CSC 4103 - Operating Systems
Spring 2008

Lecture - II

OS Structures

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Announcements

- Teaching Assistant:
  - Asim Shrestrah
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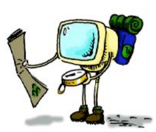
- All of you should be now in the class mailing list.
  - Let me know if you haven't received any messages yet.
- Lecture notes are available on the course web site.

Roadmap

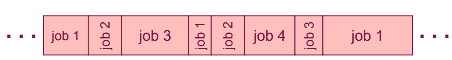
- OS Structures
  - Multiprogramming and Timesharing
  - Storage Structure
  - System Calls
- OS Design and Implementation
  - Different Design Approaches



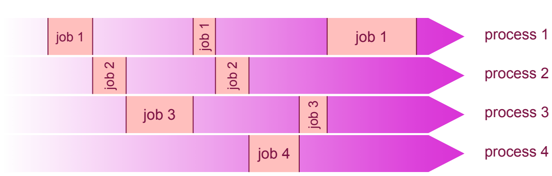
Operating System Structure

- **Multiprogramming** needed for efficiency
  - Single process cannot keep CPU and I/O devices busy at all times
  - Multiprogramming organizes jobs (code and data) so CPU always has one to execute
  - How it works:
    - A subset of total jobs in system is kept in memory simultaneously
    - One job selected and run via **job scheduling**
    - When it has to wait (for I/O for example), OS switches to another job

Multitasking Example



(a) Multitasking from the CPU's viewpoint



(b) Multitasking from the processes' viewpoint = 4 virtual program counters

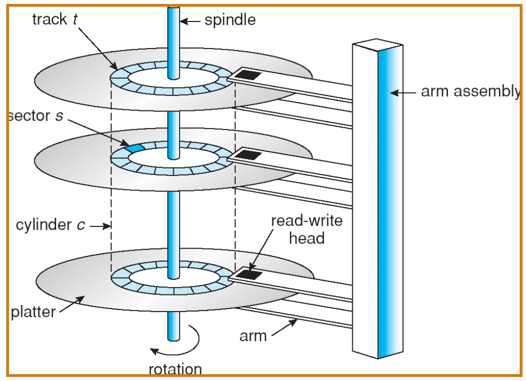
Operating System Structure

- **Timesharing** is logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing
  - **Response time** should be < 1 second
  - Each user has at least one program loaded in memory and executing ⇨ **process**
  - If several jobs ready to be brought into memory ⇨ **job scheduling**
  - If several jobs ready to run at the same time ⇨ **CPU scheduling**
  - If processes don't fit in memory, **swapping** moves them in and out to run
  - **Virtual memory** allows execution of processes not completely in memory

Storage Structure

- Main memory – only large storage media that the CPU can access directly.
- Secondary storage – extension of main memory that provides large nonvolatile storage capacity.
- Magnetic disks – rigid metal or glass platters covered with magnetic recording material
  - Disk surface is logically divided into *tracks*, which are subdivided into *sectors*.
  - The *disk controller* determines the logical interaction between the device and the computer.

Disk Architecture

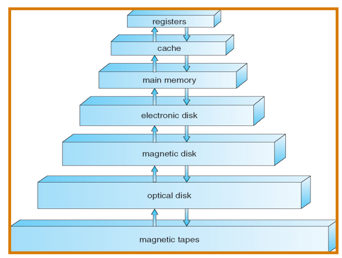


Storage Structure

- Tertiary Storage: low cost, high capacity storage
  - eg. tape libraries, CD, DVD, floppy disks
- Tape is an economical medium for purposes that do not require fast random access, e.g., backup copies of disk data, holding huge volumes of data.
- Large tape installations typically use robotic tape changers that move tapes between tape drives and storage slots in a tape library.
  - stacker – library that holds a few tapes
  - silo – library that holds thousands of tapes

Storage Hierarchy

- Storage systems organized in hierarchy.
  - Speed
  - Cost
  - Volatility*



- *Caching* – copying information into faster storage system; main memory can be viewed as a last *cache* for secondary storage.

*volatile: loses its content when the power is off.

Performance of Various Levels of Storage

- Movement between levels of storage hierarchy can be explicit or implicit

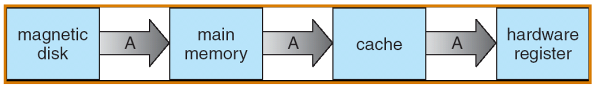
Level	1	2	3	4
Name	registers	cache	main memory	disk storage
Typical size	< 1 KB	> 16 MB	> 16 GB	> 100 GB
Implementation technology	custom memory with multiple ports, CMOS	on-chip or off-chip CMOS SRAM	CMOS DRAM	magnetic disk
Access time (ns)	0.25 – 0.5	0.5 – 25	80 – 250	5,000.000
Bandwidth (MB/sec)	20,000 – 100,000	5000 – 10,000	1000 – 5000	20 – 150
Managed by	compiler	hardware	operating system	operating system
Backed by	cache	main memory	disk	CD or tape

Caching

- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) checked first to determine if information is there
  - If it is, information used directly from the cache (fast)
  - If not, data copied to cache and used there
- Cache smaller than storage being cached
  - Cache management important design problem
  - Cache size and replacement policy

Migration of Integer A from Disk to Register

- Multitasking environments must be careful to use most recent value, not matter where it is stored in the storage hierarchy



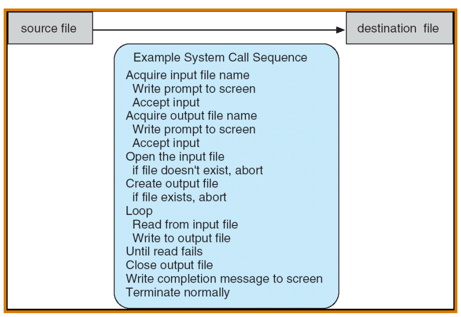
- Multiprocessor environment must provide cache coherency in hardware such that all CPUs have the most recent value in their cache
- Distributed environment situation even more complex
  - Several copies of a datum can exist

System Calls

- Programming interface to the services provided by the OS
- Typically written in a high-level language (C or C++)
- Mostly accessed by programs via a high-level **Application Program Interface (API)** rather than direct system call use
  - Ease of programming
  - portability
- Three most common APIs are Win32 API for Windows, POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and Java API for the Java virtual machine (JVM)

Example of System Calls

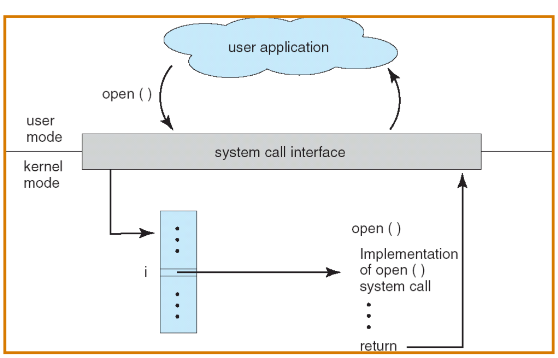
- System call sequence to copy the contents of one file to another file



System Call Implementation

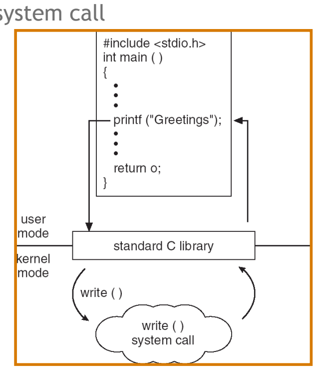
- Typically, a number associated with each system call
  - System-call interface maintains a table indexed according to these numbers
- The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values
- The caller need know nothing about how the system call is implemented
  - Just needs to obey API and understand what OS will do as a result call
  - Most details of OS interface hidden from programmer by API
    - Managed by run-time support library (set of functions built into libraries included with compiler)

API – System Call – OS Relationship



Standard C Library Example

- C program invoking printf() library call, which calls write() system call



Solaris System Call Tracing

```
# ./all.d 'pgrep xclock' XEventsQueued
dtrace: script './all.d' matched 52377 probes
CPU FUNCTION
  0 -> XEventsQueued                    U
  0   -> _XEventsQueued                 U
  0     -> _X11TransBytesReadable       U
  0     <- _X11TransBytesReadable       U
  0     -> _X11TransSocketBytesReadable U
  0     <- _X11TransSocketBytesreadable U
  0     -> ioctl                        U
  0       -> ioctl                      K
  0         -> getf                     K
  0           -> set_active_fd          K
  0           <- set_active_fd          K
  0         <- getf                     K
  0         -> get_udatamodel           K
  0         <- get_udatamodel           K
...
  0         -> releasef                 K
  0           -> clear_active_fd        K
  0           <- clear_active_fd        K
  0           -> cv_broadcast           K
  0           <- cv_broadcast           K
  0         <- releasef                 K
  0       <- ioctl                      K
  0     <- ioctl                        U
  0   <- _XEventsQueued                 U
  0 <- XEventsQueued                    U
```


Operating System Design and Implementation

Operating System Design and Implementation

- Start by defining goals and specifications
- Affected by choice of hardware, type of system
  - Batch, time shared, single user, multi user, distributed
- *User* goals and *System* goals
  - User goals – operating system should be convenient to use, easy to learn, reliable, safe, and fast
  - System goals – operating system should be easy to design, implement, and maintain, as well as flexible, reliable, error-free, and efficient
- No unique solution for defining the requirements of an OS
  - → Large variety of solutions
  - → Large variety of OS

Operating System Design and Implementation (Cont.)

- Important principle: to separate policies and mechanisms

  Policy: What will be done?
  Mechanism: How to do something?
- Eg. to ensure CPU protection
  - Use Timer construct (mechanism)
  - How long to set the timer (policy)
- The separation of policy from mechanism is allows maximum flexibility if policy decisions are to be changed later

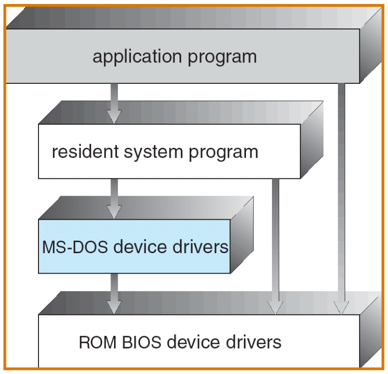
OS Design Approaches

- Simple Structure
- Layered Approach
- Microkernels
- Modules

Simple Structure

- No well defined structure
- Start as small, simple, limited systems, and then grow
- MS-DOS – written to provide the most functionality in the least space
  - Not divided into modules
  - Its interfaces and levels of functionality are not well separated
  - e.g. application programs can access low level drivers directly
    - ➔ Vulnerable to errant (malicious) programs

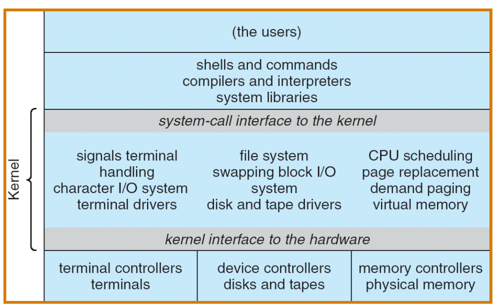
MS-DOS Structure



UNIX

- UNIX – limited by hardware functionality, the original UNIX operating system had limited structuring. The UNIX OS consists of two separable parts
  - Systems programs
  - The kernel
    - Consists of everything below the system-call interface and above the physical hardware
    - Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level

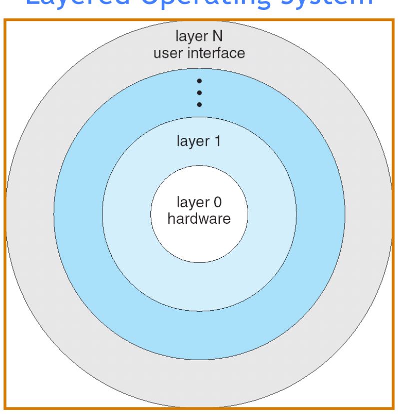
UNIX System Structure



Layered Approach

- The operating system is divided into a number of layers (levels), each built on top of lower layers.
  - The bottom layer (layer 0), is the hardware;
  - The highest (layer N) is the user interface.
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers
  - GLUnix: Global Layered Unix

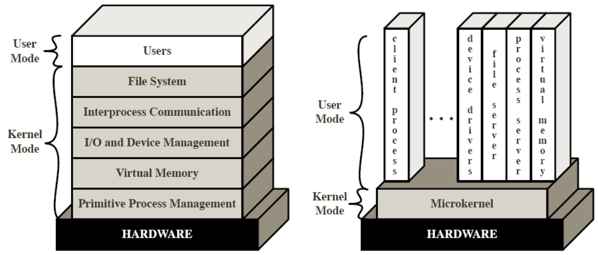
Layered Operating System



Microkernel System Structure

- Move all non-essential components from the kernel into "*user*" space
- Main function of microkernel: Communication between client programs and various services which are run in user space
  - Uses message passing (never direct interaction)
- Benefits:
  - Easier to extend the OS
  - Easier to port the OS to new architectures
  - More reliable (less code is running in kernel mode)
  - More secure
- Detriments:
  - Performance overhead of user space to kernel space communication
- Examples: QNX, Tru64 UNIX

Layered OS vs Microkernel

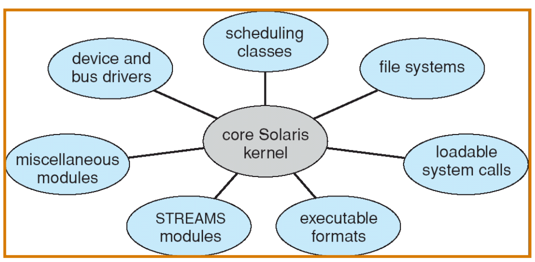


(a) Layered kernel (b) Microkernel

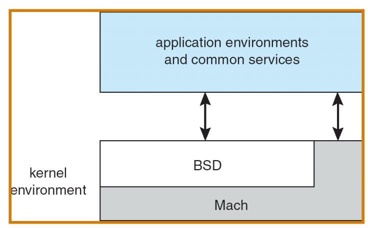
Modular Approach

- Most modern operating systems implement kernel modules
  - Uses object-oriented approach
  - Each core component is separate
  - Each talks to the others over known interfaces
  - Each is loadable as needed within the kernel
- Overall, similar to layers but more flexible
  - Any module can call any other module

Solaris Modular Approach



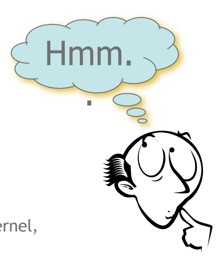
Mac OS X Structure - Hybrid



- BSD: provides support for command line interface, networking, file system, POSIX API and threads
- Mach: memory management, RPC, IPC, message passing

Summary

- OS Structures
  - Multiprogramming and Multitasking
  - Storage Structure
    - Primary, secondary & tertiary storage
  - System Calls
- OS Design and Implementation
  - Different Design Approaches
    - Unstructured, Layered, Modular, Microkernel,
    - and Hybrid approaches
- Next Lecture: Processes
- Reading Assignment: Chapter 2 from Silberschatz.



Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
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