CSE 451: Operating Systems
Winter 2001

Lecture 3
Operating System Structure:
Components and Interfaces

OS Structure

- We've described how an OS is sandwiched between the hardware and user-level processes
  - and in the previous class, we talked about the relationship between OS and hardware
  - this class: look at the functionality that the OS provides to the user-level, and the components that provide it
  - later in the course: explore each component in detail
- A useful taxonomy:
  - modules: the major OS services and abstractions
  - interfaces: specific operations that modules provide
  - structure: the way the modules are stitched together

Major OS components

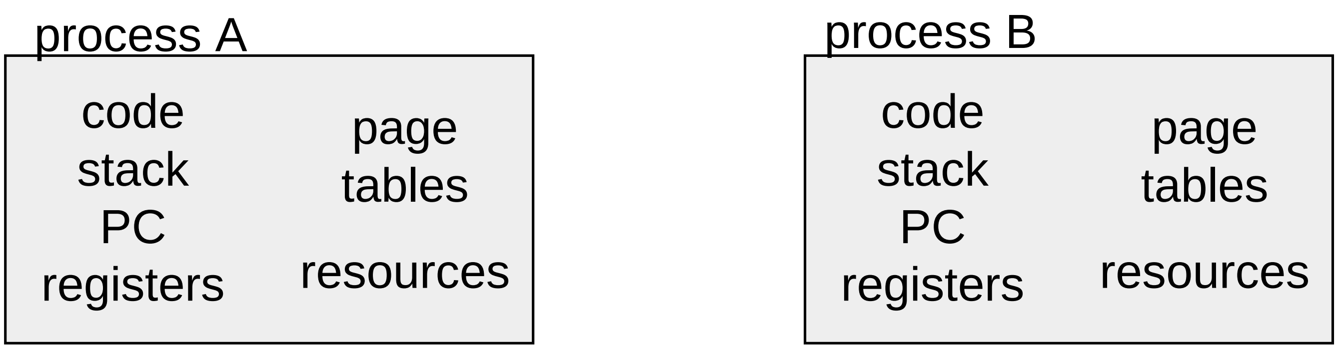
- processes
- memory
- I/O
- secondary storage
- file systems
- protection
- accounting
- shells (command interpreter, or OS UI)

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, …

Processes

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



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 (or RAM) is the directly accessed storage for the CPU
  - programs must be stored in memory to execute
  - memory access is fast (e.g. 60 ns to load/store)
    - 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
- 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, …

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 long-term storage unit
  - 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)

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
  - (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
    - …
  - protection mechanisms help to detect and contain errors, as well as preventing malicious destruction

Command Interpreter (shell)

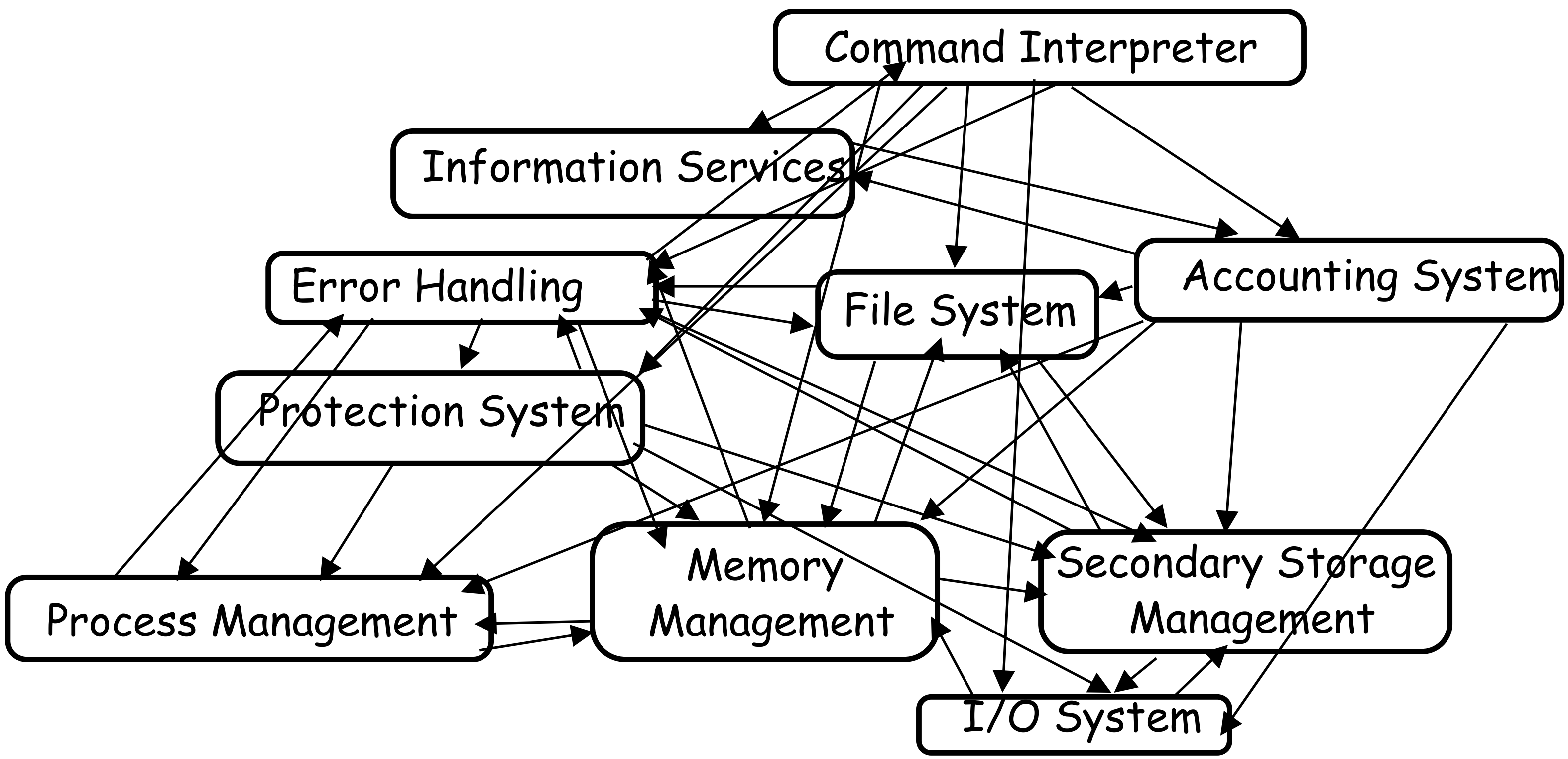
- a particular program that handles the interpretation of users' commands and helps to manage processes
  - user input may be from keyboard (command-line interface), from script files, or from the mouse (GUIs)
  - allows users to launch and control new programs
- on some systems, command interpreter may be a standard part of the OS (e.g. MSDOS, Apple II)
- on others, it's just a non-privileged process 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. MacOS

Accounting

- Keeps track of resource usage
  - both to enforce quotas
    - “you’re over your disk space limit”
  - or to produce bills
    - important for timeshared computers like mainframes

OS Structure

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

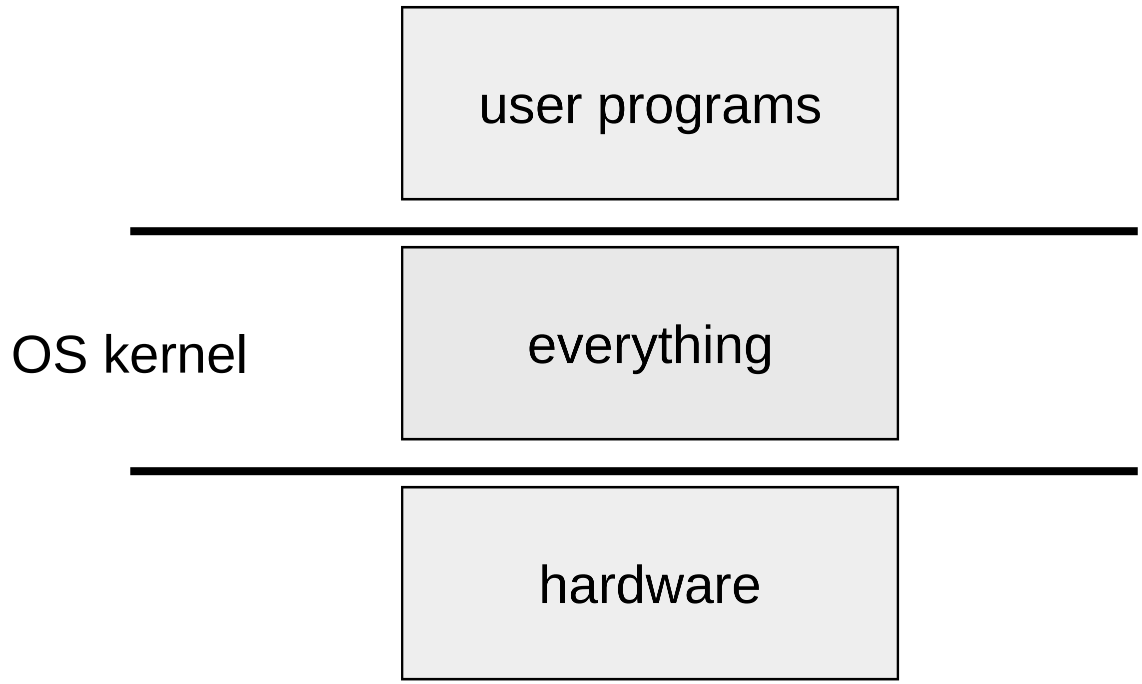


OS Structure

- 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

- Traditionally, OS's (like UNIX) were built as a monolithic kernel:



Monolithic kernels

- 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 acts as a ‘virtual machine’ to the layer above
- The first description of this approach was Dijkstra’s THE system
  - layer 0: hardware
  - layer 1: CPU scheduling
  - layer 2: memory management (sees virtual processors)
  - layer 3: console device (sees VM segments)
  - layer 4: I/O device buffering (sees ‘virtual console’)
  - layer 5: user programs (sees ‘virtual I/O drivers’)
- 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

Microkernels

- Popular in the late 80's, early 90's
  - recent resurgence of popularity for small devices
- 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), and in some ways NT (Microsoft), OSX (Apple)

Microkernel structure illustrated