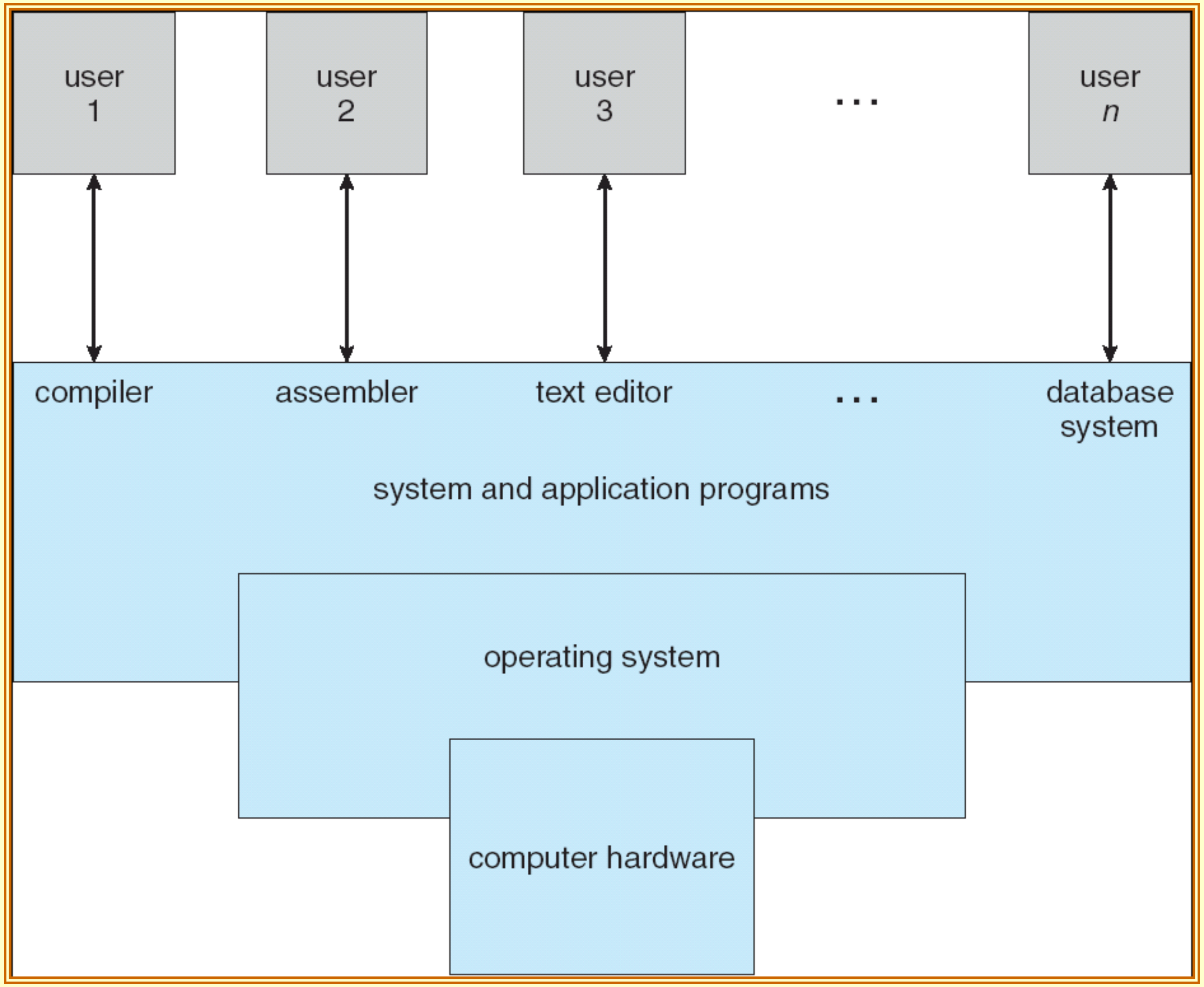
Short Break

(Not enough time to go to Campus Center for coffee!)

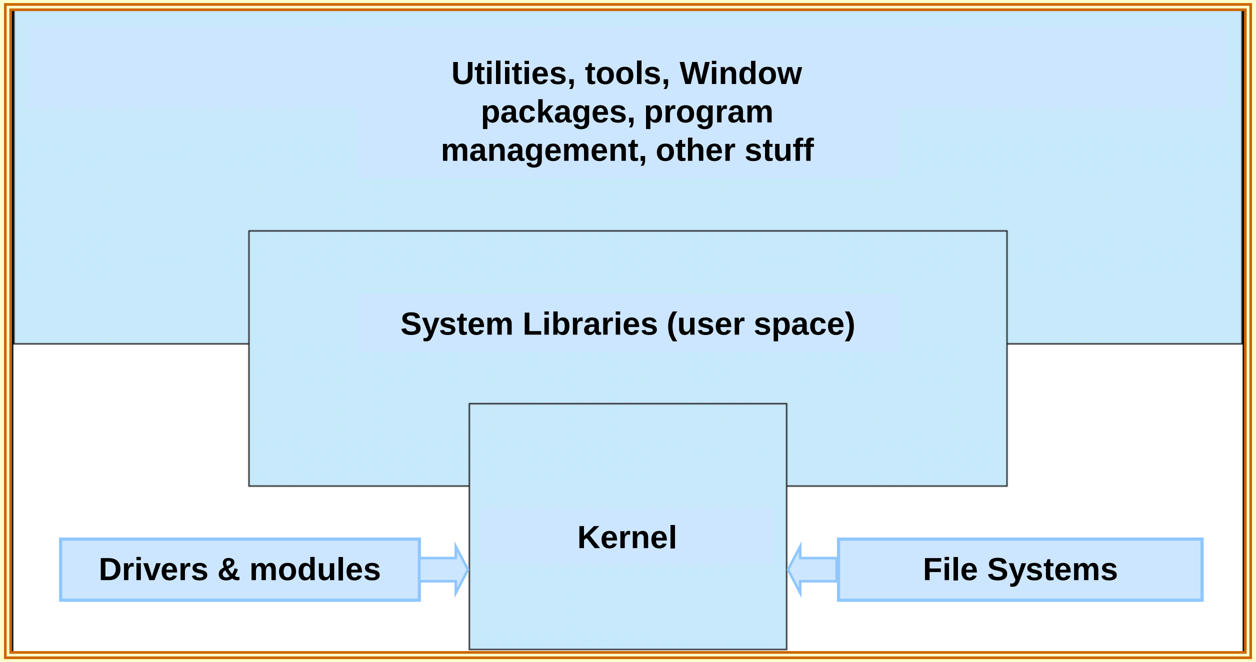
What is an Operating System?



Computer System Organization



Operating System Organization


Utilities, tools, Window packages, program management, other stuff
System Libraries (user space)
Kernel
Drivers & modules
File Systems

Major Topics in Traditional OS Courses

- structure: how is the OS organized?
- sharing: how are resources shared across users?
- naming: how are resources named (by users or programs)?
- security: how is the integrity of the OS and its resources ensured?
- protection: how is one user/program protected from another?
- performance: how do we make it all go fast?
- reliability: what happens if something goes wrong – hardware or software
- extensibility: can we add new features?
- communication: how do programs exchange information
- concurrency: how are parallel activities created and controlled?
- scale: what happens as demands or resources increase?
- persistence: how do you make data last longer than program executions?
- distribution: how do multiple computers interact with each other?
- accounting: how do we keep track of resource usage, and charge for it?

- *Is user interface package part of operating system?*

Kinds of operating systems

- Mainframe Operating Systems
- Server Operating Systems
- Multiprocessor Operating Systems
- Personal Computer Operating Systems
- Handheld Computer Operating Systems
- Embedded Operating Systems
- Sensor Node Operating Systems
- Real-time Operating Systems
- Smart-card Operating Systems
- …

Some Important Operating Systems

- **Windows**
- **IOS (i.e., Apple)**
- **Linux**
  - Android

- **Spans PCs, servers, multiprocessors, mobile devices, etc.**

OS History – Unix & Linux

- **Unix**
  - Descendant of Multics
  - First “C” version in 1973 (DEC PDP-11)
    - Timesharing for < 10 users on 32K Memory
    - Many Unix versions at Bell Labs – different goals
    - Source code made available to Universities – BSD
  - Posix (start 1981) defines standard Unix system calls
  - AT&T licensing!

OS History - Linux

- **Open Source – Linux.org**
- **First Version 1991, Linus Torvalds, 80386 processor**
  - v.01, limited devices, no networking,
  - with proper Unix process support!
- **1994, v1.0**
  - networking (Internet)
  - enhanced file system
  - many devices, dynamic kernel modules

OS History — Linux

- **1996, v2.0**
  - multiple architectures, multiple processors
  - threads, memory management ….
- **Gnome UI – introduced in 1999**
- **Recent**
  - V2.4 - 3 million lines of code
  - 7-10 million users
  - Growth by 25%/year through 2003
  - Growing use in business server market
- **Note: development convention**
  - Odd numbered minor versions “development”
  - Even numbered minor versions “stable”

Linux Versions

- **Linux 2.6.xx.yy had been the "stable" version for many years!**
- **Many revisions in *xx* and *yy!***
  - Including some rather major changes!
- **No magic in rollover from 2.x.y to 3.x.y**
  - Simply celebrating 20th anniversary of Linux development
  - Typical "social dynamic" of numbering systems!
- **Even less reason to roll over from 3.x to 4.x**

- **Version for this course:– 4.13.0-26-generic**

OS History – Windows NT/2000/XP

- **Key designer – David Cutler also designed VAX/VMS**
- **1988, v1 - Win32 API – "microkernel"**
- **1990, v3.1- Server and Workstation versions**
- **1996, v4**
  - Win95 interface
  - Graphics moved into kernel
  - More NT licenses sold than all Unix combined
  - Microkernel de-emphasized

OS History – Windows NT/2000/XP

- **Windows 2000 – NT5.0**
  - Multi-user (with terminal services)
  - Professional - desktop
  - Server and Advanced Server - Client-server application servers
  - Datacenter Server - Up to 32 processors, 64 GB RAM
- **Windows XP**
  - Windows 2000 code base
  - Revised UI
  - EOL for DOS/Windows line

OS History – Windows NT/2000/XP/etc.

- **Microsoft has 80% to 90% of OS market for …**
  - Desktops, laptops, servers, data centers, etc.
- ***Wintel* – Windows + X86**
- **WinNT 4.x is 12 million lines of code**
- **Win2000 is 18 million lines of code**
- **Windows XP – approaching 10^8 lines of code**
- **Windows Vista – early 2006**
- **Windows 7 – 2010**
- **Windows 8 – 2013**
- **Windows 10 – 2016?**

Questions?