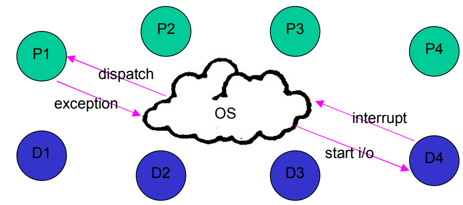
CSE 451: Operating Systems
Spring 2006

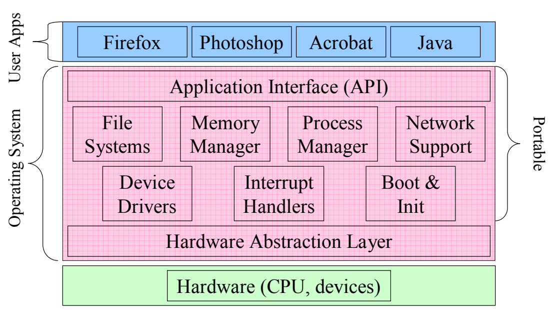
Module 3
Operating System
Components and Structure

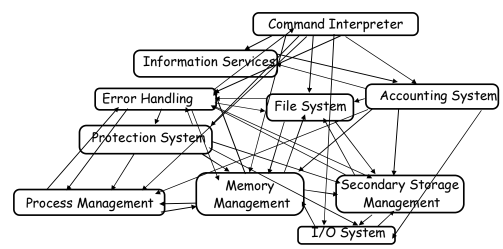
John Zahorjan
zahorjan@cs.washington.edu
Allen Center 534

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

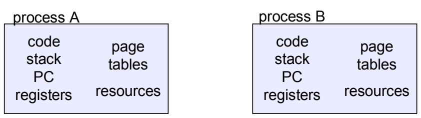
- processes
- memory
- I/O
- secondary storage
- file systems
- protection
- accounting
- shells (command interpreter, or OS UI)
- GUI
- networking

Process management

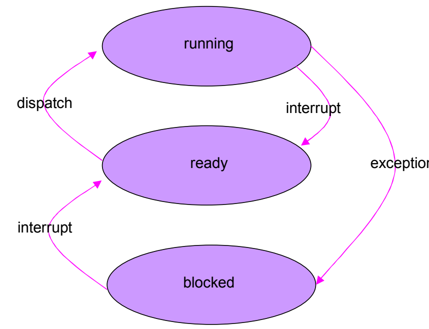
- An OS executes many kinds of activities:
  - users' programs
  - batch jobs or scripts
  - system programs
    - print spoolers, name servers, file servers, network daemons, …
- Each of these activities is encapsulated in a process
  - a process includes the execution context
    - PC, registers, VM, 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 -auwwx` 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 (or RAM) is the directly accessed storage for the CPU
  - programs must be stored in memory to execute
  - memory access is fast (e.g., 10 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, …
- 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 (e.g., MS DOS, Apple II)
- On others, it's just non-privileged code that provides an interface to the user
  - e.g., bash (or csh or tcsh or zsh or sh) on UNIX
- On others, there may be no command language
  - e.g., MacOS

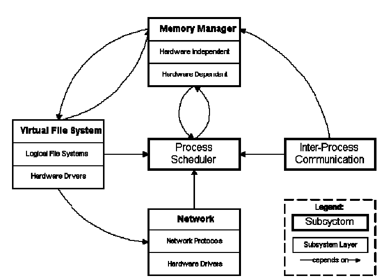
Accounting

- Keeps track of resource usage
  - both to enforce quotas
    - "you're over your disk space limit"
  - or to produce bills
    - timeshared computers like mainframes
    - hosted services

GUI … Networking … etc.

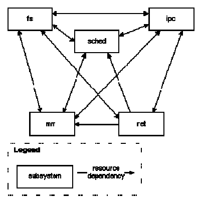
OS structure

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



Conceptual Organization
(Linux 1998)
(from http://plg.uwaterloo.ca/~itbowman/CS746G/a2/#_Toc411854285)

OS structure



Actual Organization

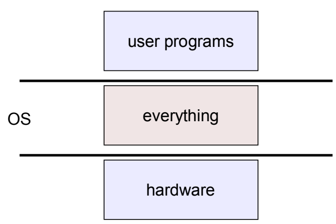
(from http://plg.uwaterloo.ca/~itbowman/CS746G/a2/#_Toc411854285)

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

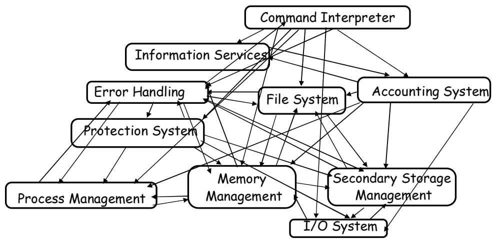
Layering

- 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

OS structure



Actual Organization

(artist's rendition)

3/31/2006 25

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)

3/31/2006 26

Microkernel structure illustrated

user processes	firefox	apache	powerpoint	user mode
system processes	file system, threads	network, scheduling	paging	user mode
microkernel	low-level VM	communication, protection	processor control	kernel
		hardware		

3/31/2006 27