Intro to Operating Systems

CSE 410, Spring 2009

Computer Systems

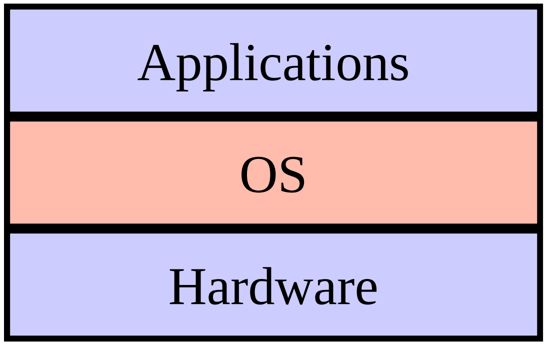
http://www.cs.washington.edu/410

Readings and References

- Reading
  - » Operating System Concepts, Silberschatz, Galvin, and Gagne
    - Ch. 1 Introduction & Ch. 2 OS Structures for background
    - Most useful for us: Sec. 1.1, 1.4-1.9, 2.1, 2.3-2.4, 2.6-2.7
  - » Slide credits: largely taken from CSE451, courtesy of Hank Levy.

What is an Operating System?

- An operating system (OS) is:
  - » a software layer to abstract away and manage details of hardware resources
  - » a set of utilities to simplify application development



Applications

OS

Hardware

-
  - » “all the code you didn’t write” in order to implement your application
- Key idea: *virtualization* of resources

The OS and hardware

- An OS mediates programs' access to hardware resources
  - Computation (CPU)
  - Volatile storage (memory) and persistent storage (disk, etc.)
  - Network communications (TCP/IP stacks, ethernet cards, etc.)
  - Input/output devices (keyboard, mouse, display, sound card, ..)
- The OS abstracts hardware into logical resources and well-defined interfaces to those resources
  - processes (CPU, memory)
  - files (disk)
  - programs (sequences of instructions)
  - sockets (network)

Why bother with an OS?

- Application benefits
  - » programming simplicity
    - see high-level abstractions (files) instead of low-level hardware details (device registers)
    - abstractions are reusable across many programs
  - » portability (across machine configurations or architectures)
    - device independence: 3Com card or Intel card?
- User benefits
  - » safety
    - program “sees” own virtual machine, thinks it owns computer
    - OS protects programs from each other (what if one crashes?)
    - OS fairly multiplexes resources across programs
  - » efficiency (cost and speed)
    - share one computer across many users
    - concurrent execution of multiple programs

The major OS issues

- **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 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 (either with hardware or with a program)?
- **extensibility**: can we add new features?
- **communication**: how do programs exchange information, including across a network?

More OS issues…

- **concurrency**: how are parallel activities (computation and I/O) created and controlled?
- **scale and growth**: 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? how do we make distribution invisible?
- **accounting**: how do we keep track of resource usage, and perhaps charge for it?

There are a huge number of engineering tradeoffs

in dealing with these issues!

Hardware/Software Changes with Time

- 1960s: mainframe computers (IBM)
- 1970s: minicomputers (DEC)
- 1980s: microprocessors and workstations (SUN)
- 1990s: PCs (rise of Microsoft, Intel, then Dell)
- 2000: Internet Services / Clusters (Amazon)
- 2006: General Cloud Computing (Google, Amazon)
- …..
- 2020: it's up to you!!

OS history

- In the very beginning…
  - » OS was just a library of code that you linked into your program; programs were loaded in their entirety into memory, and executed
  - » interfaces were literally switches and blinking lights
- And then came **batch systems**
  - » OS was stored in a portion of primary memory
  - » OS loaded the next job into memory from the card reader
    - job gets executed
    - output is printed, including a dump of memory (why?)
    - repeat…
  - » card readers and line printers were very slow
    - so CPU was idle much of the time (wastes $$)

Spooling

- Disks were much faster than card readers and printers
- Spool (Simultaneous Peripheral Operations On-Line)
  - » while one job is executing, spool next job from card reader onto disk
    - slow card reader I/O is overlapped with CPU
  - » can even spool multiple programs onto disk
    - OS must choose which to run next
    - job scheduling
  - » but, CPU still idle when a program interacts with a peripheral during execution
  - » buffering, double-buffering

Multiprogramming

- To increase system utilization, multiprogramming OSs were invented
  - » keeps multiple runnable jobs loaded in memory at once
  - » overlaps I/O of a job with computing of another
    - while one job waits for I/O completion, OS runs instructions from another job
  - » to benefit, need asynchronous I/O devices
    - need some way to know when devices are done
      - interrupts
      - polling
  - » goal: optimize system throughput
    - perhaps at the cost of response time…

Timesharing

- To support interactive use, create a timesharing OS:
  - multiple terminals into one machine
  - each user has illusion of entire machine to him/herself
  - optimize response time, perhaps at the cost of throughput
- Timeslicing
  - divide CPU equally among the users
  - if job is truly interactive (e.g. editor), then can jump between programs and users faster than users can generate load
  - permits users to interactively view, edit, debug running programs (why does this matter?)
- MIT Multics system (mid-1960's) was the first large timeshared system
  - nearly all OS concepts can be traced back to Multics

Timesharing

- In early 1980s, a *single* timeshared VAX/780 (like the one in the Allen Center atrium) ran computing for the *entire* CSE department.
- A typical VAX/780 was 1 MIPS (1 MHz) and had 16MB of RAM and 100MB of disk.
- An iPhone is 400 MIPS, has 128MB of RAM (way too little though) and 8GB of disk.

Parallel systems

- Some applications can be written as multiple parallel threads or processes
  - » can speed up the execution by running multiple threads/processes simultaneously on multiple CPUs [Burroughs D825, 1962]
    - true multiprocesssing (not just multiprogramming)
  - » need OS and language primitives for dividing program into multiple parallel activities
  - » need OS primitives for fast communication among activities
    - degree of speedup dictated by communication/computation ratio
  - » many flavors of parallel computers today
    - SMPs (symmetric multi-processors, multi-core)
    - SMT (simultaneous multithreading [“hyperthreading”])
    - MPPs (massively parallel processors)
    - NOWs (networks of workstations) [clusters]
    - computational grid (SETI @home)

Personal computing

- Primary goal was to enable new kinds of interactive applications
- Bit-mapped display [Xerox Alto,1973]
  - New graphic/visual apps
  - new input device (the mouse)
- Move computing near the display
  - why?
- Window systems
  - the display as a managed resource
- Local area networks [Ethernet]
  - why?
- Effect on OS?

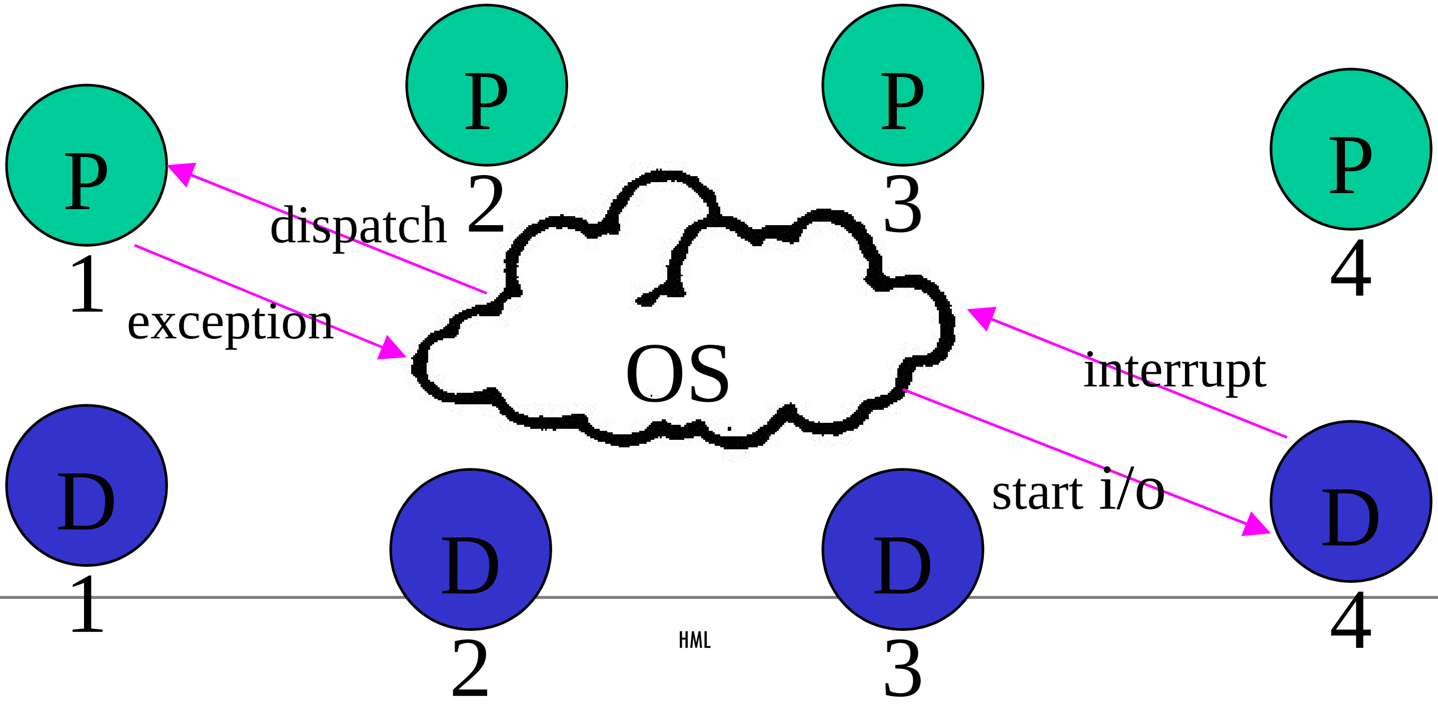
Embedded OS

- Pervasive computing
  - » cheap processors embedded everywhere
  - » how many are on your body now? in your car?
  - » cell phones, PDAs, games, iPod, network computers, …
- Typically very constrained hardware resources
  - » slow processors
  - » small amount of memory
  - » no disk or tiny disk
  - » typically only one dedicated application
  - » limited power

- But technology changes fast
  - » embedded CPUs are getting faster
  - » storage is growing rapidly

OS structure

- The OS sits between application programs and the hardware
    - » it mediates access and abstracts away ugliness
    - » programs request services via exceptions (traps or faults)
    - » devices request attention via interrupts

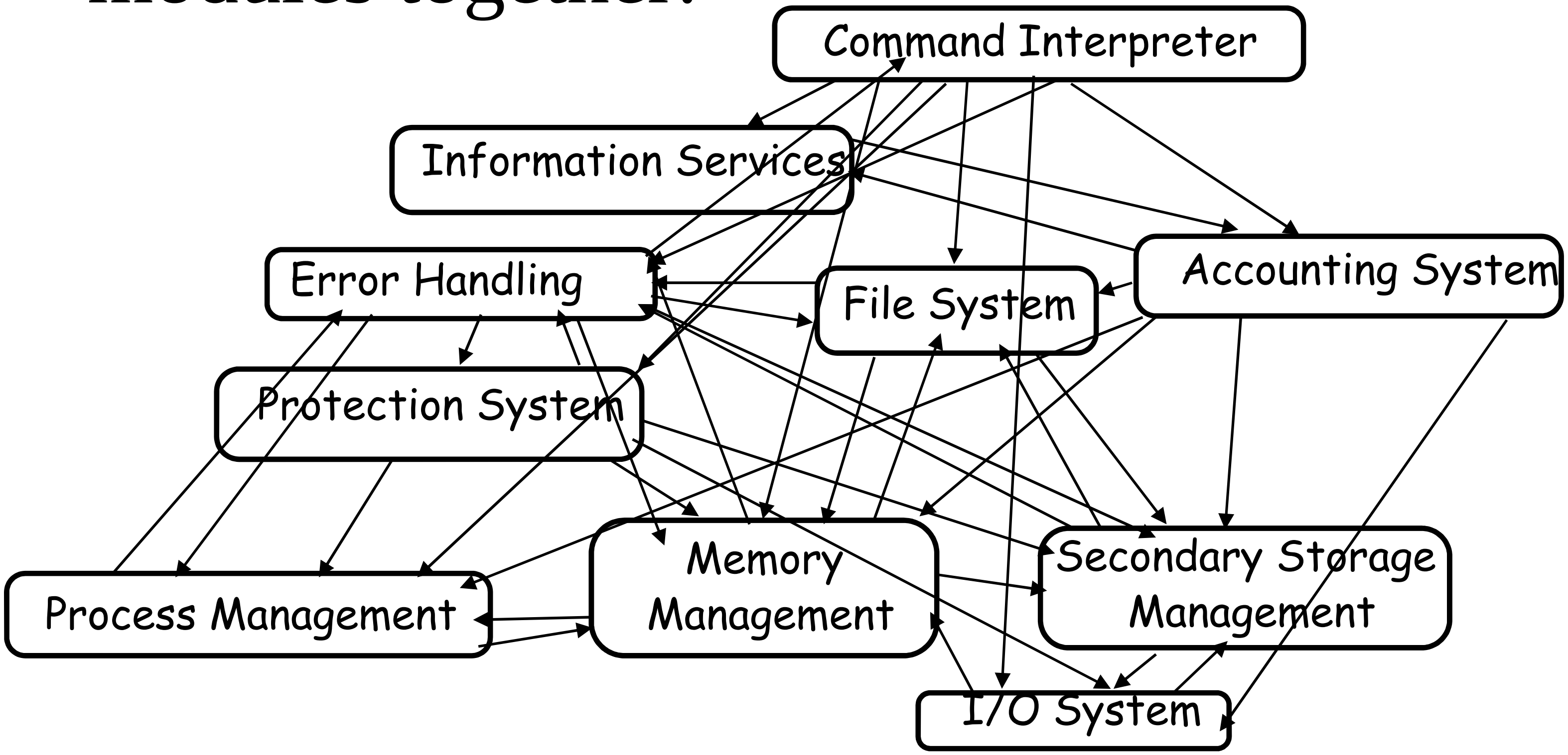


Major OS components

- processes
- memory
- I/O
- secondary storage
- file systems
- protection
- accounting
- shells (command interpreter, or OS UI)
- GUI
- networking

OS structure

- It’s not always clear how to stitch OS modules together:

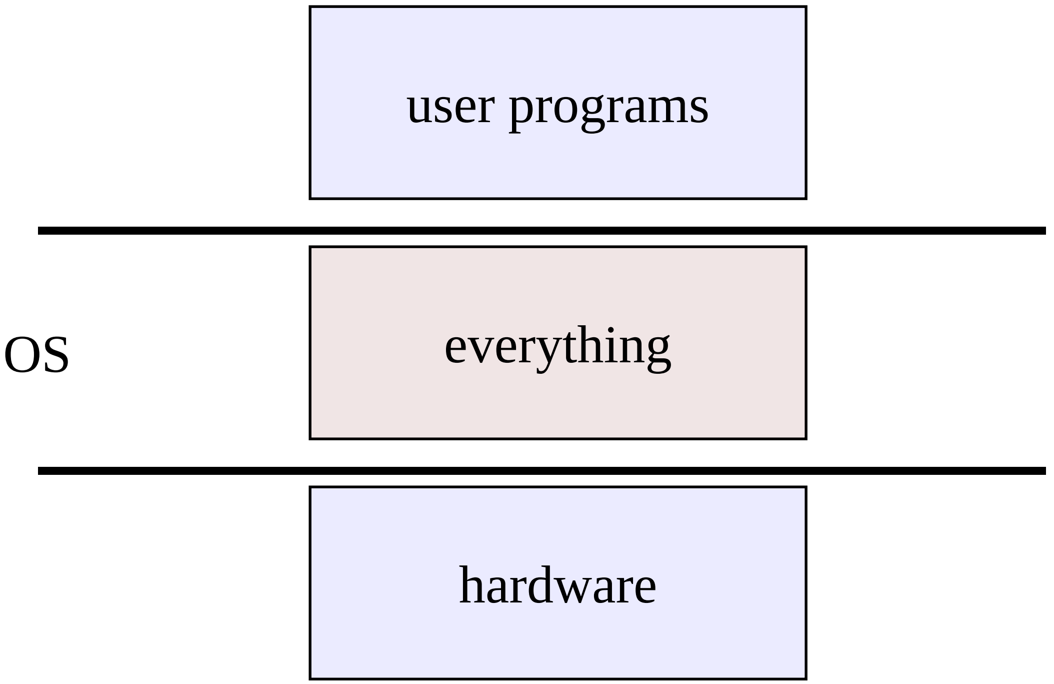


OS structure

- An OS consists of all of these components, plus:
  - » many other components
  - » system programs (privileged and non-privileged)
    - e.g., bootstrap code, the init program, …
- Major issue:
  - » how do we organize all this?
  - » what are all of the code modules, and where do they exist?
  - » how do they cooperate?
- Massive software engineering and design problem
  - » design a large, complex program that:
    - performs well, is reliable, is extensible, is backwards compatible, …

Early structure: Monolithic

- Traditionally, OS’s (like UNIX) were built as a monolithic entity:



Monolithic design

- Major advantage:
  - » cost of module interactions is low (procedure call)
- Disadvantages:
  - » hard to understand
  - » hard to modify
  - » unreliable (no isolation between system modules)
  - » hard to maintain
- What is the alternative?
  - » find a way to organize the OS in order to simplify its design and implementation

Layering

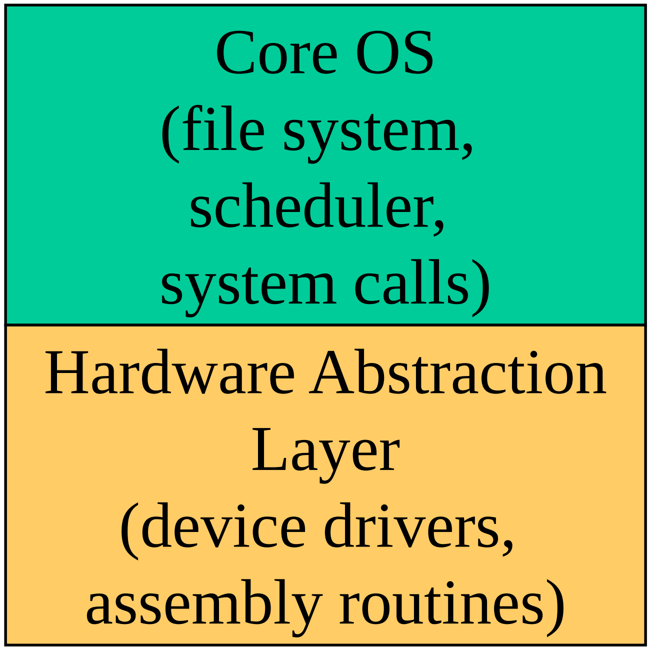
- The traditional approach is layering
  - » implement OS as a set of layers
  - » each layer presents an enhanced ‘virtual machine’ to the layer above
- The first description of this approach was Dijkstra’s THE system
  - » Layer 5: Job Managers
    - Execute users’ programs
  - » Layer 4: Device Managers
    - Handle devices and provide buffering
  - » Layer 3: Console Manager
    - Implements virtual consoles
  - » Layer 2: Page Manager
    - Implements virtual memories for each process
  - » Layer 1: Kernel
    - Implements a virtual processor for each process
  - » Layer 0: Hardware
- Each layer can be tested and verified independently

Problems with layering

- Imposes hierarchical structure
  - » but real systems are more complex:
    - file system requires VM services (buffers)
    - VM would like to use files for its backing store
  - » strict layering isn't flexible enough
- Poor performance
  - » each layer crossing has overhead associated with it
- Disjunction between model and reality
  - » systems modeled as layers, but not really built that way

Hardware Abstraction Layer

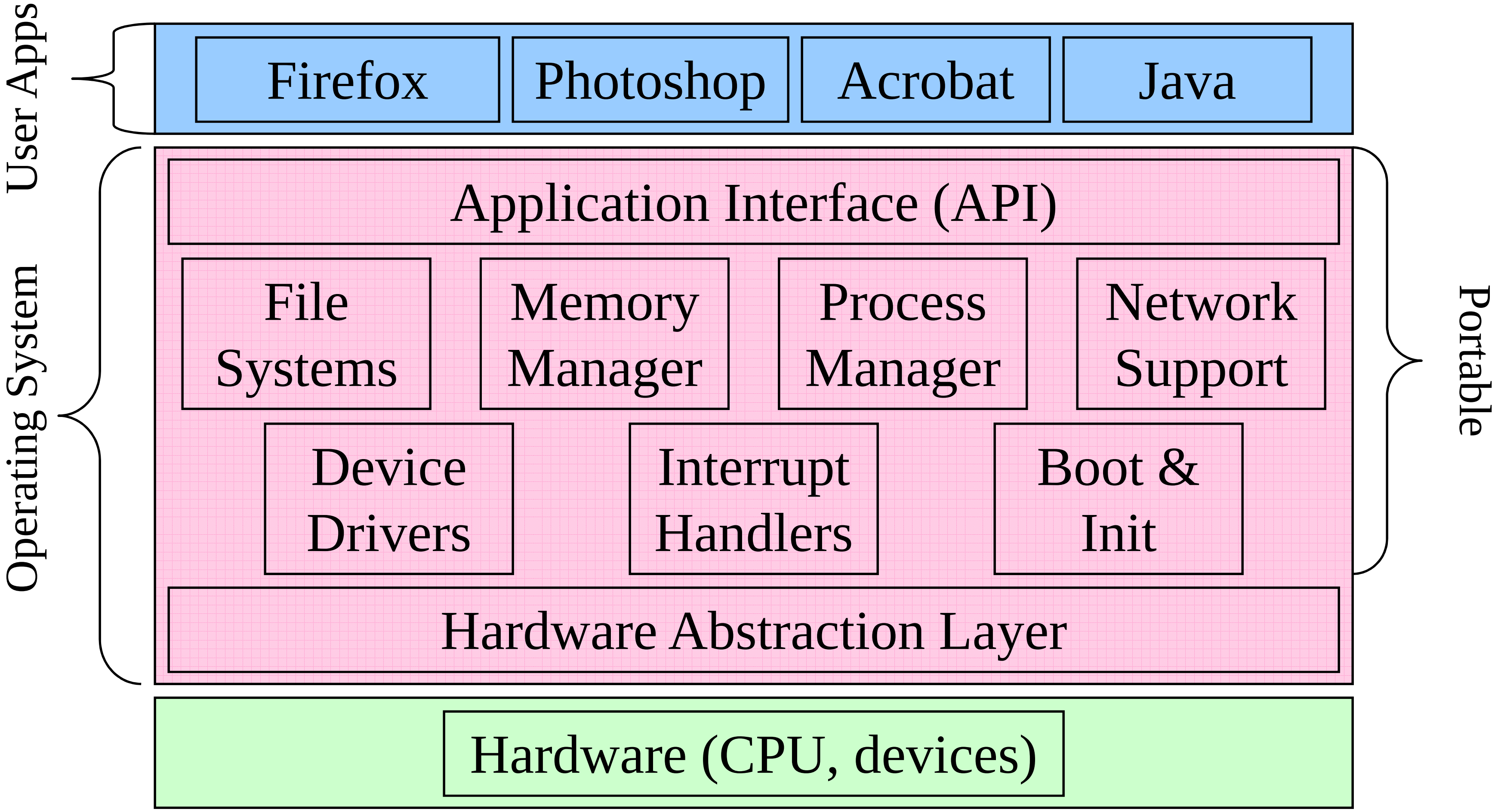
- An example of layering in modern operating systems
- Goal: separates hardware-specific routines from the "core" OS
  - Provides portability
  - Improves readability



Core OS
(file system,
scheduler,
system calls)

Hardware Abstraction Layer
(device drivers,
assembly routines)

The Sanitized Picture of OS Structure



User Apps

Firefox

Photoshop

Acrobat

Java

Operating System

Application Interface (API)

File Systems

Memory Manager

Process Manager

Network Support

Device Drivers

Interrupt Handlers

Boot & Init

Hardware Abstraction Layer

Portable

Hardware (CPU, devices)

Lower-level architecture and the OS

- Operating system functionality is dictated, at least in part, by the underlying hardware architecture
  - » includes instruction set (synchronization, I/O, …)
  - » also hardware components like MMU or DMA controllers
- Architectural support can vastly simplify (or complicate!) OS tasks
  - » e.g.: early PC operating systems (DOS, MacOS) lacked support for virtual memory, in part because at that time PCs lacked necessary hardware support

Architectural features affecting OS's

- These features were built primarily to support OS's:
    - » timer (clock) operation
    - » synchronization instructions (e.g., atomic test-and-set)
    - » memory protection
    - » I/O control operations
    - » interrupts and exceptions
    - » protected modes of execution (kernel vs. user)
    - » protected instructions
    - » system calls (and software interrupts)

Protected instructions

- some instructions are restricted to the OS
  - » known as protected or privileged instructions
- e.g., only the OS can:
  - » directly access I/O devices (disks, network cards)
    - why?
  - » manipulate memory state management
    - page table pointers, TLB loads, etc.
    - why?
  - » manipulate special ‘mode bits’
    - interrupt priority level, user/kernel mode bit
    - why?
  - » halt instruction
    - why?

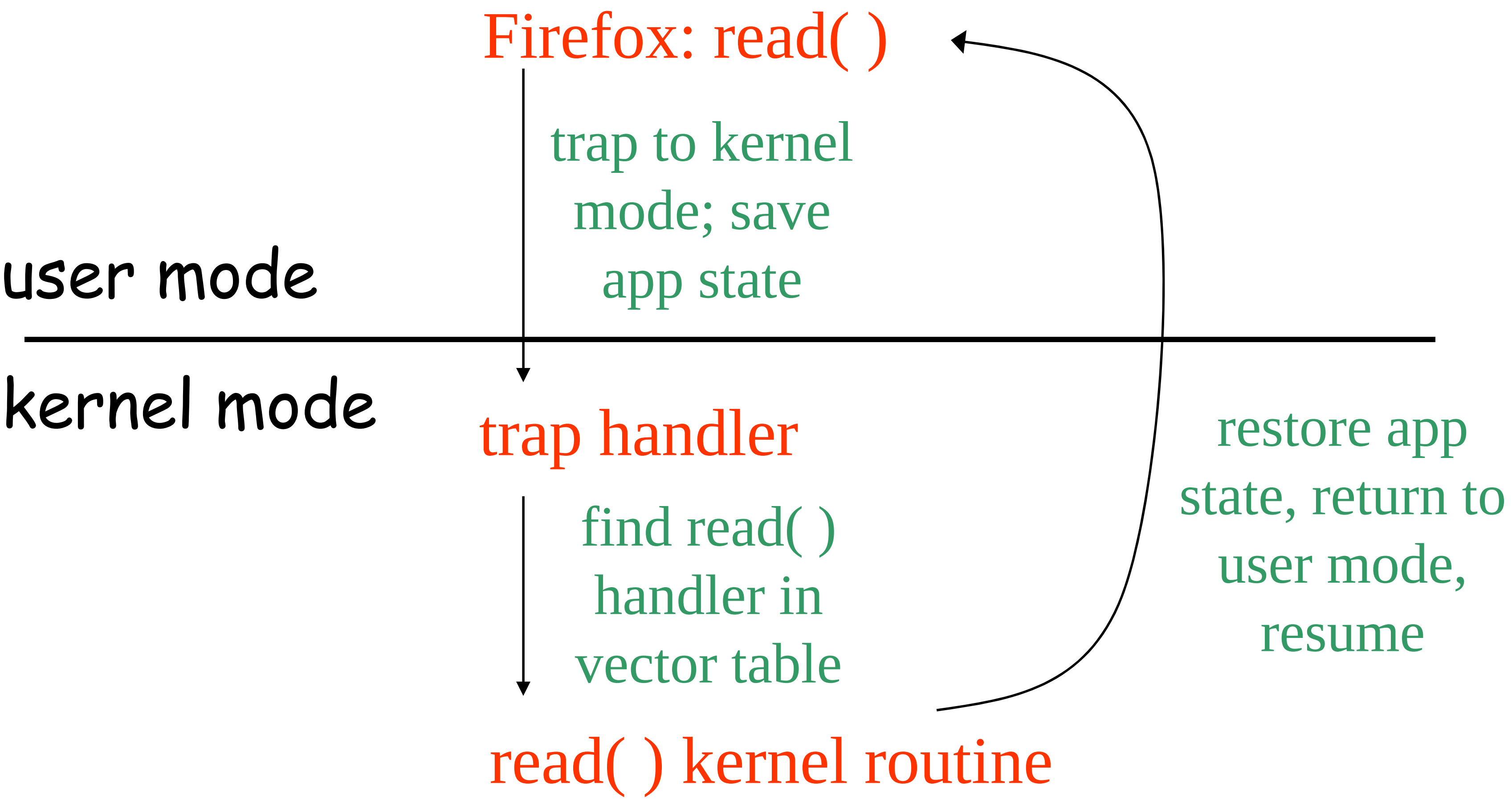
OS protection

- So how does the processor know if a protected instruction should be executed?
  - » the architecture must support at least two modes of operation: kernel mode and user mode
  - » mode is set by status bit in a protected processor register
    - user programs execute in user mode
    - OS executes in kernel mode (OS == kernel)
- Protected instructions can only be executed in the kernel mode
  - » what happens if user mode executes a protected instruction?

Crossing protection boundaries

- So how do user programs do something privileged?
  - e.g., how can you write to a disk if you can’t do I/O instructions?
- User programs must call an OS procedure
  - OS defines a sequence of system calls
  - how does the user-mode to kernel-mode transition happen?
- There must be a system call instruction, which:
  - causes an exception (throws a software interrupt), which vectors to a kernel handler
  - passes a parameter indicating which system call to invoke
  - saves caller’s state (regs, mode bit) so they can be restored
  - OS must verify caller’s parameters (e.g., pointers)
  - must be a way to return to user mode once done

A kernel crossing illustrated



Firefox: read( )

trap to kernel
mode; save
app state

user mode

kernel mode

trap handler

find read( )
handler in
vector table

read( ) kernel routine

restore app
state, return to
user mode,
resume

System call issues

- What would happen if kernel didn’t save state?
- Why must the kernel verify arguments?
- How can you reference kernel objects as arguments or results to/from system calls?

OS control flow

- after the OS has booted, all entry to the kernel happens as the result of an event
  - » event immediately stops current execution
  - » changes mode to kernel mode, event handler is called
- kernel defines handlers for each event type
  - » specific types are defined by the architecture
    - e.g.: timer event, I/O interrupt, system call trap
  - » when the processor receives an event of a given type, it
    - transfers control to handler within the OS
    - handler saves program state (PC, regs, etc.)
    - handler functionality is invoked
    - handler restores program state, returns to program

Interrupts and exceptions

- Two main types of events: interrupts and exceptions
  - » exceptions are caused by software executing instructions
    - e.g., the x86 ‘int’ instruction, MIPS ‘syscall’ instruction
    - e.g., a page fault, write to a read-only page, divide by 0
    - an expected exception is a “trap”, unexpected is a “fault”
  - » interrupts are caused by hardware devices
    - e.g., device finishes I/O
    - e.g., timer fires

I/O control

- Issues:
  - » how does the kernel start an I/O?
    - special I/O instructions
    - memory-mapped I/O
  - » how does the kernel notice an I/O has finished?
    - polling
    - interrupts
- Interrupts are basis for asynchronous I/O
  - » device performs an operation asynch to CPU
  - » device sends an interrupt signal on bus when done
  - » in memory, a vector table contains list of addresses of kernel routines to handle various interrupt types
  - » CPU switches to address indicated by vector specified by interrupt signal

Timers

- How can the OS prevent runaway user programs from hogging the CPU (infinite loops?)
  - » use a hardware timer that generates a periodic interrupt
  - » before it transfers to a user program, the OS loads the timer with a time to interrupt
    - "quantum": how big should it be set?
  - » when timer fires, an interrupt transfers control back to OS
    - at which point OS must decide which program to schedule next
    - very interesting policy question: we'll dedicate a class to it
- Should the timer be privileged?
  - » for reading or for writing?

Synchronization

- Interrupts cause a wrinkle:
  - » may occur any time, causing code to execute that interferes with code that was interrupted
  - » OS must be able to synchronize concurrent processes
- Synchronization:
  - » guarantee that short instruction sequences (e.g., read-modify-write) execute atomically
  - » one method: turn off interrupts before the sequence, execute it, then re-enable interrupts
    - architecture must support disabling interrupts
  - » another method: have special complex atomic instructions
    - read-modify-write
    - test-and-set
    - load-linked store-conditional

“Concurrent programming”

- Management of concurrency and asynchronous events is biggest difference between “systems programming” and “traditional application programming”
  - » modern “event-oriented” application programming is a middle ground
- Arises from the architecture
- Can be sugar-coated, but cannot be totally abstracted away
- Huge intellectual challenge
  - » Unlike vulnerabilities due to buffer overruns, which are just sloppy programming

Architectures are still evolving

- New features are still being introduced to meet modern demands, e.g.:
  - » Support for virtual machine monitors
  - » Hardware transaction support (to simplify parallel programming)
  - » Support for security (encryption, trusted modes)
  - » Increasingly sophisticated video / graphics
  - » Other stuff that hasn't been invented yet…

- In current technology transistors are free – CPU makers are looking for new ways to use transistors to make their chips more desirable.

- Intel's big challenge: finding applications that require new hardware support, so that you will want to upgrade to a new computer to run them.