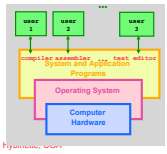
CSCI 4730
Operating Systems

Structures & System Design

Review last time: Key Questions in System Design

An operating system is a complex collection of software – too complex to be designed, implemented and/or understood as a single entity.

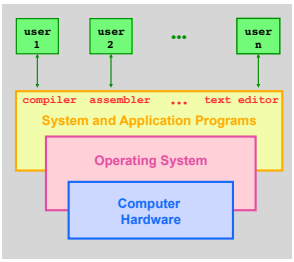
- What does the OS look like? to the user?
- What services does an operating system provide?



- Memory Management
- Process Management
- File Management
- I/O System Management
- Protection & Security

Review: Operating System Role

- Operating System
  - » A machine that emulates the hardware and provides a nice programming environment for [multiple] 'activities' (processes) in the system.
- Definition: A *process* is an activity in the system – a running program.



Operating System Design Criteria

- How do you *hide* the complexity and *limitations* of hardware from application programmers?
  - » What is the hardware interface? (the physical reality)
  - » What is the application interface? (the nicer abstraction)

In terms of **particular** hardware (i.e., CPU, Memory, Network) what criteria does your system need to address (solve).

Example Design Questions

- How to make multiple CPU appear as one CPU but faster?
- How to make limited memory appear as infinite (e.g., a large array may not fit into memory).
- How to make a mechanical disk appear to be as fast as electronic memory?
- How to make insecure, unreliable network transmissions appear to be reliable and secure?
- How to make many physical machines appear to be a single machine?

Summary of OS Roles

- Provide standard services or resources:
  - » Screen, CPU, I/O, disk, mouse
  - » resource abstraction.
- Provide for sharing of resources:
  - » coordinate between multiple applications to work together in
    - – safe, efficient, and fair ways
  - » resource sharing.

Coordination: Resource *Abstraction*

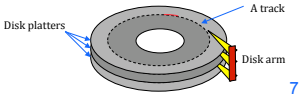
- **Example: Accessing a raw disk involves**
  - » **specifying the data, the length of data, the disk drive, the track location(s), and the sector location(s) within the corresponding track(s).**

```
write( block, len, device, track, sector );
```

- **Problem: Applications don't want to worry about the complexity of a disk.**

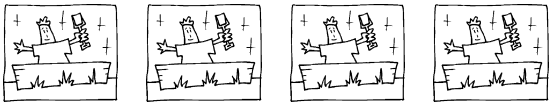
```
lseek( file, file_size, SEEK_SET );
write( file, text, len );
```

System Calls



Coordination: Resource Sharing

- **Example Goal: Protect the OS protection from other activities and provide protection across activities.**
- **Problem: Activities can crash each other (and crash the OS) unless there is coordination between them.**
- **General Solution: Constrain an activity so it only runs in its own memory environment (e.g., its own sandbox), and make sure the activity cannot access other sandboxes.**
  - » **Sandbox: Address Space (memory space)**
    - – **It's others memory spaces that the activity can't touch *including the Operating System's address space***



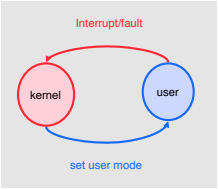
Protection Implementation: *Dual Mode Operations*

How does the OS is to prevent arbitrary programs (run by arbitrary users) from invoking accidental or malicious calls to halt the operating system or modify memory such as the master boot sector?

- **Idea: The OS is omnipotent everything else isn't.**
  - » **Two modes CPU operation:**
    - – **Kernel Mode – Anything goes – access everywhere (unrestricted access) to the underlying hardware.**
      - **Execute any CPU instruction and reference any memory access**
    - – **User Mode – Activity can only access state within its own address space (for example - web browsers, calculators, compilers, JVM, word from microsoft, power point, etc run in user mode).**

Hardware: Dual-Mode Operation

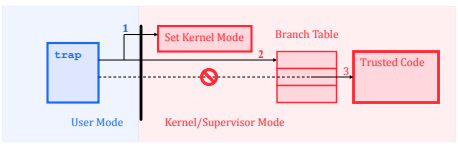
- **Mode bit (0 or 1) provided by hardware**
  - » **Provides ability to distinguish when system is running user code or kernel code**



- **Question: What is the mechanism from the point of view of a process to access kernel functions (e.g., it wants to write to disk)?**

System Calls

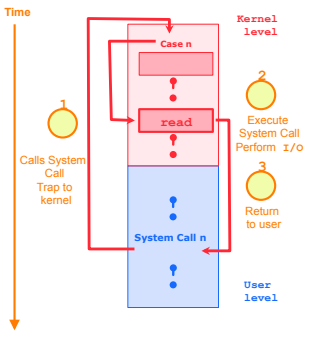
- **Mechanism for user activities (user processes) to access kernel functions.**
- **Example: UNIX implements system calls via the *trap* instruction (system call contains the trap instruction).**



- **When the control returns to the user code the CPU is switched back to User Mode.**

Example: I/O Protection

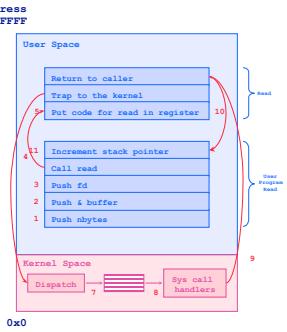
- **All I/O instructions are privileged instructions.**
- **Must ensure that a user program could never gain control of the computer in kernel mode**
  - » **Avoid a user program that, as part of its execution, stores a new address in the interrupt vector.**



System call to perform I/O Read

UNIX – details - Steps in Making a System Call

- Consider the UNIX `read` system call
  - `count = read( fd, buffer, nbytes )`
  - reads `nbytes` of data from a file (given a file descriptor `fd`) into a `buffer`
- 11 steps:
  - `1-3`: push parameters onto stack
  - `4`: calls routine
  - `5`: code for read placed in register
  - `6`: trap to OS
  - `7-8`: OS saves state, calls the appropriate handler
  - `9-10`: return control back to user program
  - `11`: pop parameters off stack

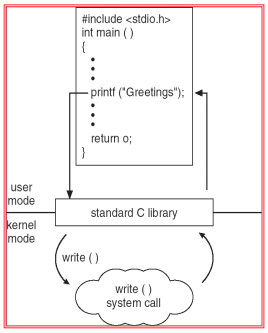


Types of System Calls

- Process control
  - `fork, execv, waitpid, exit, abort`
- File management
  - `open, close, read, write`
- Device management
  - `request device, read, write`
- Information maintenance
  - get time, get date, get process attributes
- Communications
  - message passing: send and receive messages,
    - create/delete communication connections
  - Shared memory map memory segments

Library Routines: Higher Level of Abstraction to System Calls

- Provide another level of abstraction to system calls to
  - improve portability and
  - easy of programming
- Standard POSIX C-Library (UNIX) (stdlib, stdio):
  - C program invoking `printf()` library call, which calls write() system call
- Win 32 API for Windows
- JVM

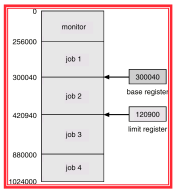


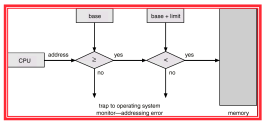
Types Hardware Protection

- Dual-Mode Operation (Privileged Operations)
  - Example: Provides: I/O Protection
- Memory Protection (Space)
- CPU Protection (Time)

Example: Memory Protection

- Must provide memory protection
  - The interrupt vector and the interrupt service routines.
- In order to have memory protection, add two registers that determine the range of legal addresses a program may access:
  - Base register – holds the smallest legal physical memory address.
  - Limit register – contains the size of the range
- Memory outside the defined range is protected.





CPU Protection

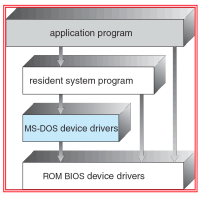
- *Timer* – interrupts computer after specified period to ensure operating system maintains control.
  - Timer is decremented every clock tick.
  - When timer reaches the value 0, an interrupt occurs.
- Timer commonly used to implement time sharing.
- Time also used to compute the current time.
- Load-timer is a privileged instruction.

OS Evolution

- Phase 1: Hardware Expensive, Humans Cheap
  - » Goal: Use computer time & space efficiently
  - » Maximize throughput while minimize the use of space
- Phase 2: Hardware Cheap, Humans Expensive
  - » Goal: Use people's time efficiently
  - » Minimize response time

Phase 1: Hardware Expensive Simple Structure: MS-DOS

- Goal: Minimize space - written to provide the most functionality in the least amount of space
  - » Simple layered structure
  - » Not divided into modules carefully
  - » Interfaces and levels of functionality are not well separated
    - – High level routine access to low level I/O routines

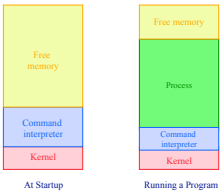


- *Current hardware:*
  - *No **dual**-mode and no hardware protection -*

Process Control: MS-DOS

*MS-DOS is a **single**-tasking OS (single user, single process)*

- Command interpreter is invoked when the computer is started
- To run a program, that program is loaded into memory – overwriting some of the command interpreter
- Upon program termination control is returned to the command interpreter which reloads its overwritten parts



can get some of benefits of multiprogramming via "terminate & stay resident" system call (forces reserves space so that process code remains in memory)

Phase 1: Hardware Expensive Multi-programming

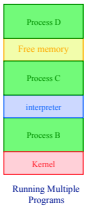
- Goal: Better throughput and utilization
  - » Provide a pool of ready jobs
  - » OS can always run a job
  - » Keep multiple jobs ready in memory
  - » When the job waits for I/O, switch to another job
    - – Keep both CPU and I/O is busy

Example: Process Control: UNIX

UNIX is a multi-programming OS (multiple users, multiple processes)

- Each user runs their own shell (command interpreter), e.g., sh, csh, bash, …
- To start a process, the shell executes a `fork` system call, the selected program is loaded into memory via an `exec` system call, and the new process executes
- depending on the command, the shell may wait for the process to finish or else continue as the process runs in the "background"
- when a process is done, it executes an exit system call to terminate, returning a status code that can be accessed by the shell

Recall: most UNIX commands are implemented by system programs



Phase b2: People time becomes more valuable

- Some hardware is becoming less expensive, e.g., keyboard, monitors (per user), mainframes still expensive.
- Time sharing system
- Goal: Improve user response time
- Approach:
  - » Switch between jobs to give appearance of dedicated machine
  - » More complex scheduling needed, concurrency control and synchronization.

Phase 2a: Inexpensive Personal Computers

- 1980 Hardware (software more expensive)
  - » Entire machine is inexpensive
  - » One dedicated machine per user
- Goal: Give user control over machine
- Approach:
  - » Remove time sharing between users
  - » Work with little main memory

Phase 2b: Inexpensive Powerful Computers

- 1990s Hardware
  - » PCs with increasing computation and storage
  - » User connect via the web
- Goal of OS
  - » Allow single user to run several application simultaneously
  - » Provide security from malicious attacks
  - » Efficiently support web servers
- Approach:
  - » Add back time-sharing, protection and virtual memory

Current Systems Trends

- OS changes due to both hardware and users
- Current trends:
  - » Multiprocessors
  - » Network systems
  - » Virtual machines
- OS Code base is LARGE
  - » Millions lines of code
  - » 1000 person-years of work
- Code is complex and poorly understood
  - » System outlives any of its builder
  - » System will ALWAYS contain bugs
  - » Behavior hard to predict, tuning is done by guessing

Review

- How do devices communicate?
- What is multiprogramming?
- What is time-sharing?
- What is a process?
- What type of 'protection' does hardware provide?

Review OS Core Components

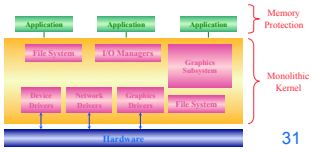
- Processor Scheduler
  - » When a process executes
- Memory Manager
  - » When and how memory is located to a process
- File System
  - » Organize data in persistent storage
- Communication (e.g., networking)
  - » Enables processes to communicate with each other, and how.

Evolution of the Structure the OS

- Monolithic Kernel
  - » 2 (3) Layers
    - – Hardware
    - – System
    - – User
- More layers & provide interface between them
- Keep only the essential layer in the kernel
  - » Micro Kernel

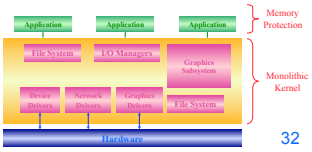
Monolithic Kernels

- Earliest and most common OS architecture (UNIX, MS-DOS)
- Every component of the OS is contained in the Kernel
- Examples: OS/360, VMS and Linux



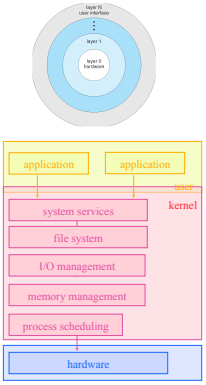
Monolithic Kernels

- Advantages:
  - Highly efficient because of direct communication between components
  - Susceptible to malicious code - all code execute with unrestricted access to the system.
- Disadvantages:
  - Difficult to isolate source of bugs and other errors
  - Hard to modify and maintain
  - Kernel gets bigger as the OS develops.



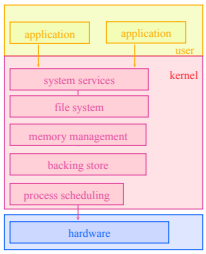
Layered Approach

- Divides the OS into a number of layers (levels).
  - each built on top of lower layers.
  - bottom layer 0 is the hardware; highest the UI.
- With modularity:
  - layers are selected such that each uses functions (operations) and services of only *lower-level* layers



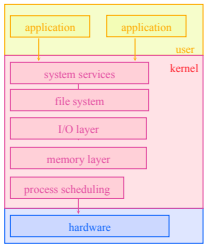
Layered Approach

- Approach: Higher level layers access services of lower level functions:
  - Example: Device driver for backing store (disk space used by virtual memory) must be lower than memory managers because memory management 'uses' the ability of the device driver.
- Problem: Which level should be lower a device driver for backing store of scheduler?
  - Example:
    - Backing store need the scheduler because the driver may need to wait for I/O and the CPU can be rescheduled at that time.
    - CPU scheduler need to use backing store because it may need to keep more space in memory than is physically available.



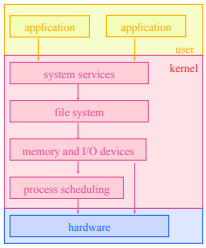
Layered Approach

- Problem: Efficiency?
  - I/O layer, memory layer, scheduler layer, hardware
  - I/O operations triggers may call three layers.
  - Each layer passes parameters, modifies data etc.
  - Lots of layers, adds overhead



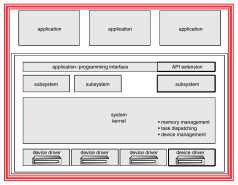
Layered Approach

- Examples: THE, Windows XP and LINUX have some level of layering.
- Advantages:
  - Modular, Reuse
- Disadvantages:
  - Hard to define layers
    - Example: CPU scheduler is lower than virtual memory driver (driver may need to wait for I/O) yet the scheduler may have more info than can fit in memory
  - Efficiency - slower each layer adds overheads



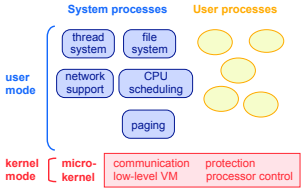
Layered OS's Trend

- **Trend is towards fewer layers, i.e. OS/2**



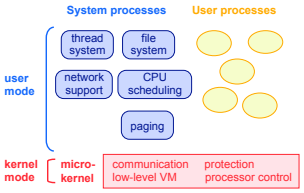
Microkernel System Structure

- **Approach: Separate kernel programs into system and user level programs (or libraries)**
  - » **Moves as much from the kernel into "*user*" space**
  - » **Minimal kernel only essential components**
    - – **Kernel: process, memory and communication management (main function of kernel)**
    - – **Communication takes place between user modules using message passing.**



Microkernel System Structure

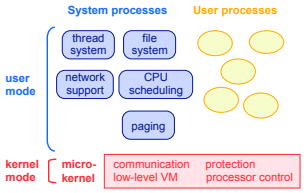
- **Advantages:**
  - » **Easier to extend a microkernel**
    - – **add functionality does not need to modify kernel**
  - » **Easier to port the operating system to new architectures**
  - » **More reliable (less code is running in kernel mode)**
  - » **Less points of failures.**
  - » **More secure**
- **Disadvantages:**
  - » **Slow: Performance overhead of user space to kernel space communication**



Examples: Mach, MacOS X, Windows NT

Microkernel System Structure

- **Windows NT first version that used pure layered microkernel approach and moved code into higher layers but later moved them back to kernel space for performance reasons.**

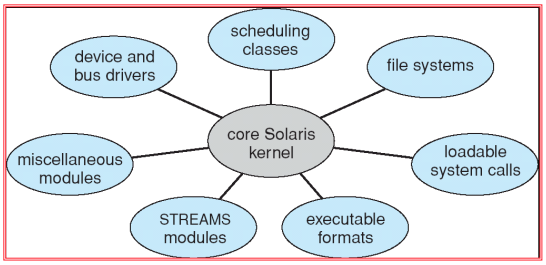


Examples: Mach, MacOS X, Windows NT

Monolithic Kernel: Modules

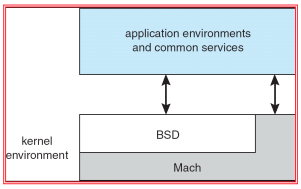
- **Most modern operating systems implement kernel modules: dynamically loadable modules.**
  - » **Uses object-oriented approach**
  - » **Each core component is separate**
  - » **Each talks to the others over known interfaces**
  - » **Each is loadable as needed within the kernel**
- **Overall, similar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

Solaris Modular Approach



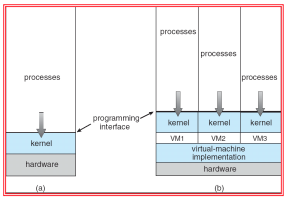
Mac OS X Structure

- Hybrid structure using a layered structure.
- Kernel environment at one level.
  - » Mach micro kernel provides
    - – memory management
    - – support for RPC & IPC
    - – message passing
    - – thread scheduling
  - » BSD provides BSD command line interface
  - » support for networking and file system
  - » Posix API's pthreads
  - » I/O Kit
  - » Dynamically loadedable modules (extensions)



Virtual Machines

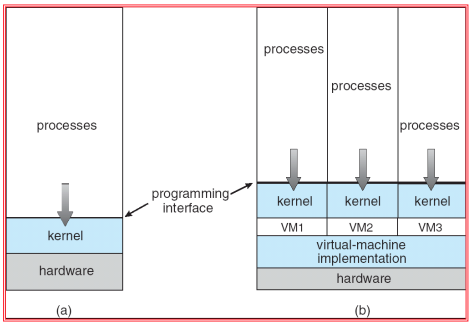
- A *virtual machine* takes the layered approach to its logical conclusion.
  - » It treats hardware and the operating system kernel as though they were all hardware
- A virtual machine provides an interface *identical* to the underlying bare hardware
- The operating system creates the illusion of multiple processes, each executing on its own processor with its own (virtual) memory



Virtual Machines (Cont.)

- The resources of the physical computer are shared to create the virtual machines
  - » CPU scheduling can create the appearance that users have their own processor
  - » Spooling and a file system can provide virtual card readers and virtual line printers
  - » A normal user time-sharing terminal serves as the virtual machine operator's console
  - » Limitation: disk drives -> solution -> minidisks

Virtual Machines (Cont.)



(a) Nonvirtual machine (b) virtual machine

Virtual Machines (Cont.)

- The virtual-machine concept provides complete protection of system resources since each virtual machine is isolated from all other virtual machines. This isolation, however, permits no direct sharing of resources.
- A virtual-machine system is a perfect vehicle for operating-systems research and development. System development is done on the virtual machine, instead of on a physical machine and so does not disrupt normal system operation.
- The virtual machine concept is difficult to implement due to the effort required to provide an *exact* duplicate to the underlying machine

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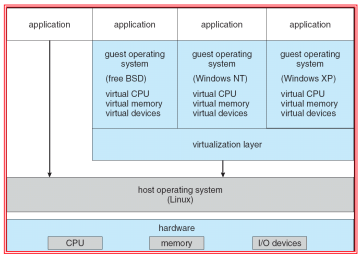
- Disadvantages:
  - » The virtual machine concept is difficult to implement due to the effort required to provide an *exact* duplicate to the underlying machine.

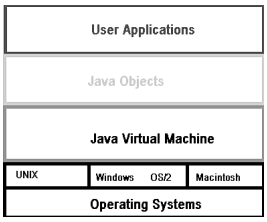
VMware Architecture



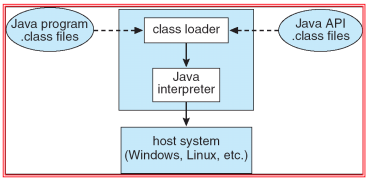
- Abstracts Intel 80X86 hardware into isolated virtual machines
- Runs as an application on a host operating system
- Run guest OSs as independent virtual machines

Java Virtual Machine

- Used to run Java programs
- JVM is a specification for an abstract computer (not a physical machine)
- Compiled Java programs are platform-neutral byte codes executed by a Java Virtual Machine (JVM).
- JVM consists of
  - » class loader
  - » class verifier
  - » runtime interpreter



The Java Virtual Machine



1. source code (.java) is compiled into platform-neutral bytecodes (.class)
2. class loader: loads compiled files and Java API
3. class verifier: checks validity/security of code
4. code is executed by java interpreter (running on JVM)