CS111
Operating Systems Principles

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Introduction to Operating Systems

Instructor

- Background (non-academic)
  - professional engineer w/over 40 years in OS
    - commercial Unix/Linux, SMP and distributed
    - development, leadership, staff and executive roles
  - I am here because I love teaching and I love OS
- Getting in touch with me (in order)
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This Course

- This is a revised curriculum with new goals:
  - understanding and exploiting OS services
  - foundation concepts and principles
  - common problems that have been solved in OS
  - evolving directions in system architecture
- This is not a course in how to build an OS
  - you will not read or write any kernel-mode code
  - you will not study or build any parts of a toy OS

Learning Objectives

- We started with a list of learning objectives
  - over 300 concepts, issues, approaches and skills
- All activities in this course are based on them
  - the reading has been chosen introduce them
  - the lectures are designed to reinforce them
  - the projects have been chosen to exercise them
  - the exams will test your mastery of them
- Study this list to understand the course goals
- Use this list to guide your pre-exam review

Course Web Site(s)

http://web.cs.ucla.edu/classes/spring16/cs111
- course syllabus
- reading, lecture and exam schedule
- copies of lecture slides
- supplementary reading and study materials

https://ccle.ucla.edu/course/view/16S-COMSCI111-1
- announcements
- (per lecture) on-line quizzes
- projects descriptions and submission
- discussion forum

Reading and Quizzes

- Reading
  - Remzi Arpaci-Dusseau OS in Three Easy Pieces
  - Saltzer – System Design (complexity and security)
  - numerous monographs to fill in gaps
  - average 40pp/day, but there is one 84 page day
- Quizzes
  - 4-8 short questions on the assigned reading
  - online (CCLE), due before start of each lecture
  - purpose: to ensure that you do the reading

Lectures

- Lectures will not
  - re-teach material well-covered by the reading
- Lectures will be used to
  - clarify and elaborate on the reading
  - explore implications and applications
  - discuss material not covered by the reading
  - discuss questions raised by students
- All lecture slides will be posted on-line
  - to aid you in your note-taking and review

Projects

- Skill development and demonstration

  P0 – a warm-up to confirm your readiness

  P1 – processes, I/O and IPC (in 2 parts)

  P2 – synchronization (in 3 parts)

  P3 – file systems (in 2 parts)

  an embedded system project or research paper
- one part is due every Monday by midnight
  - start each project as soon as you finish previous
  - be ready to talk to TA about problems on Friday
  - finish the project over the weekend

Academic Honesty

- Acceptable:
  - study and discuss problems/approaches w/friends
  - independent research on problems/approaches
- Unacceptable:
  - submitting work you did not independently create (or failing to cite your sources)
  - sharing code or answers with class-mates
  - using reference materials in closed-book exams
- Detailed rules are in the course syllabus

Why is OS a required course?

- Most CS discussions involve OS concepts
- Many hard problems have been solved in OS
  - synchronization, security, scalability, distributed computing, dynamic resource management, …
  - the same solutions apply in other areas
- Few will ever build an OS, but most of us will:
  - set-up, configure, and manage computer systems
  - write programs that exploit OS features
  - work w/complex distributed/parallel software
  - build abstracted services and resources
  - troubleshoot problems in complex systems

Why do I build Operating Systems?

- They are held to high pragmatic standards:
  - performance, correctness, robustness, scalability, availability, maintainability, extensibility
  - they demand meticulous attention to detail
- They must also meet high aesthetic standards
  - they must be general, powerful, and elegant (to be understandable by a single person)
- The requirements are ever changing
  - exploit the capabilities of ever-evolving hardware
  - enable new classes of systems and applications
- *Worthy adversaries* attract interesting people

What does Operating System do?

- manages the hardware
  - allocate hardware among the applications
  - enforce controlled sharing/privacy
  - oversee execution and handle errors
- abstract the bare hardware
  - make it easier to use
  - make the software more hardware independent
- new abstractions to enable applications
  - powerful features beyond the bare hardware

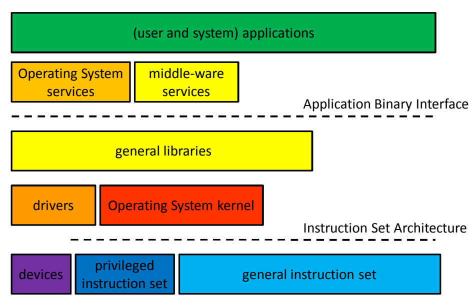
What makes the OS special?

- It is always in control of the hardware
  - first software loaded when the machine boots
  - continues running while apps come and go
- It alone has complete access to hardware
  - privileged instructions, all memory and devices
  - mediates application access to the hardware
- It is trusted
  - to store, manage, and protect critical data
  - to perform all requested operations in good faith

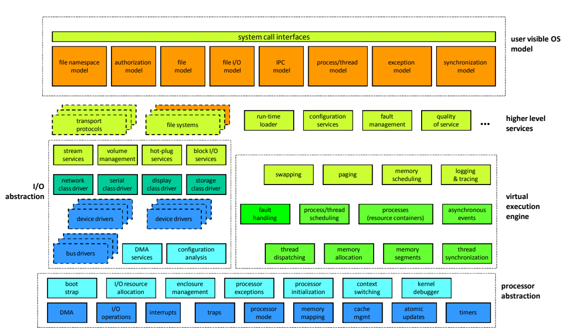
What does an OS look like?

- applications see objects and operations
  - CPU supports data types and operations
    - bytes, shorts, longs, floats, pointers ...
    - add, multiply, copy, compare, indirection, branch ...
  - OS supports richer objects, higher operations
    - files, processes, threads, segments, ports, ...
    - create, destroy, read, write, signal, ...
- much of what OS does is behind-the-scenes
  - plug & play, power management, fault-handling, domain services, upgrade management, ...

Software Layering



Internal Structure (artists conception)



What functionality is in the OS

- as much as necessary, as little as possible
  - OS code is very expensive to develop and maintain
  - it is important to distinguish OS from kernel
- functionality must be in the OS if it ...
  - requires the use of privileged instructions
  - requires the manipulation of OS data structures
  - required for security, trust, or resource integrity
- other simple functions can be in libraries
- complex functionality provided by services

Operating Systems Goals

- Application Platform
  - powerful
  - standards compliant
  - advanced/evolving
  - stable interfaces
  - tool availability
  - well supported
  - wide adoption
  - domain versatility
- Service Platform
  - high performance
  - robust and reliable
  - highly available
  - multi/omni-platform
  - managablility
  - well supported
- General
  - maintainable
  - extensible
  - binary distribution model

S/W Principles from this course

- Mechanism/Policy Separation
  - to meet a wide range of evolving needs
- Interfaces as contracts
  - implementations are not interfaces
- Appropriate abstraction and Information Hiding
  - to manage complexity and provide power
- Dynamic Equilibrium
  - robust adaptive resource allocation
- Fundamental role of data structures
  - find the right data structures, the code is easy

Life lessons from this course

- There Ain't No Such Thing As A Free Lunch
  - everything has a cost, there are always trade-offs
- Keep it Simple, Stupid!
  - avoid overly complex/clever solutions
  - they usually create more problems than they solve
- Be very clear what your goals are
  - make the right trade-offs, focus on the right problems
- Responsible and sustainable living
  - take responsibility for our actions/consequences
  - nothing is lost, everything is eventually recycled
  - it is all in the details

A Brief History of Operating Systems

- 1950s … OS? We don't need no stinking OS!
- 1960s batch processing
  - job sequencing, memory allocation, I/O services
- 1970s time sharing
  - multi-user, interactive service, file systems
- 1980s work stations and personal computers
  - graphical user interfaces, productivity tools
- 1990s work groups and the world wide web
  - shared data, standard protocols, domain services
- 2000 large scale distributed systems
  - the network IS the computer

assignments

- reading for the next lecture
  - Saltzer 1.4-1.5 (dealing with complexity)
  - Linux Programmers' Guide: libraries and tools
  - wikipedia articles:
    - linkage conventions
    - dynamic loading
    - APIs, ABIs

Quiz 2 is due <u>before</u> the lecture!

Get started on Project 0:

http://web.cs.ucla.edu/spring16/cs111/projects/Project0.html

Supplementary Slides

Maintainability

- operating systems have very long lives
  - basic requirements will change many times
  - support costs will dwarf initial development
  - this makes maintainability critical
    - understandability
    - modularity/modifiability
    - testability

Maintainable: understandability

- code must be learnable by mortals
  - it will not be maintained by the original developers
  - new people must be able to come up to speed
- code must be well organized
  - nobody can understand 1M lines of random code
  - it must have understandable, hierarchical structure
- documentation
  - high level structure, and organizing principles
  - functionality, design, and rationale for modules
  - how to solve common problems

Maintainable: modularity

- modules must be understandable in isolation
  - modules should perform coherent functions
  - well specified interfaces for each module
  - implementation details hidden within module
  - inter-module dependencies are few/simple/clean
- modules must be independently changeable
  - lots of side effects mean lots of bugs
  - changes to one module should not affect others
- Keep It Simple Stupid
  - costs of complexity usually outweigh the rewards

Maintainable: testability

- thorough testing is key to reliability
  - all modules must be thoroughly testable
  - most modules should be testable in isolation
- testability must be designed in from the start
  - observability of internal state
  - triggerability of all operations and situations
  - isolability of functionality
- testing must be automated
  - functionality, regression, performance,
  - stress testing, error handling handling

Instruction Set Architectures (ISAs)

- the set of instructions supported by a computer
  - what bit patterns correspond to what operations
- there are many different ISAs (all incompatible)
  - different word/bus widths (8, 16, 32, 64 bit)
  - different features (low power, DSPs, floating point)
  - different design philosophies (RISC vs CISC)
  - competitive reasons (68000, x86, PowerPC)
- they usually come in families
  - newer models add features (e.g. Pentium vs 386)
  - but remain upwards-compatible with older models
    - a program written for an ISA will run on any compliant CPU

Platforms

- ISA doesn't completely define a computer
  - functionality beyond user mode instructions
    - interrupt controllers, DMA controllers
    - memory management unit, I/O busses
    - BIOS, configuration, diagnostic features
    - multi-processor & interconnect support
  - I/O devices
    - display, disk, network, serial device controllers
- these variations are called "platforms"
  - the platform on which the OS must run

Portability to multiple ISAs

- successful OS will run on many ISAs
  - some customers cannot choose their ISA
  - if you don't support it, you can't sell to them
- minimal assumptions about specific h/w
  - general frameworks are h/w independent
    - file systems, protocols, processes, etc.
  - h/w assumptions isolated to specific modules
    - context switching, I/O, memory management
  - careful use of types
    - word length, sign extension, byte order, alignment

Binary Distribution Model

- binary is the opposite of source
  - a source distribution must be compiled
  - a binary distribution is ready to run
- one binary distribution per ISA
  - no need for special per-OEM OS versions
- binary model for platform support
  - device drivers can be added, after-market
    - can be written and distributed by 3rd parties
    - same driver works with many versions of OS

Binary Configuration Model

- eliminate manual/static configuration
  - enable one distribution to serve all users
  - improve both ease of use and performance
- automatic hardware discovery
  - self identifying busses
    - PCI, USB, PCMCIA, EISA, etc.
  - automatically find and load required drivers
- automatic resource allocation
  - eliminate fixed sized resource pools
  - dynamically (re)allocate resources on demand

Flexibility

- different customers have different needs
- we cannot anticipate all possible needs
- we must design for flexibility/extension
  - mechanism/policy separation
    - allow customers to override default policies
    - changing policies w/o having to change the OS
  - dynamically loadable features
    - allow new features to be added, after market
    - file systems, protocols, load module formats, etc.
  - feature independence and orthogonality

Interface Stability

- people want new releases of an OS
  - new features, bug fixes, enhancements
- people also fear new releases of an OS
  - OS changes can break old applications
- how can we prevent such problems?
  - define well specified Application Interfaces
  - apps only use committed interfaces
  - OS vendors preserve upwards-compatibility