Operating Systems

CS 4410 - CS 4411

Lorenzo Alvisi Anne Bracy

Spring 2017

These slides build upon many rounds of teaching CS 4410
by Professors Sirer, Bracy, van Renesse, George, Agarwal

About Prof. Bracy

- Professional Interests
  - Teaching: intro to programming, digital design, computer architecture, system software, operating systems
  - Research: microarchitecture, instruction fusion
- Past:
  - Educated @ Stanford & University of Pennsylvania
  - Worked @ WashU in St. Louis & Intel Labs
- Other pursuits: novice skier, intemediate jazz conoisseur, advanced toddler wrangler

About Prof. Alvisi

- Research interests: building scalable distributed systems that can be depended upon
  - PC Chair of SOSP '17
- Undergrad in Physics at ; Ph.D. in CS at
- Taught at
- Other pursuits: motorcycling, classical music, traveling

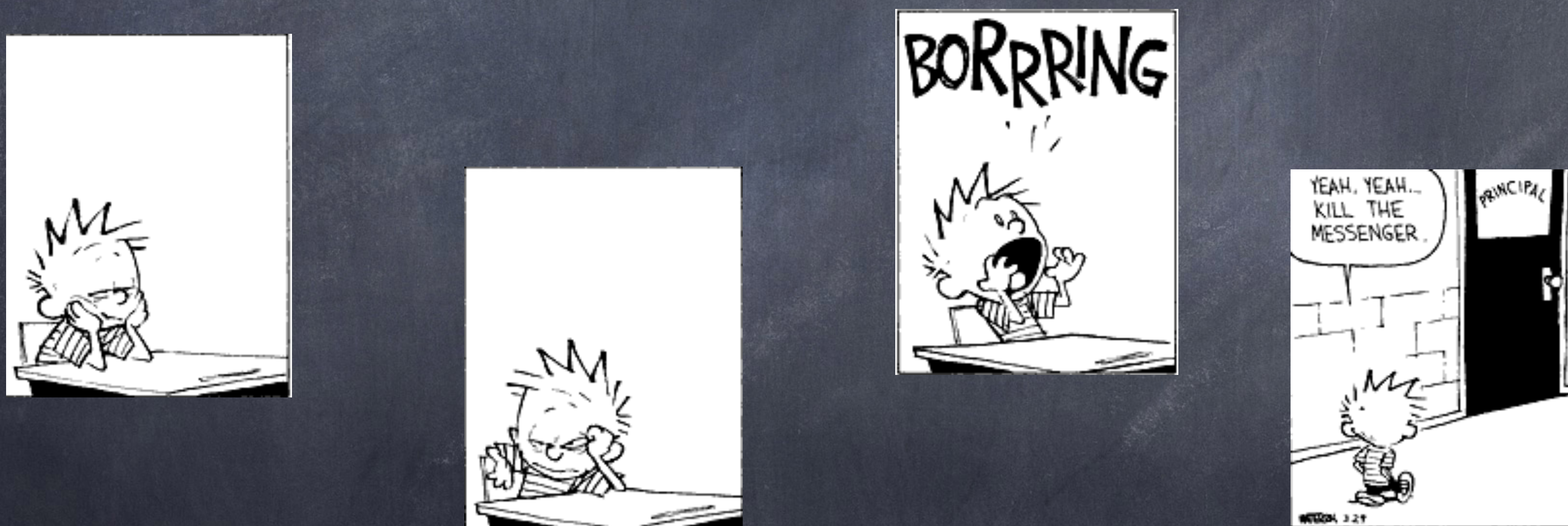
About You

?

Meet the OS

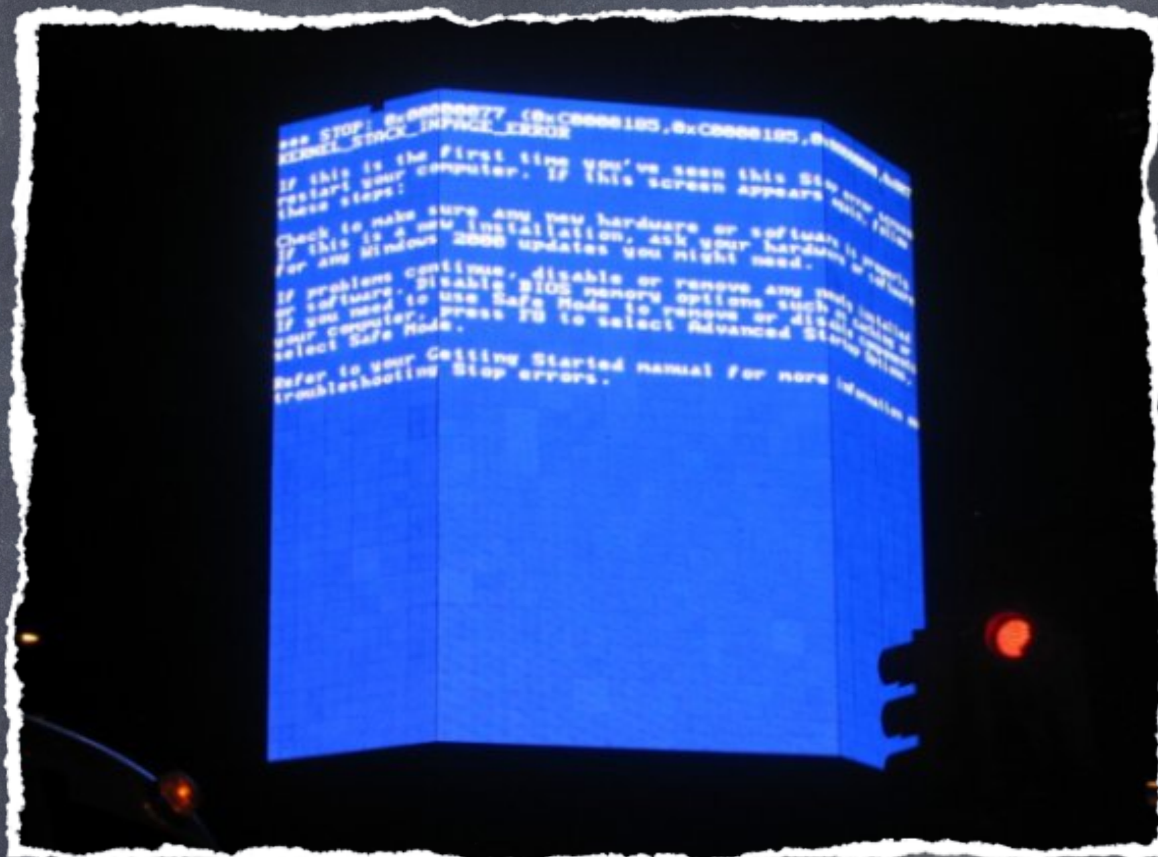
- Software that manages a computer's resources
- Makes it easier to write the applications you want to write
- Makes you want to use the applications you wrote by running them efficiently

Why study Operating Systems?



Why study Operating Systems?

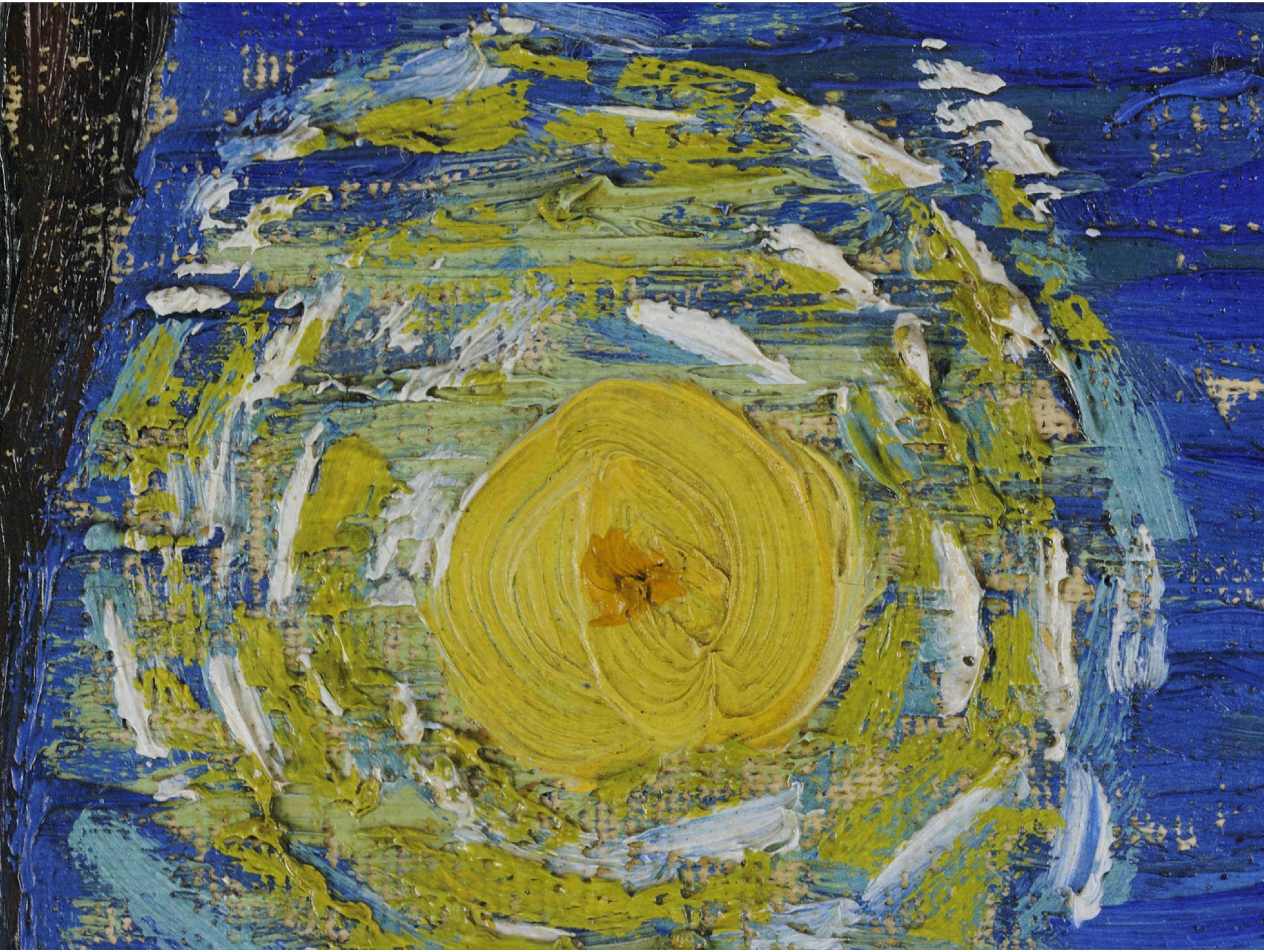
- To learn how to manage complexity through appropriate abstractions
  - infinite CPU, infinite memory, files, locks, etc.
- To learn about design
  - performance vs. robustness, functionality vs. simplicity, HW vs. SW, etc.
- To learn how computers work
- Because OSs are everywhere!



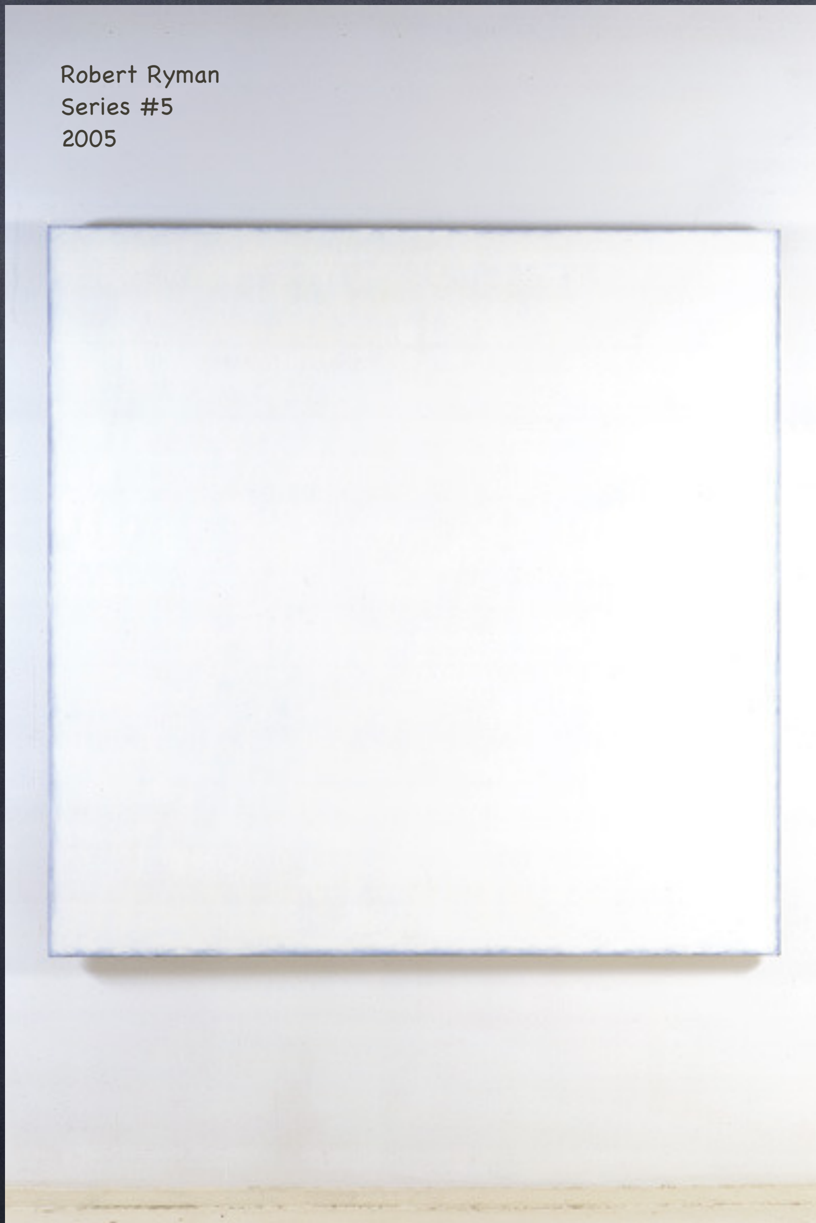
Where's the OS?
Las Vegas

Where's the OS?
New York

What will the course be like?



White


Robert Ryman
Series #5
2005


Ti

+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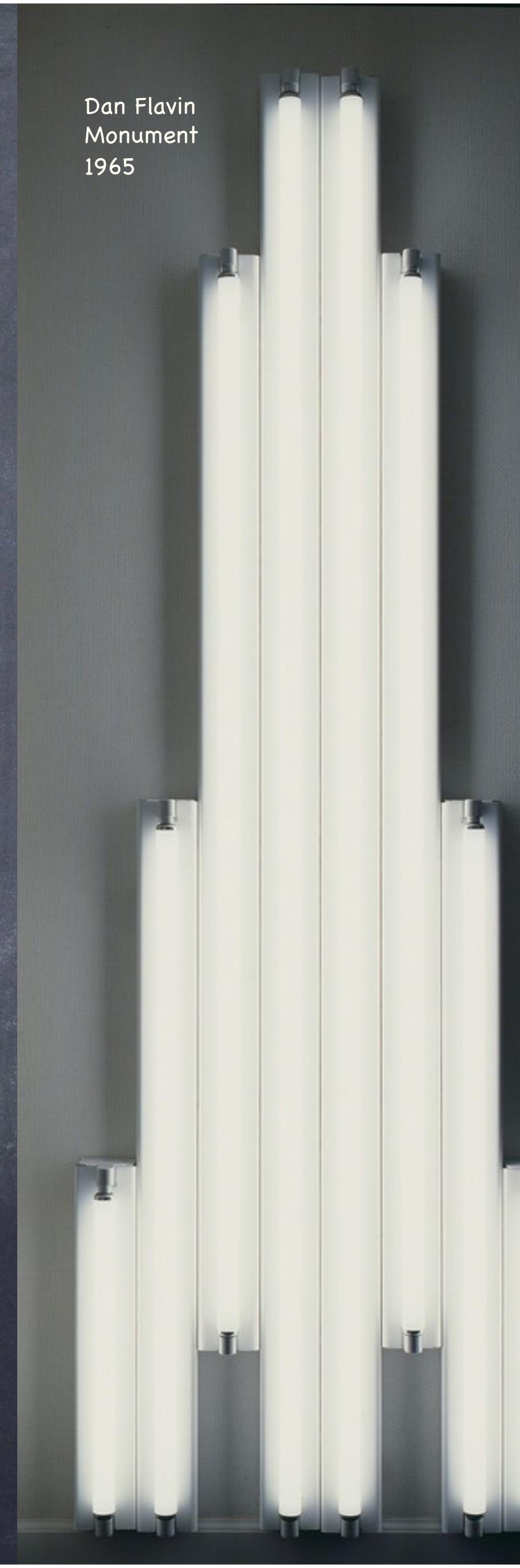
1978


Dan Flavin
Monument
1965

Cambia, Todo Cambia

	1981	1996	2011	Factor
MIPS	1	300	10000	10K
$/MIPS	$100K	$30	$0.50	200K
DRAM	128KB	128MB	10GB	100K
Disk	10MB	4GB	1TB	100K
Home Internet	9.6Kbps	256 Kbps	5Mbps	500
LAN Network	3Mbps (shared)	10 Mbps	1Gbps	300
# Users	100	100 Mb/s	<<1	100+

Painting*

- Order
- Design
- Tension
- Balance
- Harmony

System building

- Reliability
- Availability
- Portability
- Efficiency
- Security

*Sondheim: Sunday in the Park with George

Logistics

- Lectures
  - 4410: Tu-Th 1:25-2:40pm, Olin 155
  - 4411: F: 2:30-3:30pm, Hollister B14 (~ every 2 weeks)
- Instructors:  
- Office Hours
  - Professor Alvisi: M: 6:00-8:00pm
  - Professor Bracy: M: 11:00-12:00pm · Tu: 3:00-4:00pm
  - TAs — a small army at your disposal!

Our Expectations

- Code of Silence
  - Absolute quiet during lectures
  - Except (duh!) for questions! Please ask!
- Luddite Zone
  - Numerous studies show that such classrooms are far more effective (pioneered by Cornell: "The Laptop and the Lecture", 2003)
  - You learn more, so do the people around you!

Communicating

- Web Page: http://www.cs.cornell.edu/Courses/cs4410
  - Office hours, assignments, lectures, and other supplemental materials will be on the web site
- Piazza: http://piazza.com/cornell/spring2017/cs4410, http://piazza.com/cornell/spring2017/cs4411 (soon)
  - Public posts: for everyone
    - Don't post code
    - Use posts, not email
  - Private posts: for instructor/TA eyes only
- Personal emergencies: email cs4410-prof@cornell.edu (goes to us both)

Assignments/ Projects

- Code distributed through github
  - http://github.coecis.cornell.edu
  - we'll need your ids — more on this later
- Submissions through CMS

Administrative

- You are expected to keep up with
  - Lectures and Readings
  - Exams
  - Assignments (4410) and Projects (4411)
- Textbook
  - Anderson and Dahlin (1st or 2nd edition)
  - Subset of Kurose and Ross "Computer Networking: A Top-Down Approach".

Grading

- CS4410
  - ~48% Programming Assignments*
  - ~50% Exams (best 2 of 3)
  - ~2% Course evaluation, etc.
- CS4411
  - ~98% Projects
  - ~2% Course evaluation, etc.
- Grading will not be on a curve
  - We want to give everyone an A+
  - It's a time trial: you are <u>not</u> running against your peers

* if you are enrolled in both 4410 and 4411, your 4410 Programming Assignments grade will be 12% A1, 12% A2, 24% the average of your 6 Prac project grades

Programming Assignments (CS4410)

- 4 assignments
  - Shell
  - Concurrent programming
  - Networking
  - File systems
- To be done individually
- 4 slip days – at most 2 per assignment

Start early! Time management is key

Projects (CS4411)

- 6 project, to be done in teams of 2
  - Threads and Concurrency
  - Basic Datagram Networking
  - Routing
  - Scheduling
  - Reliable Streaming Protocol
  - File Systems
- Google form to indicate team's composition
  - No partner? We've got a Google form for that too! Or search on Piazza
- Working in pairs
  - Start early; time management is key; Manage the team effort
  - Don't let your team member down
- 4 slip days — at most 1 per assignment

Academic Integrity and Honor Code

All submitted work must be your own (CS4410) or your group's (CS4411)

- Project groups submit joint work
  - All programming assignments must be your own independent work
  - Group projects must represent solely the work of the two members of the group
  - OK to study together (with the Game of Thrones rule) but never look at someone else's code (fellow student, or online, or…)

Violations are easy to detect & will be prosecuted

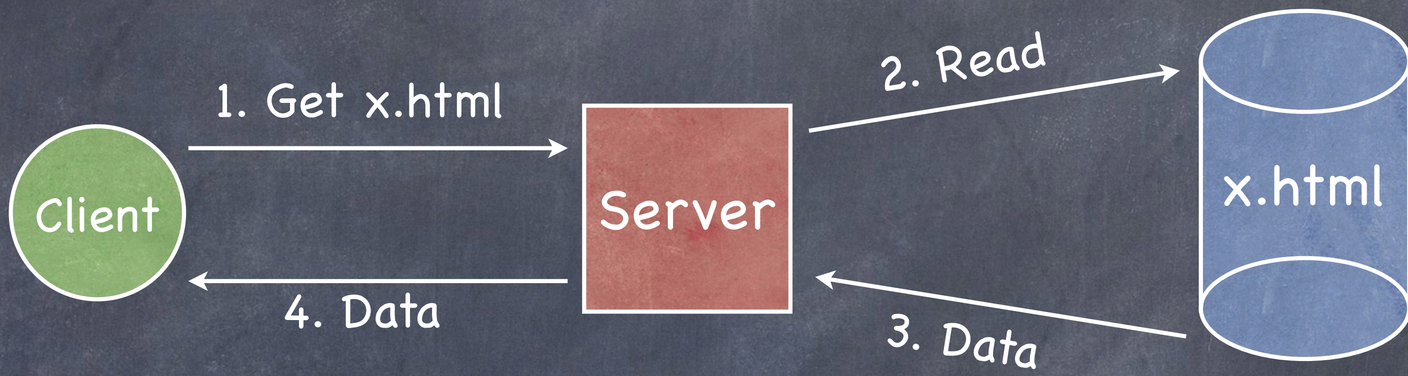
- Closed book exams, no calculators

Prerequisites

- We are checking your prerequisites
  - informally CS3410; or cs3420; or equivalent course on "Architecture & Systems Software"
- If you don't meet them, we'll contact you

Questions?

Running a Web Server



- How does the OS
  - allow multiple applications to communicate with each other?
  - handle multiple concurrent requests?
  - support access to shared data (such as the cache)?
  - protect against malicious scripts?
  - enable different apps to share the data they have produced?
  - support consistent changes to complex data structures?
  - handle clients and servers of different speed?
  - transparently move to more powerful hardware?

Course objective

Leg 1

1. Learn how to approach complex problems
    - Fundamental issues
        - coordination, abstraction
    - Explore design space
    - Examine case studies

- Goal: Forever mutate your brain (Mwahahahaahhaha!)
- Timescale: Big, long-term payoff

Leg 2

2. Learn how to apply specific techniques

   - Debug complex systems
   - Time-tested solutions to hard problems
   - Hacking will not succeed
     - concurrent programming, transactions, etc

- Goal: Be a good engineer
- Timescale: Now — and in 20 years

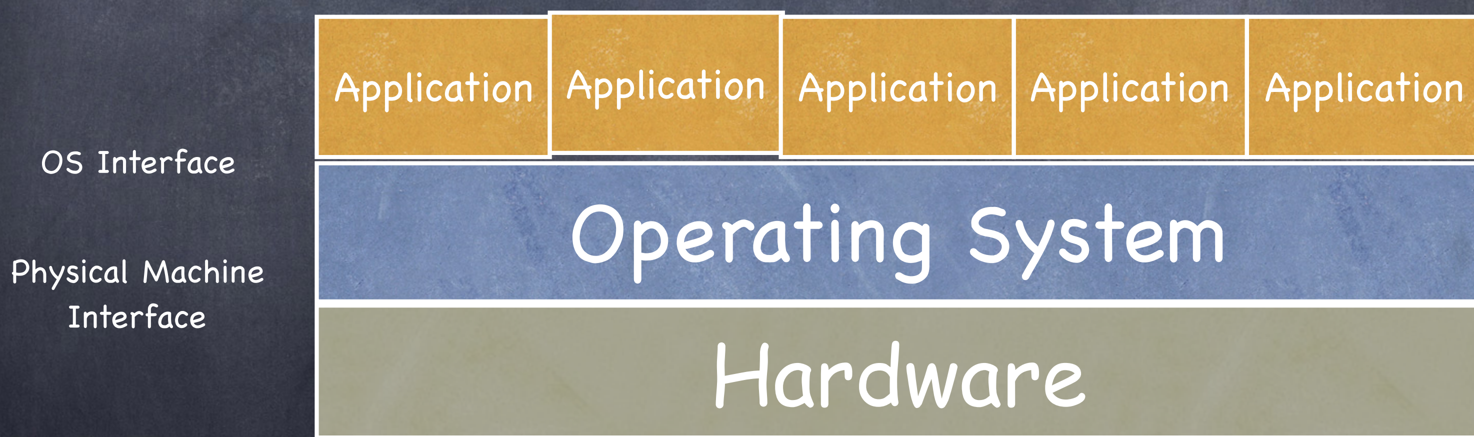
Leg 3

3. Learn how, in detail, current OSs work

- FS, network stack, internal data structures, VM… of
  - MacOS, Linux, iOS, Windows
- Goal: Well… know in detail how current OSs work!
- Timescale: Better be now, because all will change tomorrow

What is an OS?

- An Operating System implements a virtual machine whose interface is more convenient* that the raw hardware interface



* easier to use, simpler to code, more reliable, more secure…

"All the code you did not write"

More than one hat

- Referee
- Illusionist
- Glue

More than one hat

- Referee
  - Manages shared resources such as CPU, memory, disks, networks, displays, cameras, etc.
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  - Look! Infinite memory! Your own private processor!
- Glue
  - Offers a set of common services (e.g. U.I. routines)
  - Separates apps from I/O devices

OS as a referee

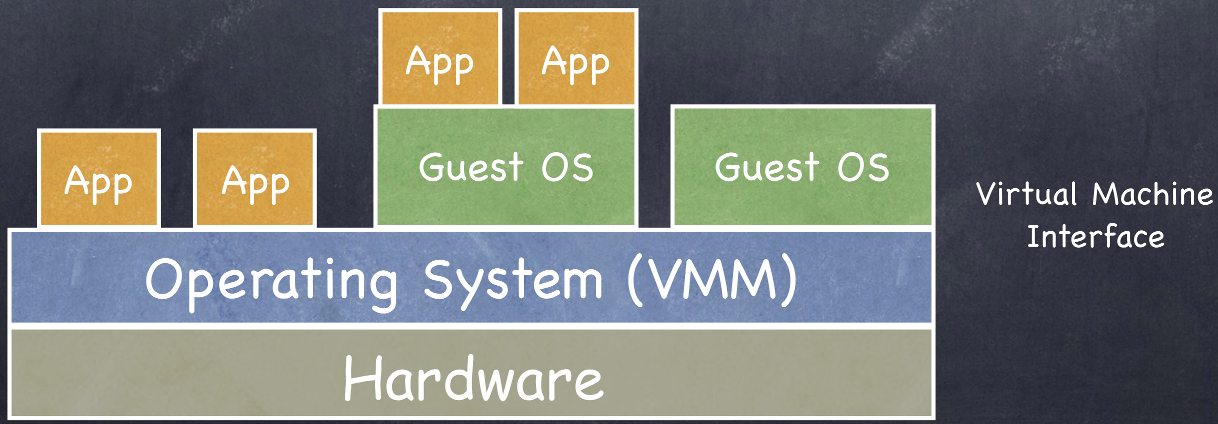
- Resource allocation
  - When multiple concurrent tasks, how does OS decide who gets how much?
- Isolation
  - A faulty app should not disrupt other apps or OS
    - OS must export less than full power of underlying hardware
- Communication/Coordination
  - Apps need to coordinate and share state
    - Web site: select ads, cache recent data, fetch/merge data from disk, etc

OS as an illusionist

- Illusion of resources that are not physically present
  - Virtualization
    - processor, memory, screen space, disk, network

OS as an illusionist

- Illusion of resources that are not physically present
  - Virtualization
    - processor, memory, screen space, disk, network
    - We can virtualize the entire computer!
      - fooling the illusionist itself!
      - ease of debugging, portability, isolation



OS as an illusionist

- Illusion of resources that are not physically present
  - Atomic operations
    - hardware guarantees atomicity at the word level
      - what happens during concurrent updates to complex data structures?
      - what if computer crashes during a block write?
    - at the hardware level, packets are lost...
  - Reliable communication channels

OS as a glue

- Offers standard services to simplify app design and facilitate sharing
  - send/receive of byte streams
  - read/write files
  - pass messages
  - share memory
  - UI
- Decouples hardware and app development
  - ...but database may need to be aware of specific disk drive

What makes a good OS?

The right set of abstractions

A good abstraction:

- is portable and hides implementation details
- has an intuitive and easy-to-use interface
- can be installed many times
- is efficient and reasonably easy to implement

OS: a collection of abstractions

- Processes (abstract CPU and RAM)
- Files (abstract disks)
- Network endpoints (abstract NIC)
- Windows (abstract screens)
- …

Think of them as objects with state and methods

Issues in OS Design

- Structure: how is the OS organized?
- Concurrency: how are parallel activities created and controlled?
- Sharing: how are resources shared?
- Naming: how are resources named by users?
- Protection: how are distrusting parties protected from each other?
- Security: how to authenticate, authorize, and ensure privacy?
- Performance: how to make it fast?

More issues in OS Design

- Reliability: how do we deal with failures??
- Portability: how to write once, run anywhere?
- Extensibility: how do we add new features?
- Communication: how do we exchange information?
- Scale: what happens as demands increase?
- Persistence: how do we make information outlast the processes that created it?
- Accounting: who pays the bill and how do we control resource usage?

A Short History of Operating Systems

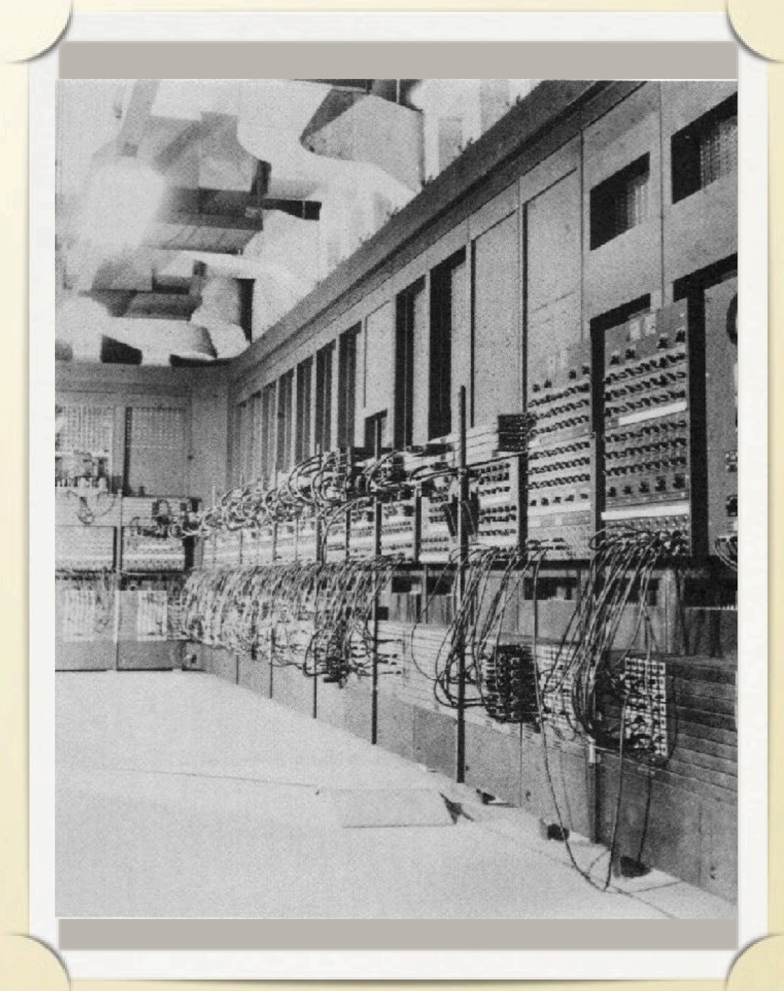
History of Operating Systems

- Phase 1: Hardware is expensive, humans are cheap
  - User at console: single-user systems
  - Batching systems
  - Multi-programming systems

Hand programmed machines (1945-1955)

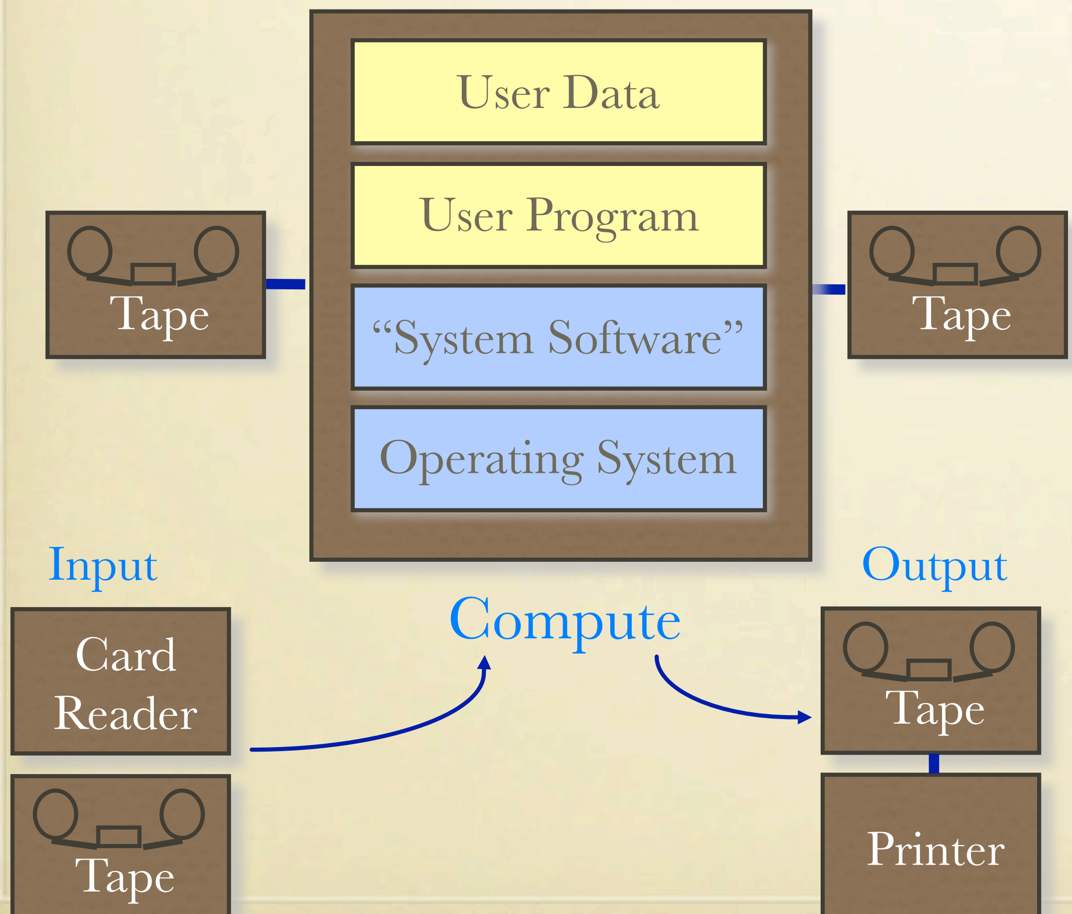
- Single user systems
- OS = loader + libraries of common subroutines
- Problem: low utilization of expensive components

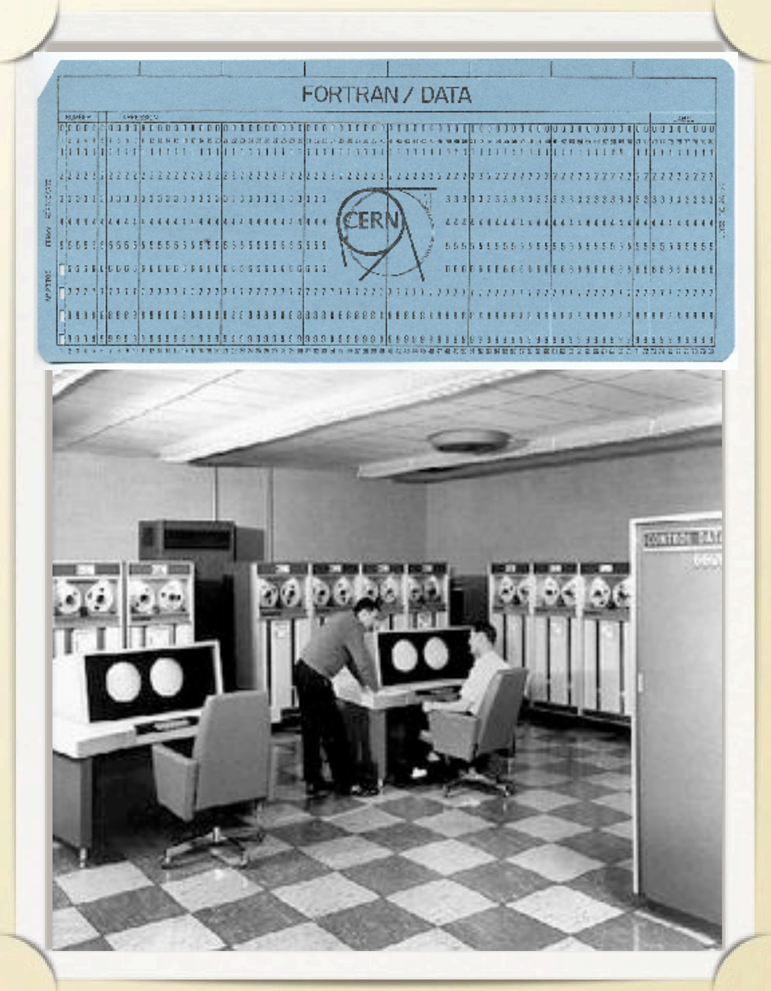
$$\frac{\textit{time device busy}}{\textit{observation interval}} = \%\ \textit{utilization}$$



Batch Processing (1955-1965)

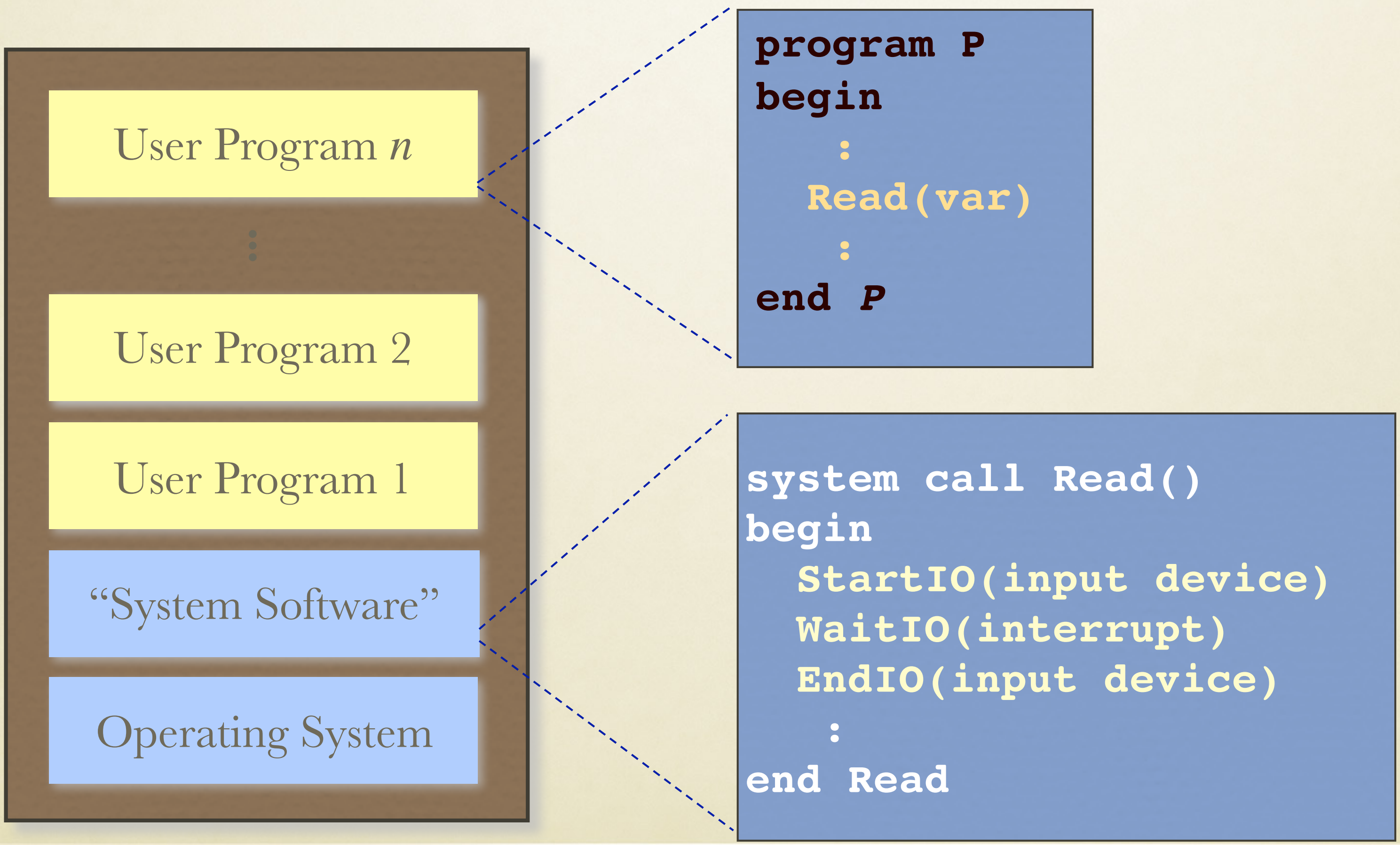
Operating system = loader + sequencer + output processor





MULTIPROGRAMMING (1965-1980)

Keep several jobs in memory and multiplex CPU between jobs



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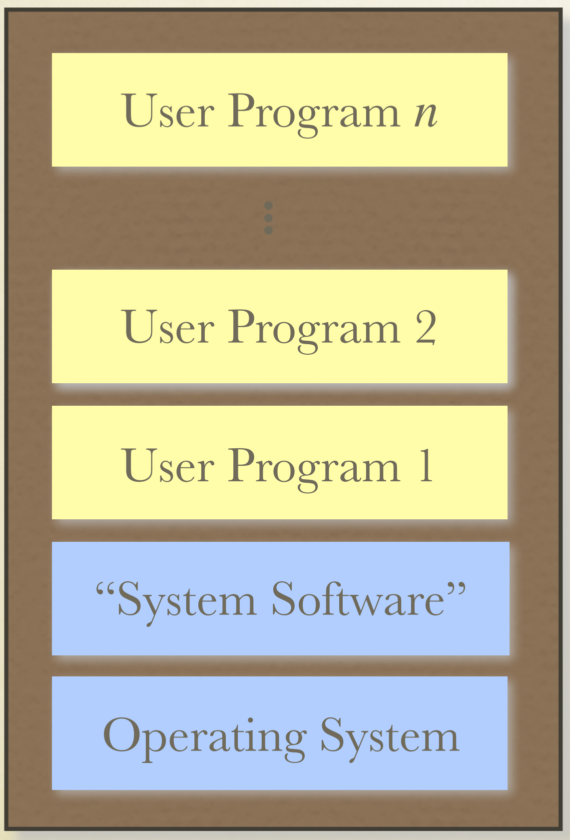

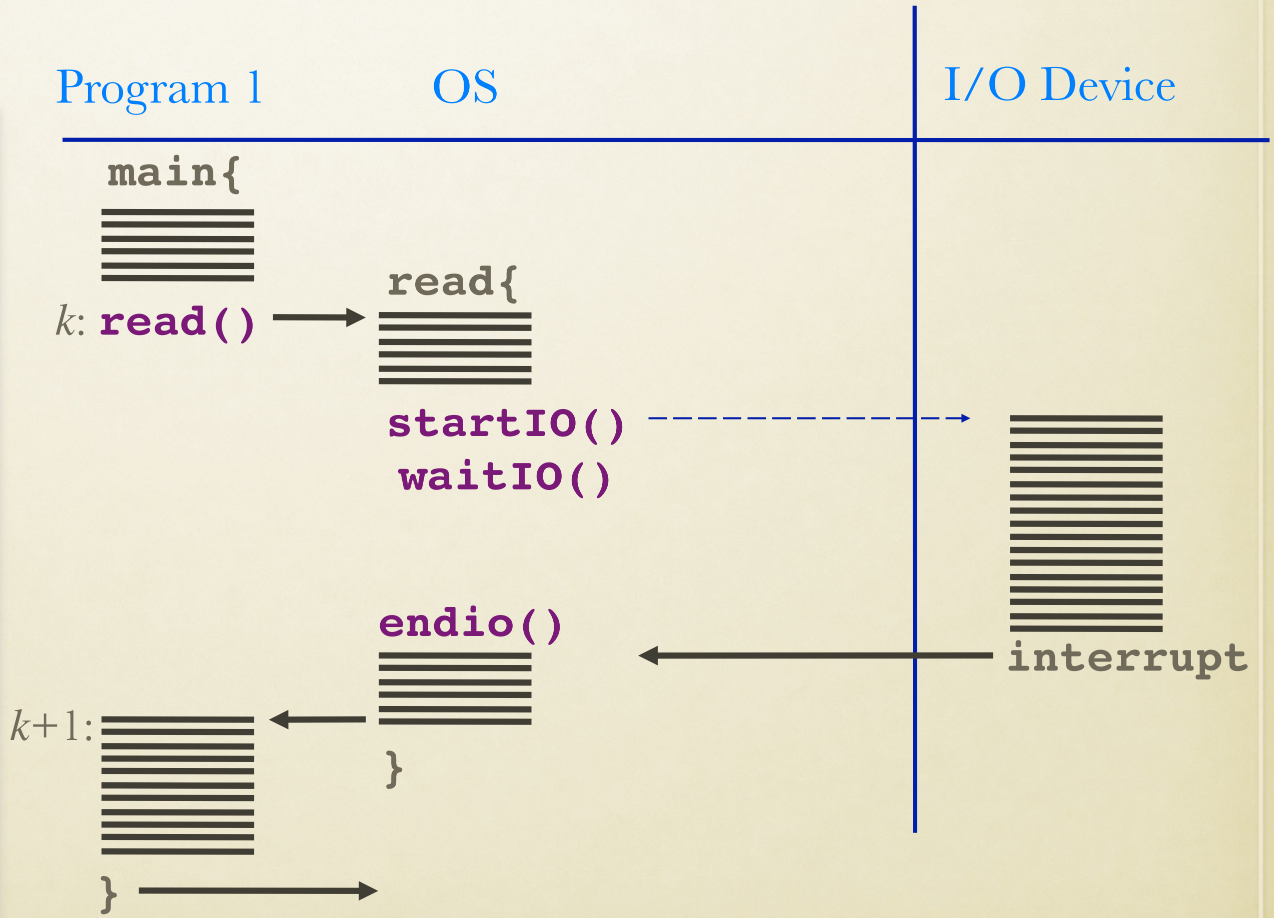

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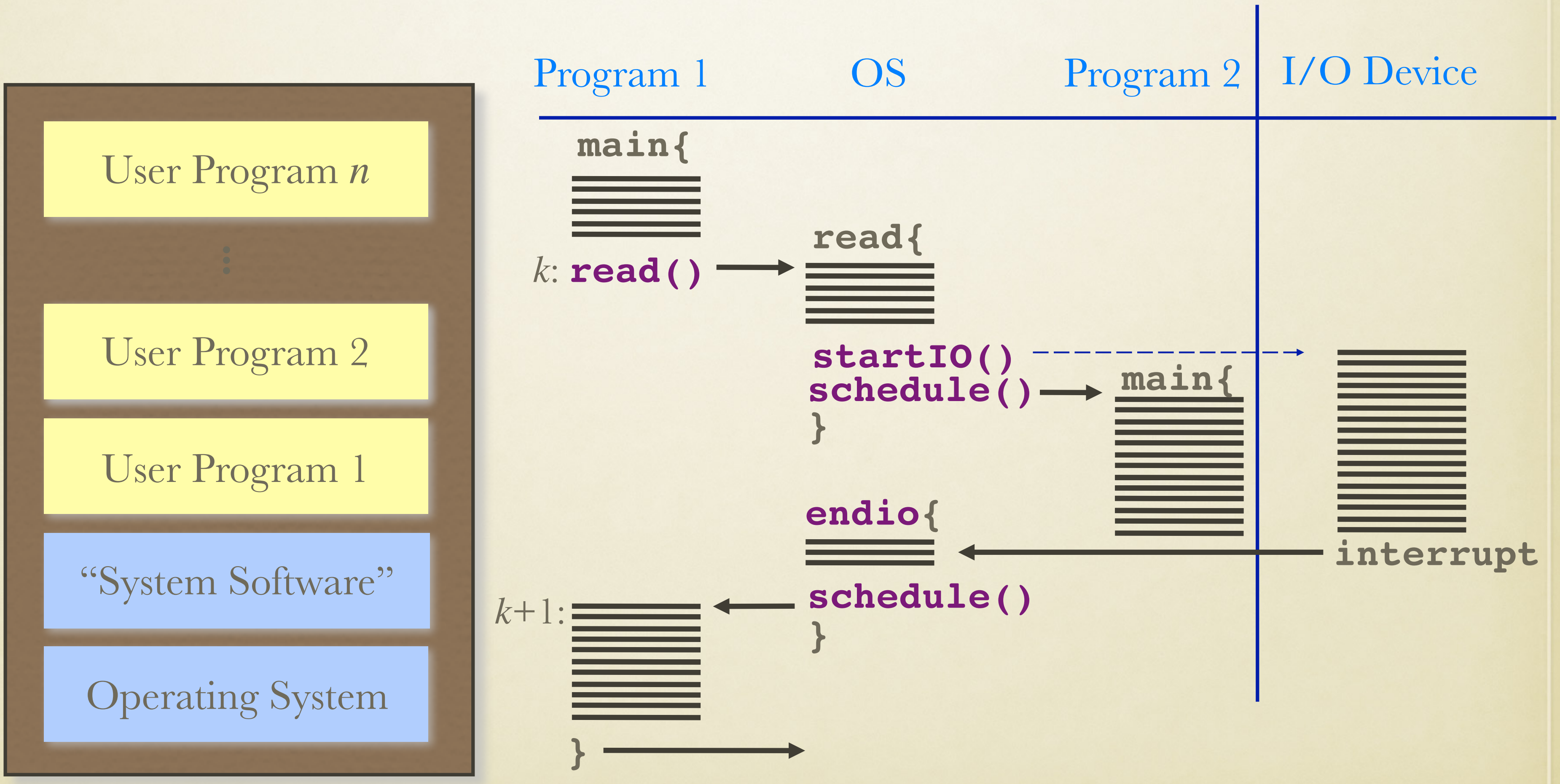

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- Phase 1: Hardware is expensive, humans are cheap
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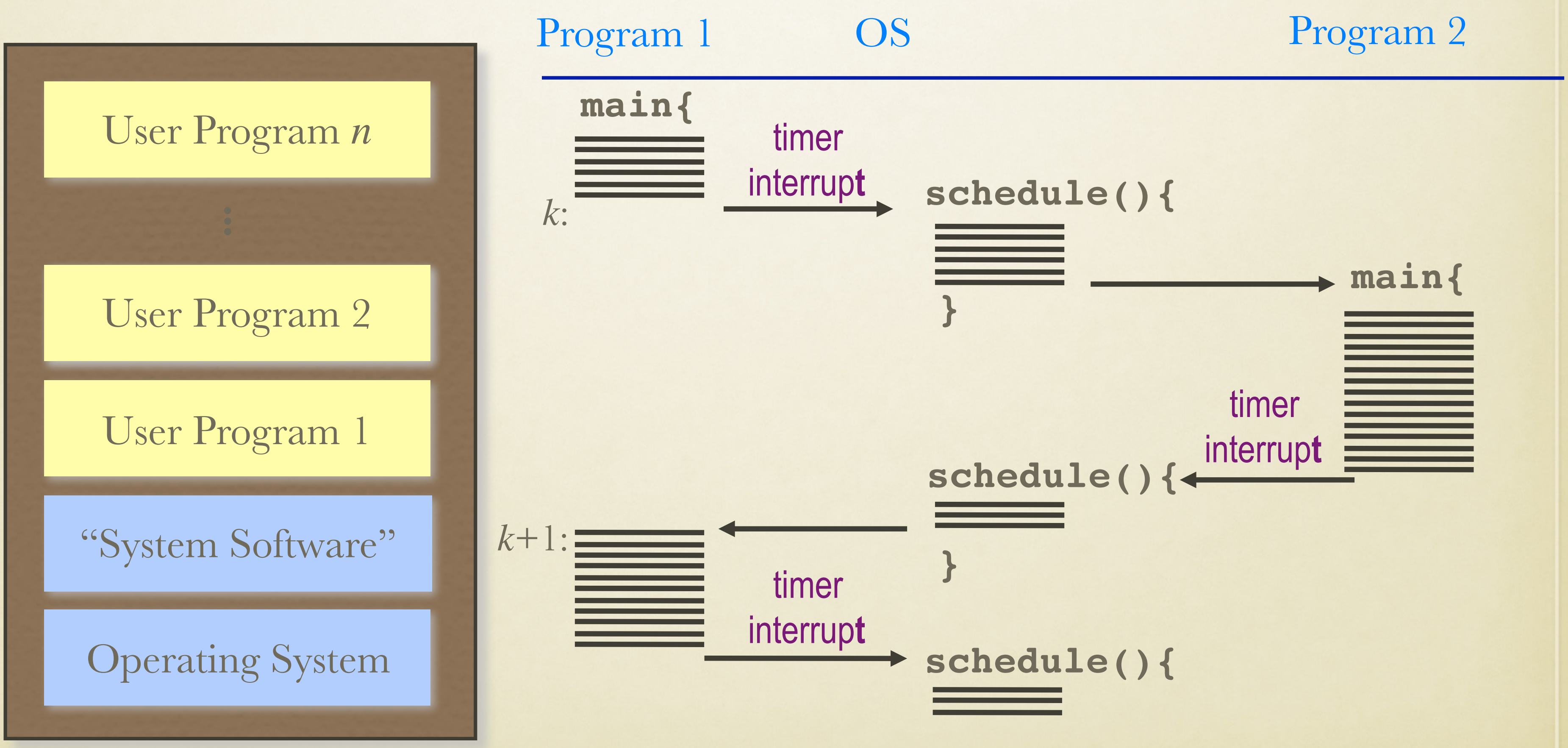
  - Multi-programming systems
- Phase 2: Hardware is cheap, humans are expensive
  - Time sharing: Users use cheap terminals and share servers

Timesharing (1970-)

A timer interrupt is used to multiplex CPU between jobs



History of Operating Systems

- Phase 1: Hardware is expensive, humans are cheap
  - User at console: single-user systems
  - Batching systems
  - Multi-programming systems
- Phase 2: Hardware is cheap, humans are expensive
  - Time sharing: Users use cheap terminals and share servers
- Phase 3: Hardware is very cheap, humans are very expensive
  - Personal computing: One system per user
  - Distributed computing: many systems per user
  - Ubiquitous computing: LOTS of systems per users

Operating Systems for PCs

Personal computing systems

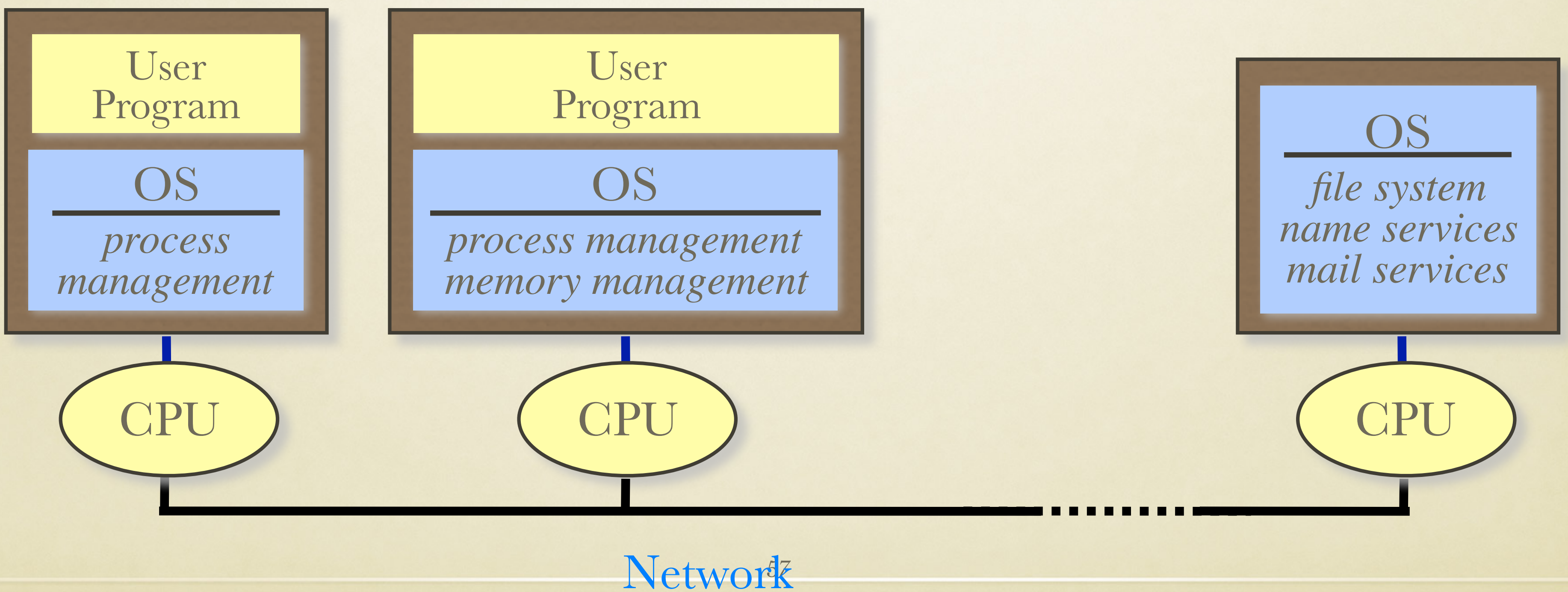
- Single user
- Utilization no longer a concern
- Emphasis on user interface and API
- Many services & features not present

Evolution

- Initially: OS as a simple service provider (simple libraries)
- Now: Multi-application systems with support for coordination

Distributed Operating Systems

- Abstraction: a multi-processor system as a single processor one.
- New challenges in consistency, reliability, resource management, performance, etc.
- Examples: SANs, Oracle Parallel Server



Ubiquitous Computing

- Challenges
  - Small memory size
  - Slow processor
  - Battery concerns
  - Scale
  - Security
  - Naming

Genealogy of modern Operating Systems