Introduction to Operating Systems

1A. Administrative introduction to course
1B. Why study Operating Systems?
1C. What is an Operating System?
1D. Principles to be covered in this course
1E. A (very) brief history of Operating Systems
1F. Operating System Goals

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)
  - email: mark.kampe@gmail.com
  - GoogleTalk: mark.kampe@gmail.com
  - office: BH 4531M, TR 1-1:50, 4-4:50

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/spring18/cs111
- course syllabus, key learning objectives
- reading, lecture, exam schedule, projects
- copies of lecture slides

https://ccle.ucla.edu/course/view/18S-COMSCI111-1
- course announcements
- (per lecture) on-line quizzes
- project submission

https://piazza.com
- topic/project discussion, lecture requests

Reading and Quizzes

- Reading
  - Remzi Arpaci-Dusseau OS in Three Easy Pieces
  - numerous monographs to fill in gaps
  - average 35pp/day, but there is one 70 page day
- Quizzes
  - 4-6 short questions on the assigned reading
  - online (CCLE), due before start of each lecture
  - purpose: to ensure that you do the reading and are prepared for the lecture and discussions

Lectures

- I would prefer not to
  - re-teach material well-covered by the reading
- I would prefer to use lectures 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
  - to enable you to suggest alternative subjects

Projects

- Format:
  - individual programming projects w/questions
  - written in C to be run on Linux systems
  - one will require you to buy an embedded system
- Goals:
  - Develop ability to exploit OS features
  - Reinforce principles from reading and lectures
  - Develop programming/problem solving ability
  - Practice software project skills

Projects

- Subjects
  - P0 – a warm-up to confirm your readiness
  - P1 – processes, I/O and IPC (2 parts)
  - P2 – synchronization (2 parts)
  - P3 – file systems (2 parts)
  - P4 – Embedded Systems/Internet of Things (3 parts)
- broken into ~weekly deliverables
  - start each project as soon as you finish previous
  - be ready to discuss problems on Friday
  - finish the project over the weekend

Instructor/TA Responsibilities

- Instructor: lectures, readings, and tests
  - ask me about issues related to these
  - TA's do not follow the reading and lectures
- TA's: projects
  - they will do all assignments, assistance, grading
  - all questions on projects should go to them

Course Load

- reputation: THE hardest undergrad CS class
  - fast pace through much non-trivial material
- expectations you should have
  - lectures 4-6 hours/week
  - reading 3-6 hours/week
  - projects 3-20 hours/week
  - exam study 5-15 hours (twice)
- keeping up (week by week) is critical

  catching up (after falling behind) is difficult

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

Academic Honesty – Projects

- Do your own projects
  - If you need additional help, ask the instructor
- You must design and write all your own code
  - Do not ask others how they solved the problem
  - Do not copy solutions from the web, files or listings
  - Cite any research sources you use
- Protect yourself
  - Do not show other people your solutions
  - Be careful with old listings

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, …
  - same solutions are used in many 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

Relation to Other Courses

- Build on concepts and skills from other courses
  - data structures, algorithms, computer architecture
  - programming languages, assembly language programming
- Provide you with valuable foundation concepts
  - processes, threads, virtual address space, files
  - capabilities, synchronization, leases, deadlock, granularity
- Prepare you to work with more advanced subjects
  - data bases, file systems, and distributed computing
  - security, fault-tolerance, high availability
  - computer system modelling, queuing theory, ...

Why did I choose Operating Systems?

- They (and their problems) are extremely complex
- 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
  - general, powerful, and elegant (these characteristics make the complexity manageable)
- 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
  - fairly allocate hardware among the applications
  - ensure privacy and enable controlled sharing
  - oversee program execution and handle errors
- abstract the bare hardware
  - make it easier to use
  - make the applications platform-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
- Parts of it have 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

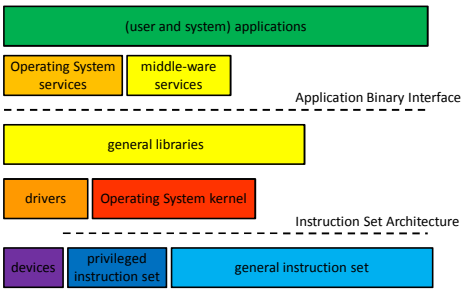
Privileged Instructions

- most CPU instructions can be used by anyone
  - e.g. arithmetic, logical, data movement, flow control
- some instructions are privileged
  - e.g. operations associated with I/O, interrupts, virtual address spaces, and processor mode.
  - these could compromise data privacy or integrity
  - they can only be executed when in privileged modes
  - otherwise they are illegal operations (cause exception)
- the operating system runs in privileged modes
  - giving it full control of the computer

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, …

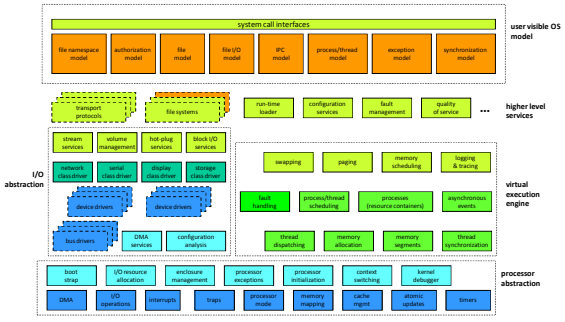
Software Layering



What functionality is in the OS

- as much as necessary, as little as possible
  - OS code is very expensive to develop and maintain
  - it may be useful 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

Internal Structure (artists conception)



Complexity Management

- Layered/Hierarchical Structure
  - can be understood progressively, piece-at-a-time
- Modularity and Functional Encapsulation
  - hiding complexity and simplifying interfaces
- Generalizing and Unifying Abstractions
  - high level organizing concepts
  - reusable solution paradigms
- Indirection, Federation and Deferred Binding
  - TBD plug-ins for TBD problems
- Appropriate Abstraction
  - functionality well-suited for intended uses

S/W Principles from this course

- Mechanism/Policy Separation
  - to meet a wide range of evolving needs
- Interfaces as contracts
  - implementations are not interfaces
- Dynamic Equilibrium
  - robust adaptive resource allocation
- Fundamental role of data structures
  - find the right data structures, the code is easy
- Iterative Solutions/Progressive Refinement
  - incremental improvements to working approaches

Life lessons from Operating Systems

- There Ain't No Such Thing As A Free Lunch
  - everything has a cost, there are always trade-offs to make
- Keep it Simple, Stupid!
  - avoid overly complex/clever solutions
- The Devil is in the Details
  - precious few things are as simple as they initially seem
- Correctness and Expedience are often at odds
  - correct solutions are often complex and/or expensive
- Be very clear about what your goals are
  - make the right trade-offs, focus on the right problems
  - don't over-constrain your problems
- Responsible and sustainable living
  - take responsibility for our actions/consequences
  - nothing is lost, everything is eventually recycled

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

General OS Trends

- They have grown larger and more sophisticated
- Role has changed from shepherding the h/w to:
  - shielding applications from the hardware
  - providing powerful platform for applications
  - coordinating computation and data movement
- Best understood through services they provide
  - capabilities they add
  - applications they enable
  - problems they eliminate

OS Convergence

- In the 1960s, there were many OS
  - one for every different computer and use
  - they were (relatively) small, simple, and cheap
  - software portability wasn't even a concept
- The world is now a very different place
  - OS are extremely large, complex and expensive
  - software portability is critically important
  - the number of surviving OS is small and shrinking
  - they must serve a much wider range of platforms

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

Assignments

- Project 0
  - look at the posted project description
  - get started on the implementation
  - encounter problems BEFORE your lab session
- For next lecture
  - (review) OS Principles
  - interface Stability
  - software Interfaces
  - take CCLE quiz #2
  - suggest different/additional discussion topics

Supplementary Slides

Course Grading

- Basis for grading:
  - quizzes 10%
  - projects 50% (P0 5%, all others 10%)
  - midterm 15%
  - final exam part-1 15%
  - final exam part-2 10%
- I do not grade on a curve
  - I do look at score distribution to set break points

Late Assignments & Make-ups

- Quizzes
  - no late quizzes accepted, no make-ups
  - but I usually drop the lowest score
- Labs
  - each student gets FIVE slip days (usable on any project)
  - after that score drops by 10% per late day
- Exams
  - alternate times or make-ups may be schedulable (with advanced notice)

Midterm Examination

- When: Second lecture of the 5th week (in class)
- Scope: All lectures up to the exam date
  - Approximately 60% lecture, 40% text
- Format:
  - Closed book
  - 10-15 essay questions, most with short answers
- Goals:
  - Test understanding of key concepts
  - Test ability to apply principles to practical problems

Final Exam

- When: Finals week
- Scope: Entire course
- Format:
  - 6-8 hard multi-part essay questions
  - You get to pick a subset of them to answer
- Goals:
  - Test mastery of key concepts
  - Test ability to apply key concepts to real problems
  - Use key concepts to gain insight into new problems

Academic Honesty and the Internet

- You might be able to find existing answers to some of the assignments on line
- Remember, if you can find it, so can we
  - and we have, before
- It IS NOT OK to copy the answers from other people's old assignments
  - people who tried that have been caught and referred to the Office of the Dean of Students
- ANYTHING you get off the Internet must be treated as reference material
  - If you use it, cite it

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

A Certain Irony

- Today's smart phone is immensely more powerful than 1960s mainframes
- But we used the mainframes for the biggest computing tasks we had
- While we use our powerful smart phones to move information around and display stuff
- Which has implications for their operating systems . . .

Why?

- Ultimately because it's what users want
- The OS must provide core services to applications
- Applications have become more complex
  - More complex internal behavior
  - More complex interfaces
  - More interactions with other software
- The OS needs to help with all that complexity

OS Convergence

- There are a handful of widely used OSes
  - And a few special purpose ones (E.g., real time and embedded system OSes)
- New ones come along very rarely
- OS in the same family (e.g., Windows or Linux) are used for vastly different purposes
  - Making things challenging for the OS designer
- Most OS are based on pretty old models
  - Linux comes from Unix (1970s vintage)
  - Windows from the early 1980s

Operating Systems for Mobile Devices

- What's down at the bottom for our smart phones and other devices?
- For Apple devices, enhanced Unix
  - Based on Mach (an 80s system), with some features from other 80s systems (like BSD Unix)
- For Android, ultimately Linux
- For Microsoft, ultimately Windows CE
  - Which has its origins in the 1990s
- None of these is all that new, either

Why Have OSes Converged?

- They're expensive to build and maintain
  - So it's a hard business to get into and stay in
- They only succeed if users choose them over other OS options
  - Which can't happen unless you support all the apps the users want (and preferably better)
  - Which requires other parties to do a lot of work
- You need to have some clear advantage over present acceptable alternatives

A Resulting OS Challenge

- We are basing the OS we use today on an architecture designed 20-40 years ago
- We can make some changes in the architecture
- But not too many
  - Due to compatibility
  - And fundamental characteristics of the architecture
- Requires OS designers and builders to shoehorn what's needed today into what made sense yesterday

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

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 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

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

Conclusion

- Understanding operating systems is critical to understanding how computers work
- Operating systems interact directly with the hardware
- Operating systems provide services via abstractions
- Operating systems are constrained by many non-technical factors

Discussion Slides

Deeper

- What makes a hierarchical structure more easily understood?
  1. *Because function and structure a layer can usually be understood without having to completely understand its implementation.*
  2. *Because the expansion of one sub-system can usually be understood without having to understand the expansion of other sub-systems.*

Deeper

- What are side effects and what gives rise to them?
  1. *A side effect is a situation where an action one object has non-obvious consequences (perhaps even to other objects).*
  2. *They often happen when state is shared between seemingly independent modules and functions.*

Deeper

- How is the multitasking in a timesharing system different from that in a batch system?
  1. *There is no interaction between tasks in a batch system. Each thinks it has the whole computer to itself. Parallel tasks in a timesharing system can interact with one-another.*
  2. *A timesharing system wants to provide good interactive response time to every task, which probably means preemptive scheduling.*

Deeper

- What are the key differences between operations and objects) implemented in the CPU (e.g. arithmetic and logical operations on 32 bit integers) and those implemented in the operating system (e.g. get/release operations on locks)?
  1. *operations implemented in the OS are more easily changed or added.*
  2. *objects implemented in the OS are more likely to have multi-user/multi-thread semantics.*

Deeper

- Why is it important that testing be automated?
  1. *If tests are automated, they can be run often (e.g. after every change) with very little cost or effort.*
  2. *Automatically executed tests are much more likely to be run completely and correctly every time, and all discrepancies are much more likely to be noted and reported.*

Consider

- What OS features are most important to end-users who run applications?
  reliability, performance,
  upwards compatibility in releases,
  platform support (runs on their hardware)
  availability of key applications
  security

Consider

- What OS features are most important to companies that use computers to provide services?
  reliability, performance,
  upwards compatibility in releases,
  platform support (wide range of platforms)
  manageability, total cost of ownership,
  support (updates and bug fixes),
  flexibility (in configurations and applications),
  security

Consider

- What OS features are most important to programmers who write new applications?
  reliability, performance,
  upwards compatibility in releases,
  standards conformance,
  functionality (current and roadmap),
  middle-ware, tools,
  documentation,
  support (how to …)

Consider

- What OS features are most important to programmers who support the OS?
  reliability, performance,
  understandability,
  modularity,
  tools,
  testability,
  binary extensibility

Consider

- What OS features are most important to a company that builds the OS?
  they want what their customers want,
  at the lowest possible price

Deeper

- What is wrong with distributing an OS in source form?
  1. *On what, are you going to compile it?*
  2. *Are your customers competent to build the OS? Do they want to build the OS?*
  3. *Do you really want to give all of your customers the sources to your main product?*

Deeper

- Automatic dynamic resource allocation is obviously simpler for the users. Why might it actually be more efficient?

The fractions of system resources dedicated to various uses are not pre-configured, but can dynamically respond to changing needs?

Deeper

- What is wrong with an OS vendor binding a browser into the desktop?.
  1. *It makes it difficult for customers to choose and use another browser.*
  2. *it effectively excludes other browser developers from selling their browsers on your OS.*
  3. *If you own a significant share of the OS market, this is a monopolistic practice that will get you sued, fined, or excluded from markets.*

Deeper

- How could a (non-bug) change to an OS break customer applications or systems?
  1. *By changing an interface that a critical application used, the application might no longer work on the new OS version.*
  2. *By no longer supporting a particular device, a customer (who has that device) might find the new release to be unusable.*

Spare Parts