Computer Systems

CSE 410 Autumn 2013

20 – OS Introduction & Structure

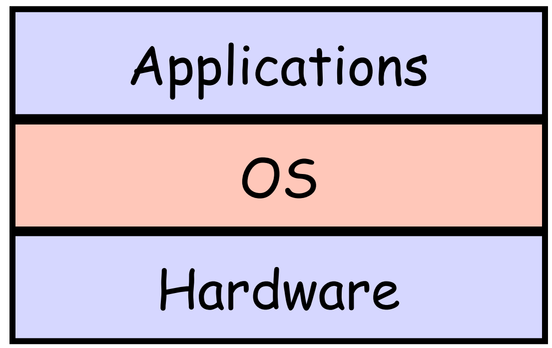
Slides adapted from CSE 451 material by Gribble, Lazowska, Levy, and Zahorjan

What is an Operating System?

- **Answers:**
  - I don't know
  - Nobody knows
  - The book has some ideas – see Sec. 1.7
  - They're programs – big hairy programs
    - The Linux source has over 1.7M lines of C

Okay. What are some goals of an OS?

The traditional picture



- **"The OS is everything you don't need to write in order to run your application"**
- **This depiction invites you to think of the OS as a library**
  - In some ways, it is:
    - all operations on I/O devices require OS calls (syscalls)
  - In other ways, it isn't:
    - you use the CPU/memory without OS calls
    - it intervenes without having been explicitly called

The OS and hardware

- **An OS mediates programs' access to hardware resources (*sharing* and *protection*)**
  - computation (CPU)
  - volatile storage (memory) and persistent storage (disk, etc.)
  - network communications (TCP/IP stacks, Ethernet cards, etc.)
  - input/output devices (keyboard, display, sound card, etc.)
- **The OS abstracts hardware into logical resources and well-defined interfaces to those resources (*ease of use*)**
  - 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" its own virtual machine, thinks it "owns" the computer
    - OS protects programs from each other
    - 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 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 (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: 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 perhaps charge for it?

There are tradeoffs, not right and wrong!

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)
  - privileged instructions
  - system calls (and software interrupts)
  - virtualization architectures

Privileged instructions

- **some instructions are restricted to the OS**
  - known as 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
    - why?

OS protection

- **So how does the processor know if a privileged instruction should be executed?**
  - the architecture must support at least two modes of operation: kernel mode and user mode
    - VAX, x86 support 4 protection modes; OS might not use all 4
  - mode is set by status bit in a protected processor register
    - user programs execute in user mode
    - OS executes in kernel (privileged) mode (OS == kernel)
- **Privileged instructions can only be executed in kernel (privileged) mode**
  - what happens if code running in user mode attempts to execute a privileged instruction?

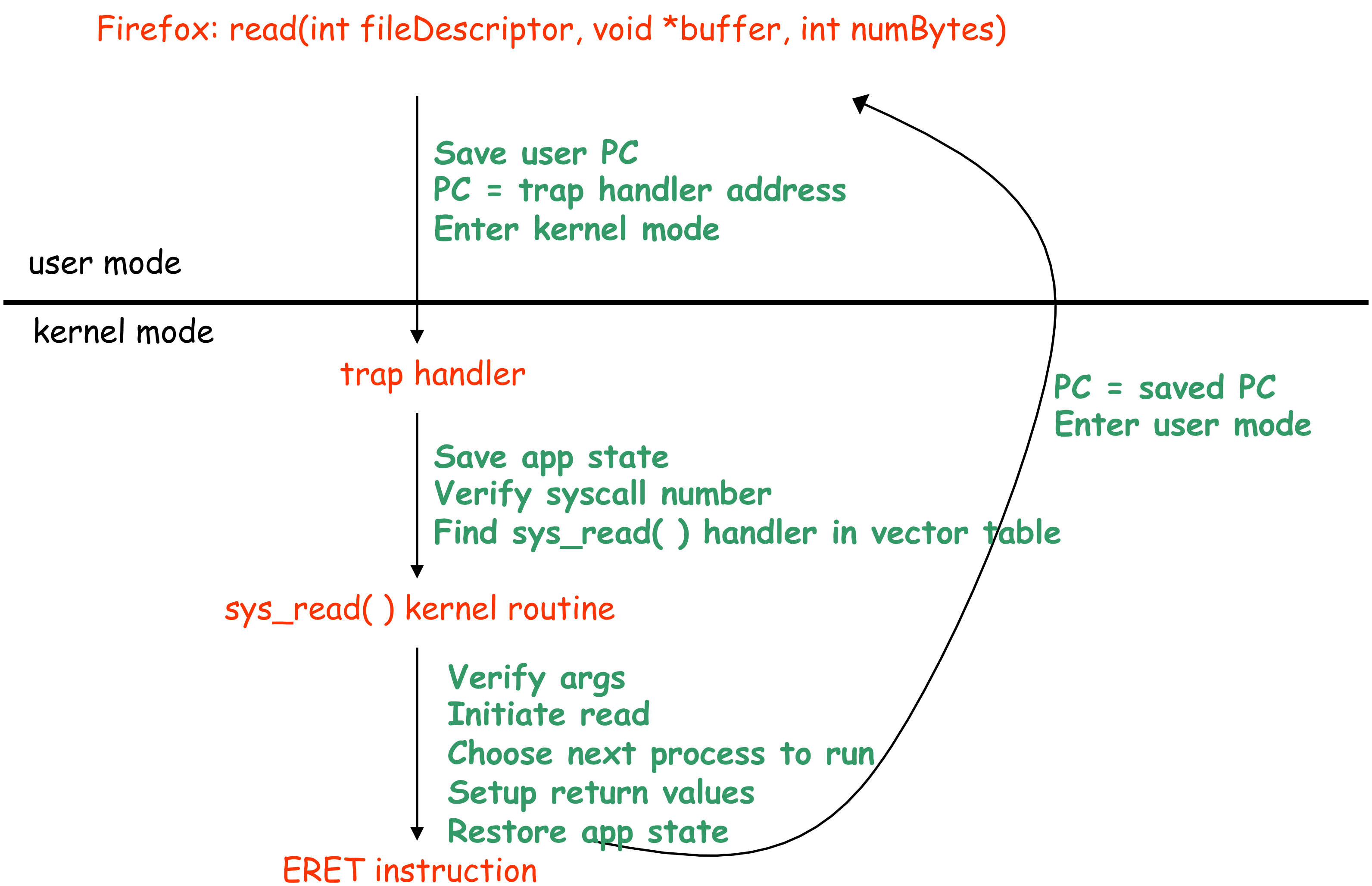
Crossing protection boundaries

- **So how do user programs do something privileged?**
  - e.g., how can you write to a disk if you can't execute an I/O instructions?
- **User programs must call an OS procedure – that is, get the OS to do it for them**
  - OS defines a set of system calls
  - User-mode program executes system call instruction (**`int`** on x86)
- **x86 `int` / x86-64 syscall instructions**
  - Like a <u>protected</u> procedure call
  - We've seen this earlier, but a few more details…

System calls

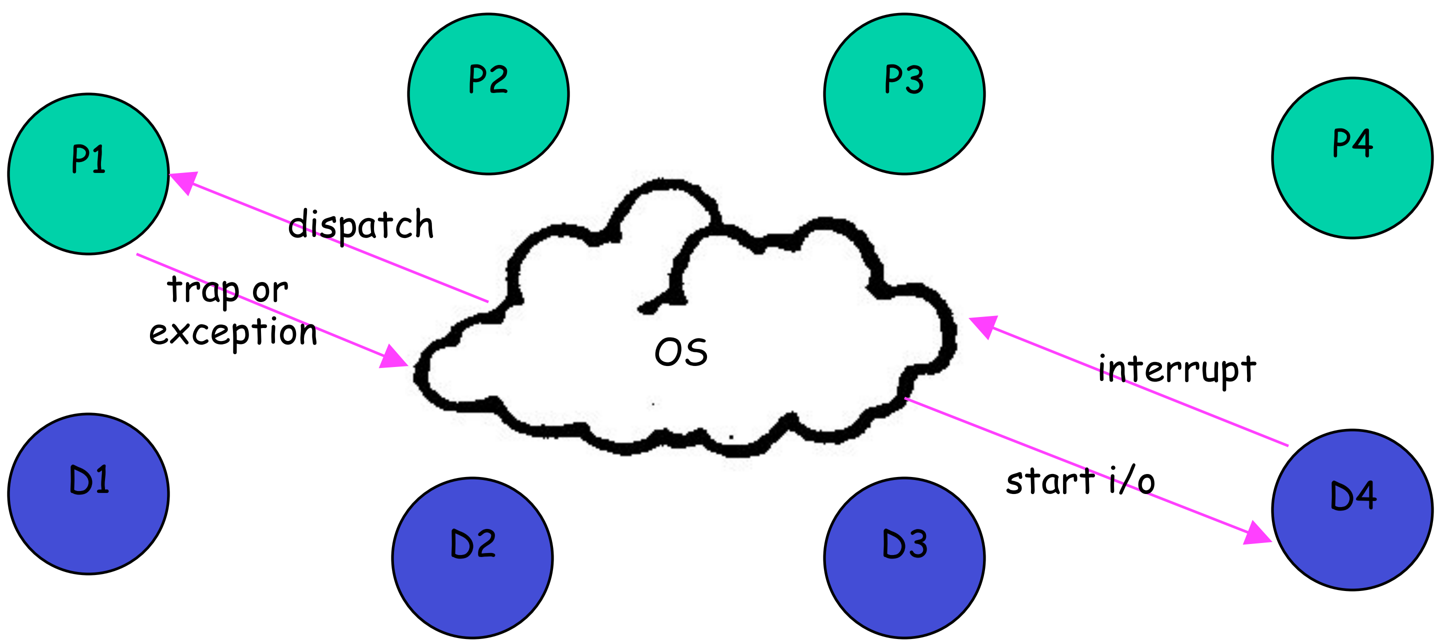
- **The syscall instruction atomically:**
  - Saves the current PC
  - Sets the execution mode to privileged
  - Sets the PC (IP) to a handler address
- **With that, it's a lot like a local procedure call**
  - Caller puts arguments in a place callee expects (registers or stack)
    - One of the args is a syscall number, indicating which OS function to invoke
  - Callee (OS) saves caller's state (registers, other control state) so it can use the CPU
  - OS function code runs
    - OS must verify caller's arguments (e.g., pointers)
  - OS returns using a special instruction
    - Automatically sets PC to return address and sets execution mode to user

A kernel crossing illustrated

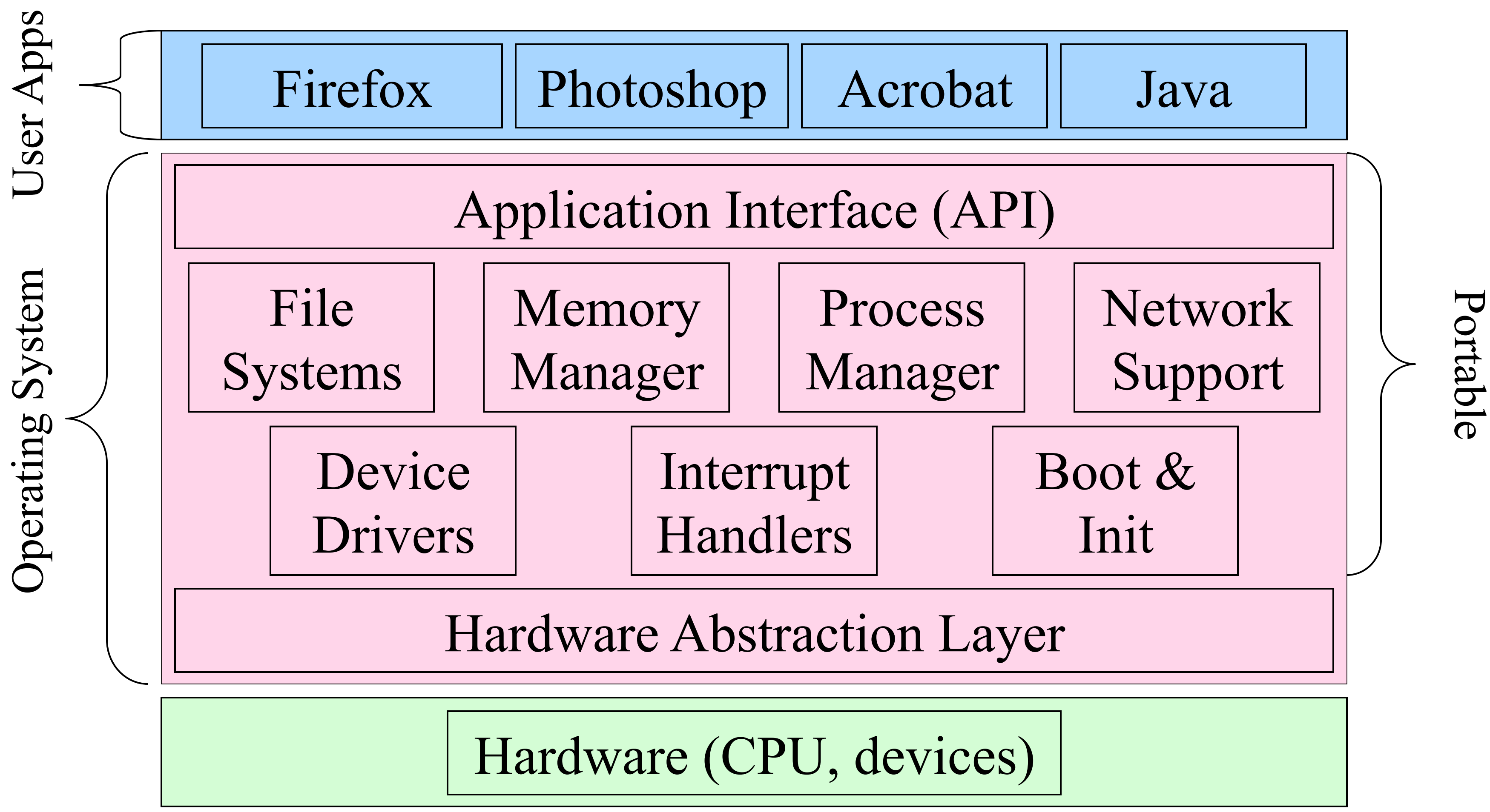


OS structure

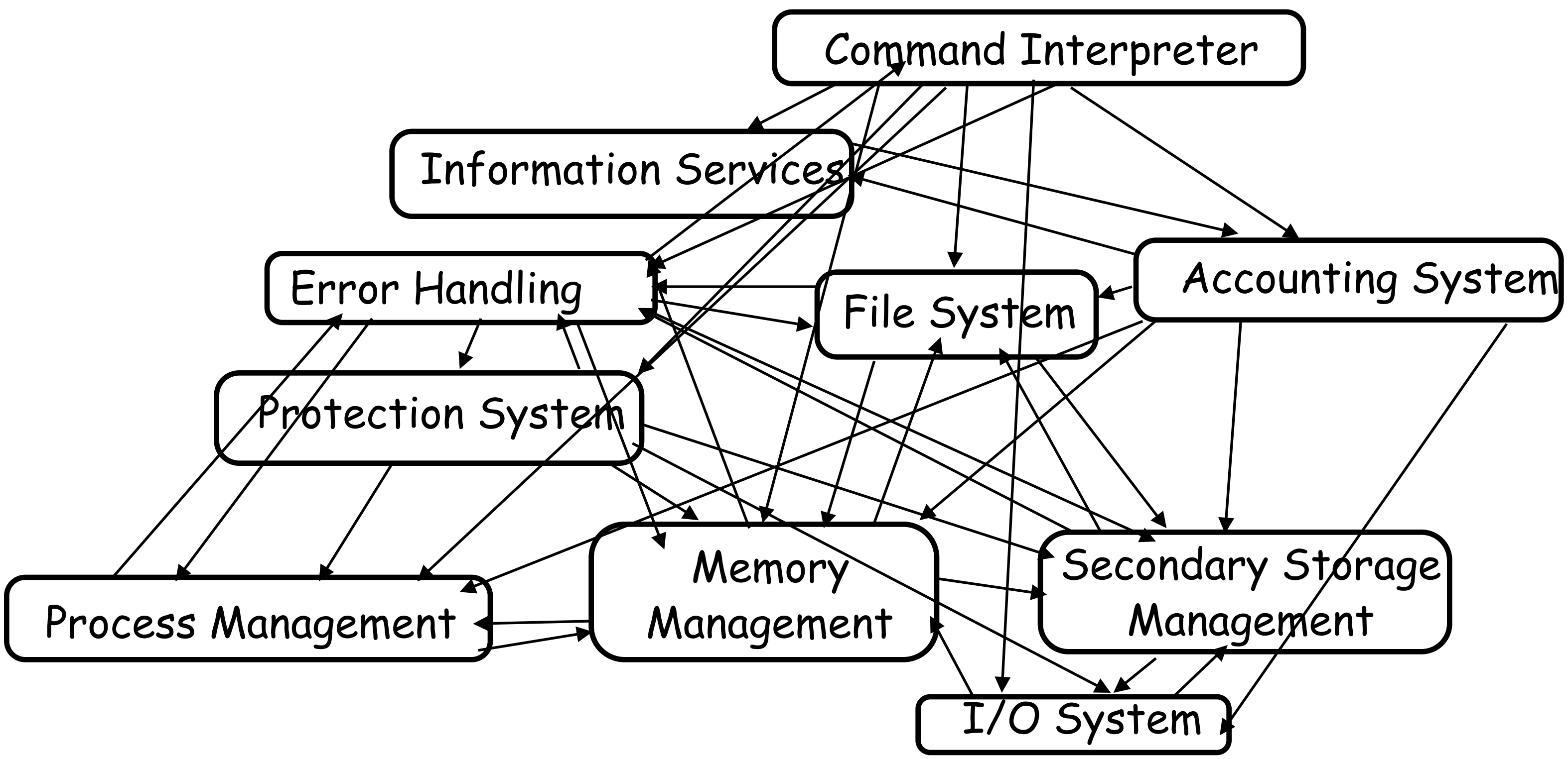
- **The OS sits between application programs and the hardware**
  - it mediates access and abstracts away ugliness
  - programs request services via traps or exceptions
  - devices request attention via interrupts



The Classic Diagram…



But reality isn't always that simple…



Major OS components

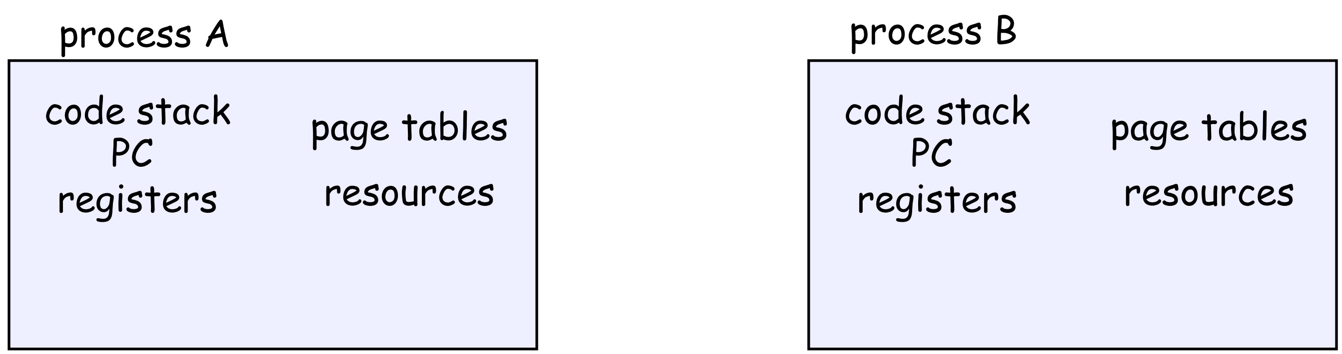
- processes
- memory
- I/O
- secondary storage
- file systems
- protection
- shells (command interpreter, or OS UI)
- GUI
- networking

Process management

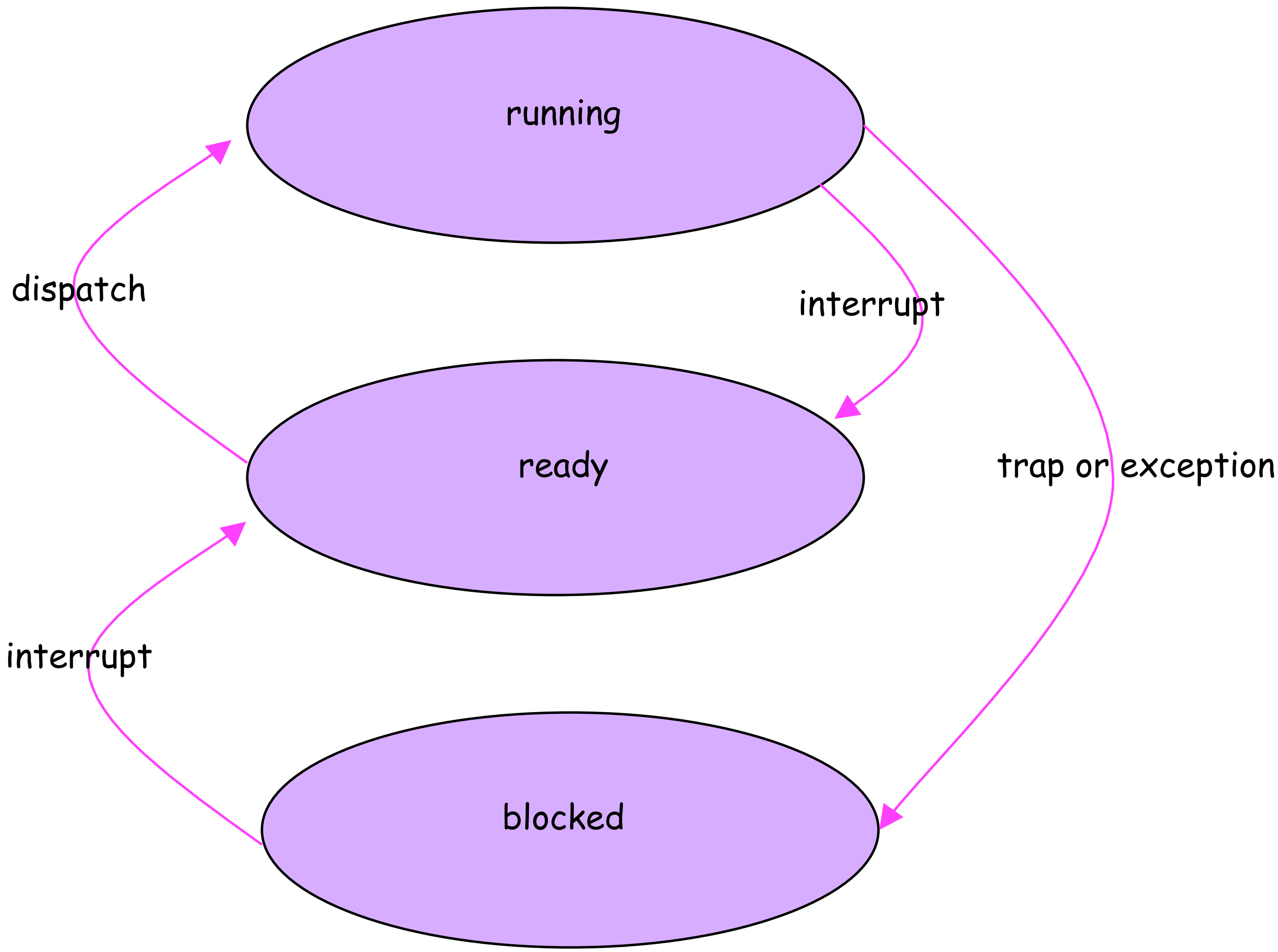
- **An OS executes many kinds of activities:**
  - users' programs
  - batch jobs or scripts
  - system programs
    - print spoolers, name servers, file servers, network daemons, …
- **Each of these activities is encapsulated in a process**
  - a process includes the execution context
    - PC, registers, VM, OS resources (e.g., open files), etc…
    - plus the program itself (code and data)
  - the OS's process module manages these processes
    - creation, destruction, scheduling, …

Program/processor/process

- **Note that a program is totally passive**
  - just bytes on a disk that encode instructions to be run
- **A process is an instance of a program being executed by a (real or virtual) processor**
  - at any instant, there may be many processes running copies of the same program (e.g., an editor); each process is separate and (usually) independent
  - Linux: `ps -auwx` to list all processes



States of a user process



Process operations

- **The OS provides the following kinds operations on processes (i.e., the process abstraction interface):**
  - create a process
  - delete a process
  - suspend a process
  - resume a process
  - clone a process
  - inter-process communication
  - inter-process synchronization
  - create/delete a child process (subprocess)

Memory management

- **The primary memory is the directly accessed storage for the CPU**
  - programs must be stored in memory to execute
  - memory access is fast
  - but memory doesn't survive power failures
- **OS must:**
  - allocate memory space for programs (explicitly and implicitly)
  - deallocate space when needed by rest of system
  - maintain mappings from physical to virtual memory
    - through page tables
  - decide how much memory to allocate to each process
    - a policy decision
  - decide when to remove a process from memory
    - also policy

I/O

- **A big chunk of the OS kernel deals with I/O**
  - hundreds of thousands of lines in NT (Windows)
- **The OS provides a standard interface between programs (user or system) and devices**
  - file system (disk), sockets (network), frame buffer (video)
- **Device drivers are the routines that interact with specific device types**
  - encapsulates device-specific knowledge
    - e.g., how to initialize a device, how to request I/O, how to handle interrupts or errors
    - examples: SCSI device drivers, Ethernet card drivers, video card drivers, sound card drivers, …
- **Note: Windows has ~35,000 device drivers!**

Secondary storage

- **Secondary storage (disk, tape) is persistent memory**
  - often magnetic media, survives power failures (hopefully)
- **Routines that interact with disks are typically at a very low level in the OS**
  - used by many components (file system, VM, …)
  - handle scheduling of disk operations, head movement, error handling, and often management of space on disks
- **Usually independent of file system**
  - although there may be cooperation
  - file system knowledge of device details can help optimize performance
    - e.g., place related files close together on disk

File systems

- **Secondary storage devices are crude and awkward**
  - e.g., "write 4096 byte block to sector 12"
- **File system: a convenient abstraction**
  - defines logical objects like files and directories
    - hides details about where on disk files live
  - as well as operations on objects like read and write
    - read/write byte ranges instead of blocks
- **A file is the basic unit of long-term storage**
  - file = named collection of persistent information
- **A directory is just a special kind of file**
  - directory = named file that contains names of other files and metadata about those files (e.g., file size)
- **Note: Sequential byte stream is only one possibility!**

File system operations

- **The file system interface defines standard operations:**
  - file (or directory) creation and deletion
  - manipulation of files and directories (read, write, extend, rename, protect)
  - copy
  - lock
- **File systems also provide higher level services**
  - accounting and quotas
  - backup (must be incremental and online!)
  - (sometimes) indexing or search
  - (sometimes) file versioning

Protection

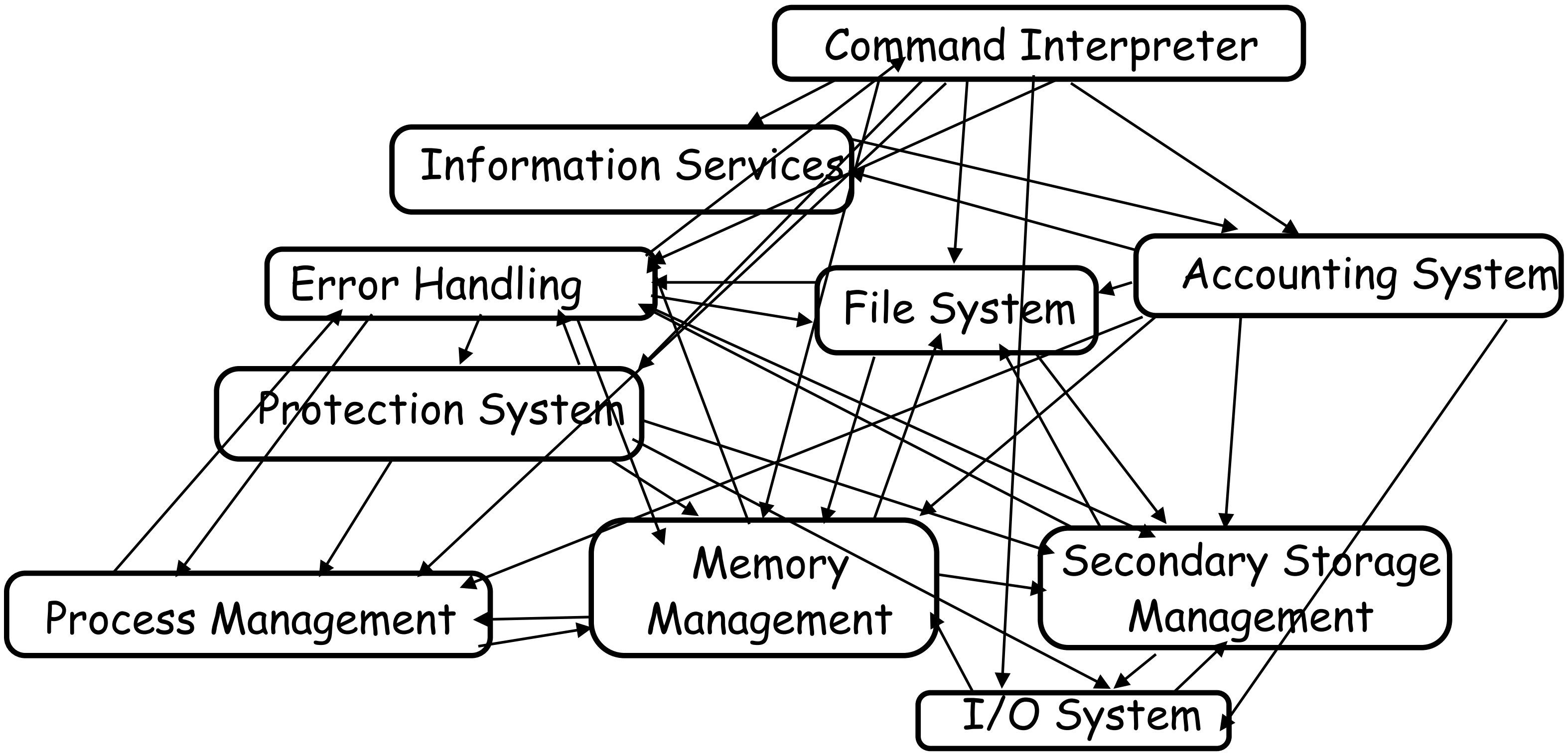
- **Protection is a general mechanism used throughout the OS**
  - all resources needed to be protected
    - memory
    - processes
    - files
    - devices
    - CPU time
    - …
  - protection mechanisms help to detect and contain unintentional errors, as well as preventing malicious destruction

Command interpreter (shell)

- **A particular program that handles the interpretation of users' commands and helps to manage processes**
  - user input may be from keyboard (command-line interface), from script files, or from the mouse (GUIs)
  - allows users to launch and control new programs
- **On some systems, command interpreter may be a standard part of the OS (mostly old/historical or tiny systems)**
- **On others, it's just non-privileged code that provides an interface to the user**
  - e.g., bash/csh/tcsh/zsh on UNIX
- **On others, there may be no command language**
  - e.g., classic MacOS (pre-OS X)

OS structure

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

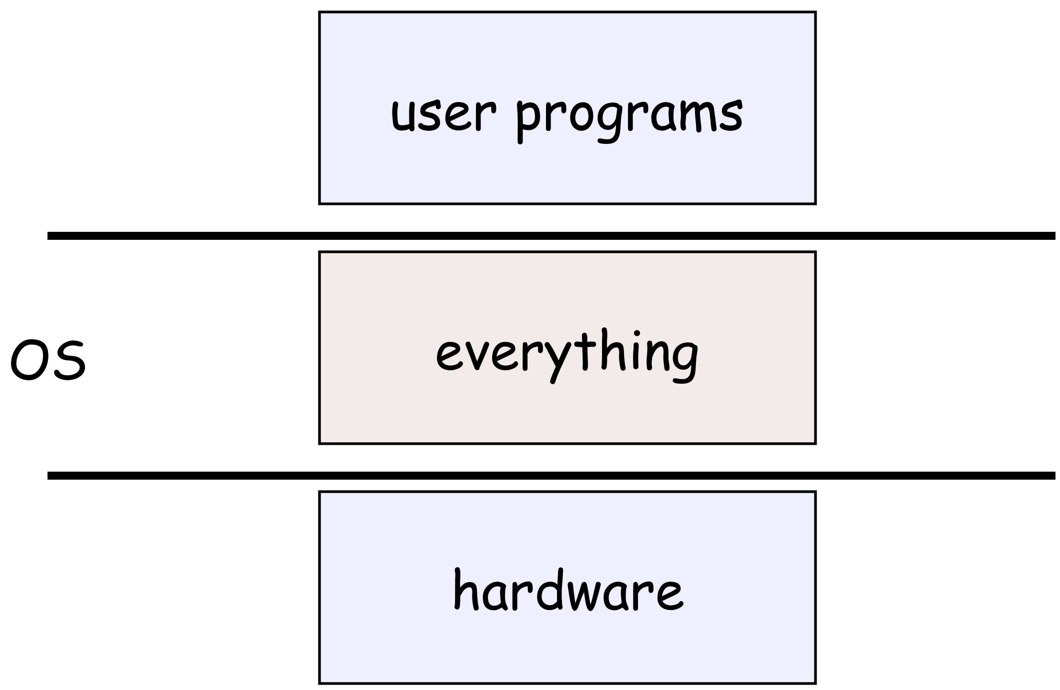


OS structure

- **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, …
  - we won't be able to go into detail in the remaining few classes (alas…)

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

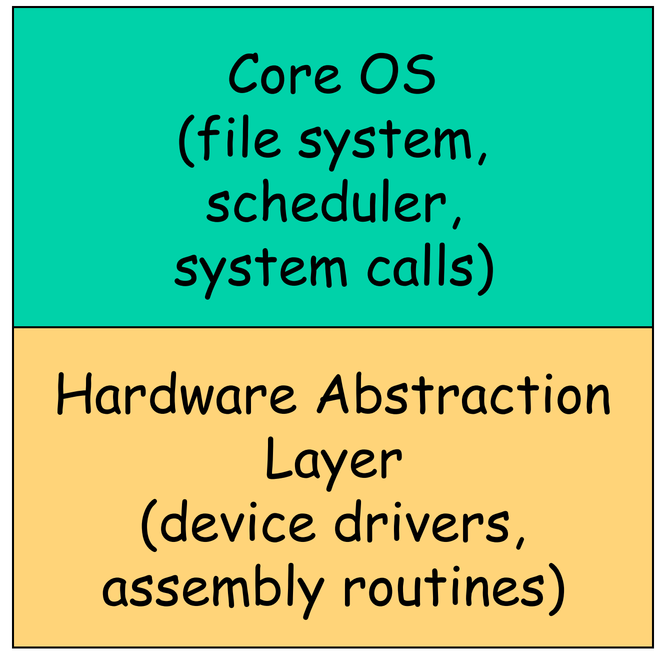
- **The traditional approach is layering**
  - implement OS as a set of layers
  - each layer presents an enhanced 'virtual machine' to the layer above
- **The first description of this approach was Dijkstra's THE system**
  - Layer 5: Job Managers
    - Execute users' programs
  - Layer 4: Device Managers
    - 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

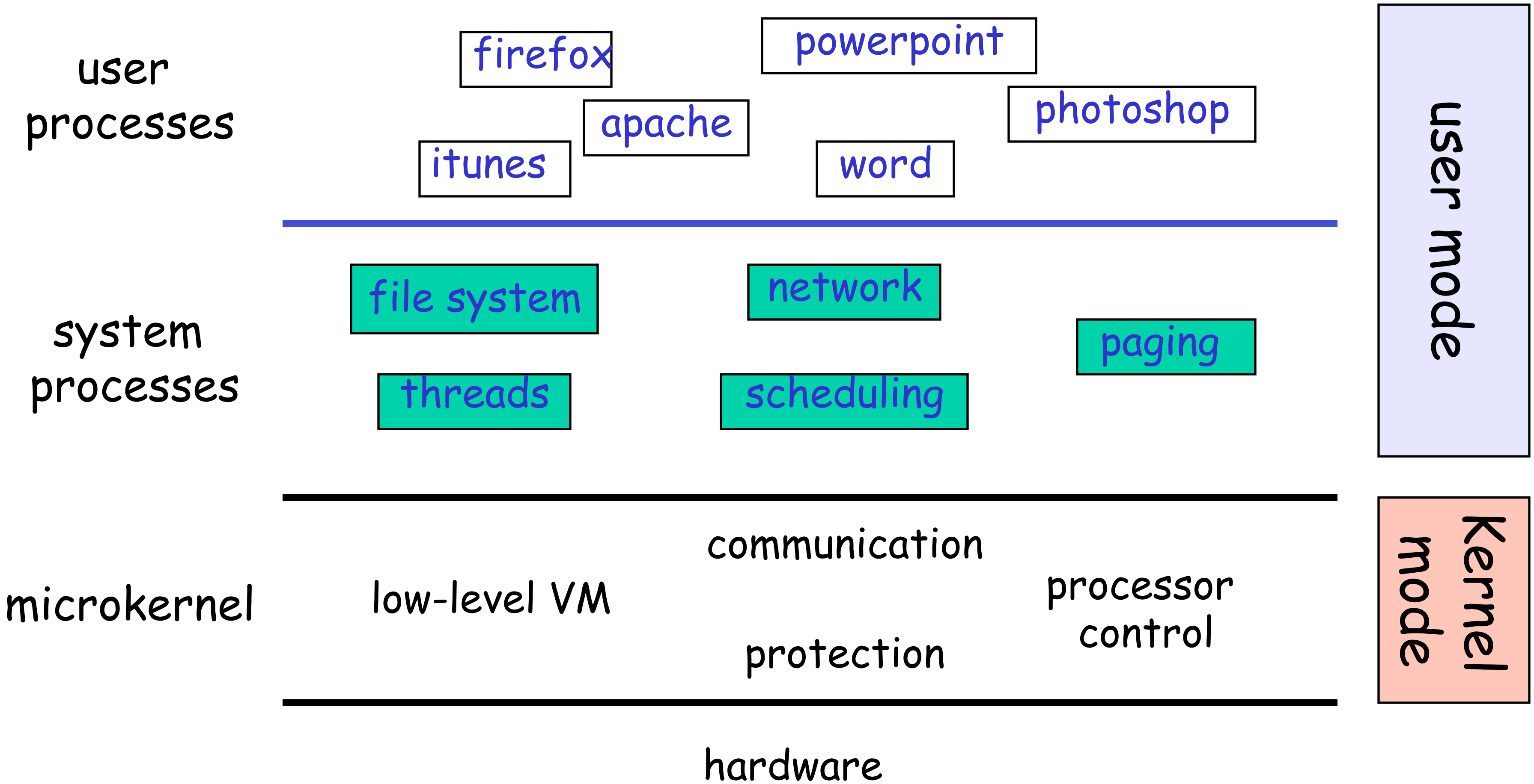
- **An example of layering in modern operating systems**
- **Goal: separates hardware-specific routines from the "core" OS**
  - Provides portability
  - Improves readability



Microkernels

- **Popular in the late 80's, early 90's**
  - recent resurgence of popularity
- **Goal:**
  - minimize what goes in kernel
  - organize rest of OS as user-level processes
- **This results in:**
  - better reliability (isolation between components)
  - ease of extension and customization
  - poor performance (user/kernel boundary crossings)
- **First microkernel system was Hydra (CMU, 1970)**
  - Follow-ons: Mach (CMU), Chorus (French UNIX-like OS), OS X (Apple), in some ways NT (Microsoft)

Microkernel structure illustrated



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Summary & Next

- **Summary**
  - OS design has been a evolutionary process of trial and error. Probably more error than success
  - Successful OS designs have run the spectrum from monolithic, to layered, to micro kernels, to virtual machine monitors
  - The role and design of an OS are still evolving
  - It is impossible to pick one “correct” way to structure an OS
- **Next…**
  - Processes and threads, one of the most fundamental pieces in an OS
  - What these are, what do they do, and how do they do it