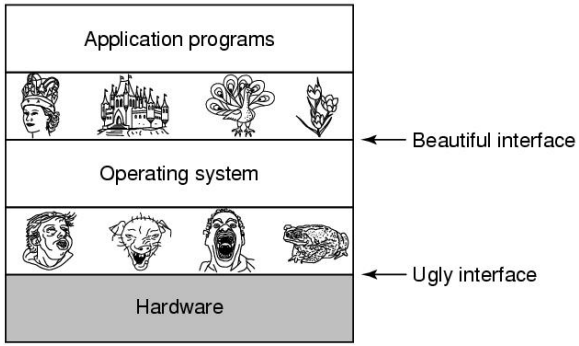
CSCI 6730 / 4730 Operating Systems

Structures & System Design

Review: What is An Operating System? Key Points

- Software ('kernel') that runs at all times
  - Really, the part of the system that runs in 'kernel mode' (or need to).
  - But note - there are exceptions to this 'rule'
- Distinguishing what makes up the OS is challenging (some grey areas)
- OS performs three unrelated functions:
  - (1) Provide abstractions of resources to the users or applications programs (extends the machine),
  - (2) Manage and coordinate hardware resources (resource manager)
    - CPU, memory, disk, printer
  - (3) Provides protection and isolation

The OS provides an *Extended Machine*

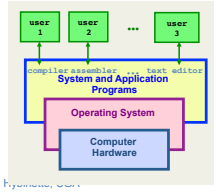


- **Operating System turn the ugly hardware into *beautiful* abstractions.**

Key Questions in System Design

How to provide a beautiful interface, consider:

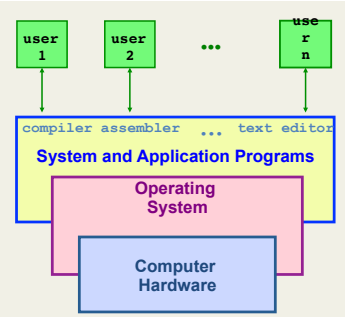
- What does the OS look like? → to the user
- What services does an operating system provide?



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

Review: Operating System Consider Roles:

- Intermediary, manager and protector.
  - (1) Emulates the hardware extending the 'machine' and
  - (2) Provides a nice (and safe) programming environment for
  - (3) [multiple] 'activities' (**processes**) in the system.



Definition: A *process* is an activity in the system – a running program, an activity that may need 'services' (we will cover this concept in detail next week).

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)
  - ~~~~~~~ TRANSFORMATIONS ~~~~~~~~~~
  - What is the application interface? (what are the nicer and more beautiful abstractions)

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

Some Example Design Questions

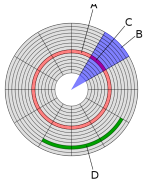
- How to make multiple CPU appear as one CPU but faster?
- How to make limited memory appear as infinite (e.g., a large array may not fit into memory).
- How to make a mechanical disk appear to be as fast as electronic memory?
- How to make insecure, unreliable network transmissions appear to be **reliable**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

GOALS
- ✓ *Fairness*
- ✓ *Timeliness*
- ✓ *Secure*
- ✓ *Reliable*
- ✓ *Ownership*
- ✓ *Single 'machininess'*
- ✓ *Power-efficient*

Focus on these OS Roles:

- Provide ***standard* services** and **resources**:
  - Screen, CPU, I/O, disk, mouse
  - Resource abstraction (extended machine)
- Provide for **sharing** of resources:
  - coordinate between multiple applications to work together in
    - safe, efficient, and fair ways (protected)
  - Resource coordination & management.

Resource *Abstraction*



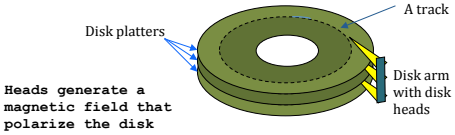
- Example: Accessing a raw disk involves
  - specifying the data, the length of data, the disk drive, the track location(s), and the sector location(s) within the corresponding track(s). (150 mph)

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

- Problem: But applications don't want to worry about the *complexity* of a disk (e.g., don't care about tracks or sectors)

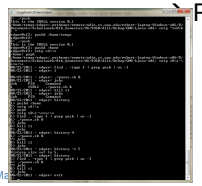
```
lseek( file, file_size, SEEK_SET );
write( file, text, len );
```

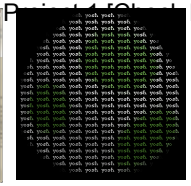
System Calls



Shell: Another Level of *Abstraction* provided to users

- Provide 'users' with access to the services provided by the kernel.
  - A 'shell' of-course,– illusion of a thin layer of abstraction to the kernel and its services.
- **CLI** – command line interface to kernel services (project 1 focus)
- **GUI** - graphical user interface to the kernel





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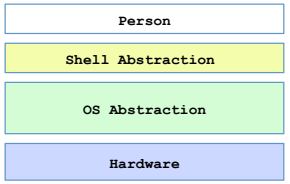
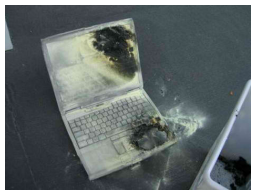


Functionality of a [CLI] 'shell'

- Provides two things:
  - Interactive Use (IU) -
  - And an environment for 'scripting' (programmable)
  - Project 1 : deals primarily with IU.
- **sh**: (Ken) thompson shell, the standard shell
  - piping and simple control structure, and wildcarding
  - Eventually replaced by the (Stephen) Bourne shell
  - Linux uses bash (bourne again shell) as their default 'sh'.
- **csh**: Bill Joy's shell – history, command line editing
- **tcsh**: (tenex c shell) extension of csh
  - great for IU, not so great for scripting
- **ksh**: (David) Korn Shell
  - original version – bulk of code is to provide a great environment for scripting provides powerful programming constructs).
  - [problem?] Proprietary (until recently -2006)

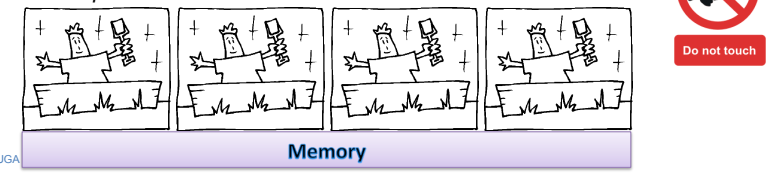
Review and Moving On…

- Looked at the OS role:
  - in abstracting the 'machine' (system calls, and shells).
- Next: OS role in *providing resources (memory)*
  - What is needed for effective sharing of resources?
    - protection



Coordination: Resource Sharing

- **Goal**: Protect the OS 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., in its own sandbox), and make sure the activity cannot access other sandboxes.
  - Sandbox: Address Space (memory space)
    - Protects activities from touching other memory spaces, memory spaces *including the Operating System's address space*



Coordination: Resource Sharing

- Areas of protection:
  - Memory
  - Writing to disk (where) – really any form of I/O.
  - Creating new processes

- **How do the OS create (and manage) these 'areas' of protection?**
- **Hardware**

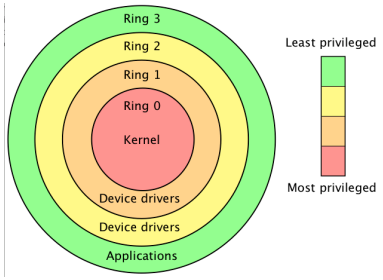
Protection Implementation: "*Dual Mode" Operations*

***How** does the OS 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?*

- General Idea: The OS is omnipotent and everything else isn't - as simple as that
  - Utilize Two CPU mode operations (provided by hardware)
    - Kernel Mode – Anything goes – access everywhere (unrestricted access) to the underlying hardware.
      - In this mode can 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).

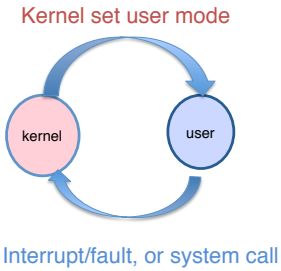
Hardware: Different modes of protection (>2 Intel)

- Hardware provides different mode 'bits' of protection – where at the lowest level – ring 0 – anything goes, unrestricted mode (the trusted kernel runs here).
  - Intel x86 architecture provides multiple levels of protection:



Hardware: Provides Dual-Mode Operation

- Mode bit (0 or 1) provided by hardware
  - Provides ability to distinguish when system is running
    - user code or
      - Non trusted code
      - Restricted.
    - kernel code
      - Trusted code



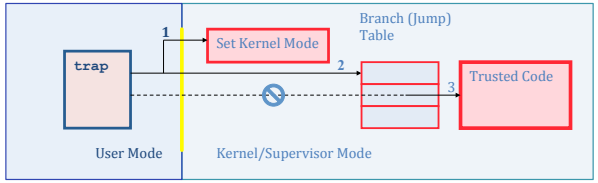
- **Question: What is the mechanism from the point of view of a process to access kernel functions (e.g., it wants to write to disk)?**

"System Calls" (e.g., Intel's trap())

- Mechanism for user activities (user processes) to access kernel functions.
- Example: UNIX implements system calls ('request calls') via the *trap()* instruction (system call, e.g., read() contains the trap instruction, internally). to the user code the CPU is switched back to User Mode.

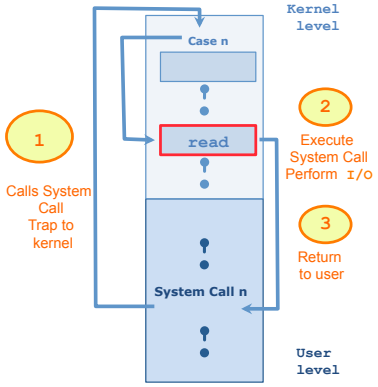
`libc is intermediate library that handles the 'packaging'`

`Trap in Linux is INT 0x80 assembly instruction`



Example: I/O "System" Calls

- **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.
    - libc

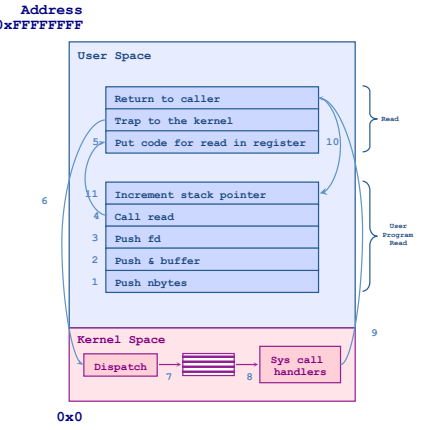


System call to perform I/O Read

UNIX – details - Steps in Making a System Call

P44-45 tannenbaum

- Consider the UNIX `read` "system" call (via a library routine)
  - `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
    - Actual system call # goes into EAX register
    - Args goes into other registers (e.g, EBX and ECX)
  - `6`: trap to OS
    - INT 0x80 assembly instruction I in LINUX
  - `7-8`: OS saves state, calls the appropriate handler (read)
  - `9-10`: return control back to user program
  - `11`: pop parameters off stack



`Art of picking Registers; http://www.swansontec.com/sregisters.html`

System Calls Triva

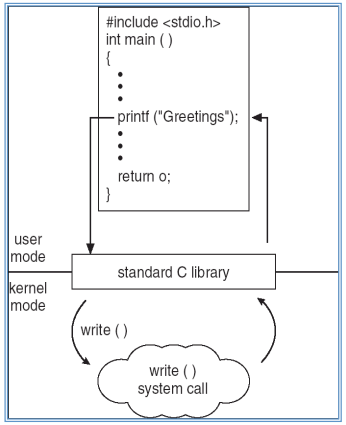
- Linux has 319 different system calls (2.6)
- Free BSD ‘almost’ 330.

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

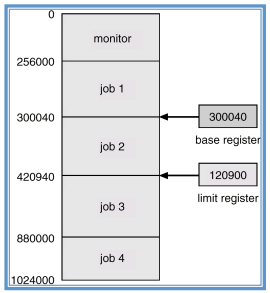


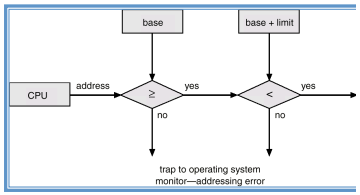
Types Hardware Protection

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

Memory Protection

- 2 registers to determine the address space 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.



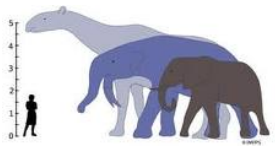


CPU Protection

- ***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.

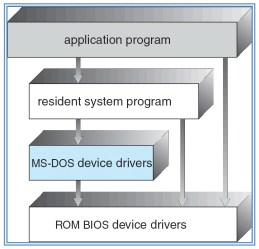
Look at OS *Evolution*

- 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 3: ?



Phase 1: Hardware Expensive Simple Structure: MS-DOS

- Goal: Minimize space used for software – code 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

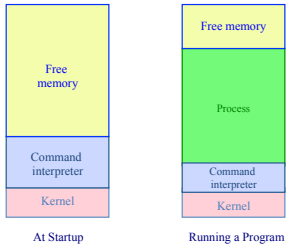


- *Current hardware (then):*
  - *No **dual**-mode and no hardware protection -*

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

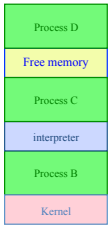
- Goal: Better throughput and utilization
  - Provide a pool of ready jobs
  - OS can always run a job
  - Keep multiple jobs ready in memory
  - When the job waits for I/O, switch to another job
    - Keep both CPU and I/O is busy

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 2: 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

Kernel Categories

- Monolithic
- Microkernel
- Hybrid Kernels
- Nanokernels
- Exokernels

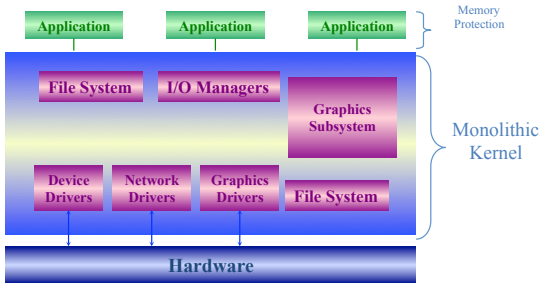
Structure the OS

The Evolution of the Layers

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

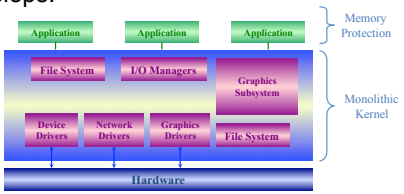
Monolithic Kernels

- 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



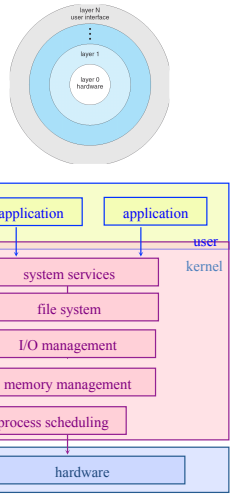
Monolithic Kernels

- 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.



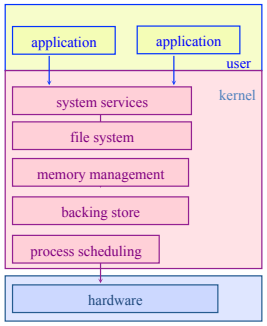
Layered Approach

- 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



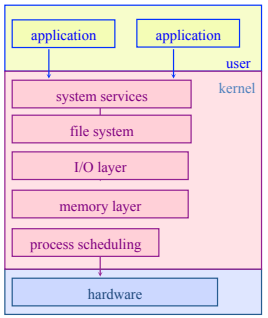
Layered Approach

- 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.



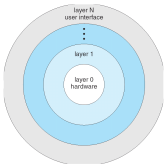
Layered Approach

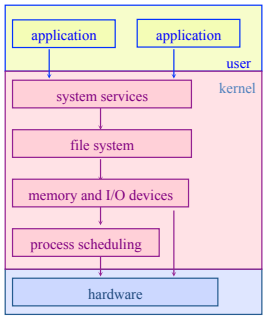
- Problem: Efficiency?
  - I/O layer, memory layer, scheduler layer, hardware
  - I/O operations triggers may call three layers.
  - Each layer passes parameters, modifies data etc.
  - Lots of layers, adds overhead



Layered Approach

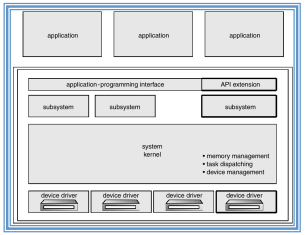
- Examples: THE, Windows XP and LINUX have some level of layering.
- Advantages:
  - Modular, Reuse
- Disadvantages:
  - Hard to define layers
    - Example: CPU scheduler is lower than virtual memory driver (driver may need to wait for I/O) yet the scheduler may have more info than can fit in memory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





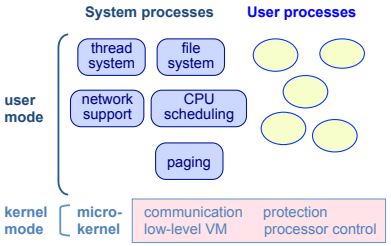
Layered OS's Trend

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



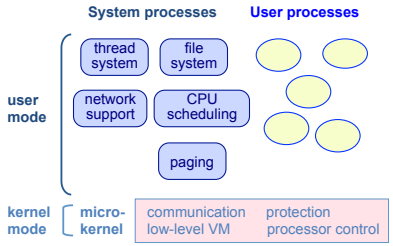
Microkernel System Structure

- 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

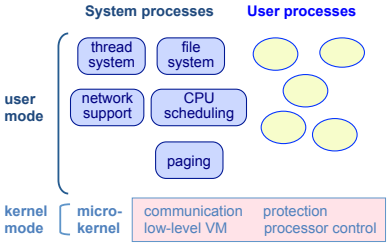
- **Advantages**:
  - **Easier to extend a microkernel**
    - **add functionality does not need to modify kernel**
  - **Easier to port the operating system to new architectures**
  - **More reliable (less code is running in kernel mode)**
  - **Less points of failures.**
  - **More secure**
- **Disadvantages**: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



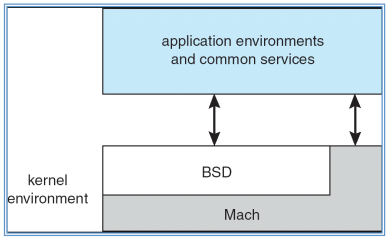
Examples: Mach, MacOS X, Windows NT

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

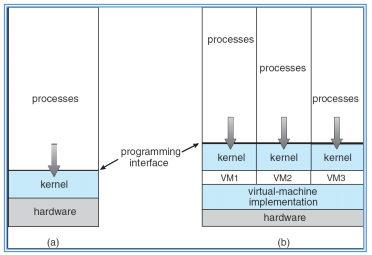
Hybrid Mac OS X Structure

- **Hybrid structure using a layered structure.**
  - **Hybrid Microkernel and Layerd Kernel**
- **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 loadeable modules (extensions)**



Virtual Machines

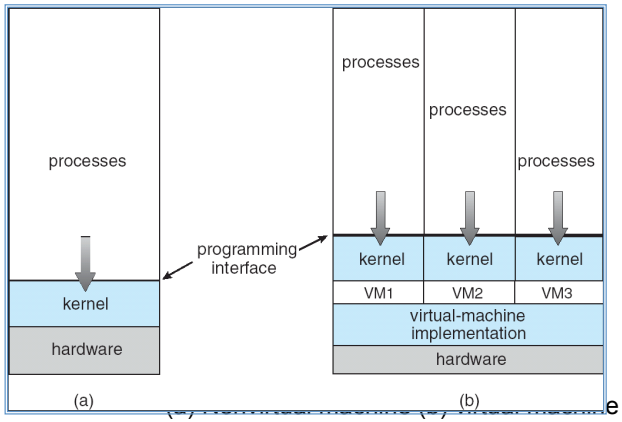
- A *virtual machine* takes the layered approach to its logical conclusion.
  - – It treats hardware and the operating system kernel as though they were all hardware
- A virtual machine provides an interface *identical* to the **underlying bare hardware**
- The operating system creates the illusion of 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

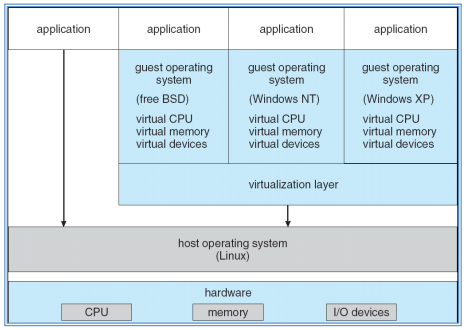
Virtual Machines (Cont.)



Virtual Machines

- Advantages:
  - Provides complete protection of system resources
    - Each virtual machine is isolated from all other virtual machines.
      - Consequence: permits no direct sharing of resources.
  - Great 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 operations.
- 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



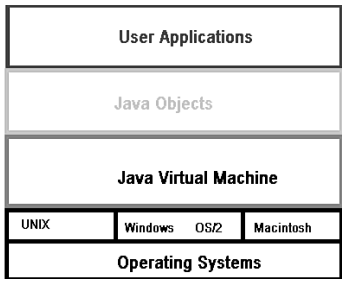
- **Abstracts Intel 80X86 hardware into isolated virtual machines**
- **Runs as an application on a host operating system**
- **Run guest OSs as independent virtual machines**

VmWare Files

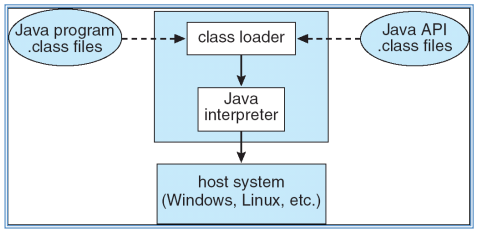
http://www.vmware.com/support/ws5/doc/ws_learning_files_in_a_vm.html

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)

Resources

System Calls:

- http://www.tldp.org/HOWTO/html_single/Implement-Sys-Call-Linux-2.6-i386/
- http://www.tamacom.com/tour/kernel/linux/
- http://www.tldp.org/LDP/khg/HyperNews/get/syscall/syscall86.html