CISC 3320 MW3

C04a: Overview of OS Design and Implementation

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Acknowledgement

- This slides are a revision of the slides by the authors of the textbook

Outline

- Operating System Design and Implementation
- Operating System Structure
- Operating System Debugging
- Operating System Generation
- System Boot

Operating System Design and Implementation

- Design and implementation of OS not "solvable", but some approaches have proven successful
- Internal structure of different Operating Systems can vary widely
- Start the design by defining goals and specifications
- Affected by choice of hardware, type of system
- 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

Policy vs. Mechanism

- Important principle
  - Separation of policy and mechanism
  - Mechanisms determine how to do something
  - Policies decide what will be done
- The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later
  - Example: timer
- Specifying and designing an OS is highly creative task of software engineering

Implementation

- Much variation
  - Early OSes in assembly language
  - Then in system programming languages like Algol, PL/1
  - Now in C, C++
- Actually usually a mix of languages
  - Lowest levels still in assembly
  - Main body in C
  - Systems programs in C, C++, scripting languages like PERL, Python, shell scripts
- In more high-level language, an OS is easier to port to other hardware
  - But slower
- Emulation can allow an OS to run on non-native hardware

Questions?

- Policy vs. mechanism
- Design and implementation concepts

Operating System Structure

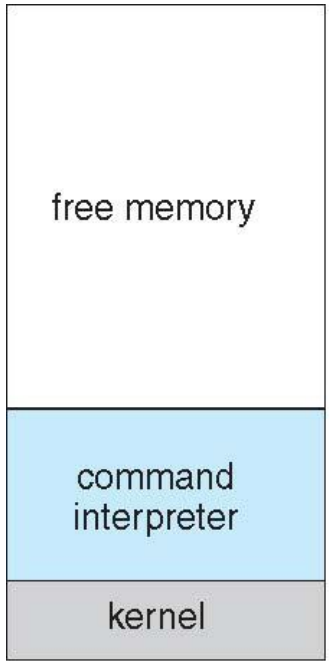
- General-purpose OS is very large program
- Various ways to structure ones
  - Simple structure
    - e.g., MS-DOS
  - More complex,
    - e.g., UNIX
  - Layered: an abstraction
  - Microkernel,
    - e.g., Mach

Simple Structure: MS-DOS

- Written to provide the most functionality in the least space
  - Not divided into modules
  - Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated

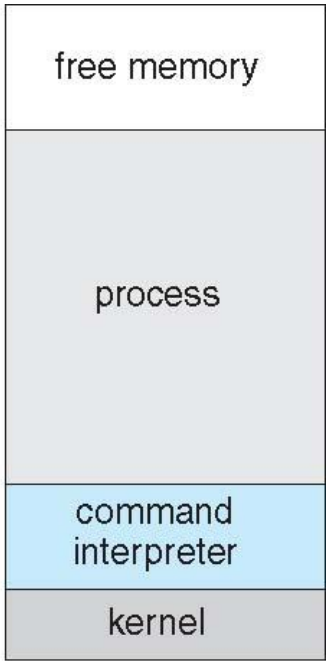
MS-DOS

- Single-tasking
- Shell invoked when system booted
- Simple method to run program
  - No process created
- Single memory space
- Loads program into memory, overwriting all but the kernel
- Program exit -> shell reloaded



(a)

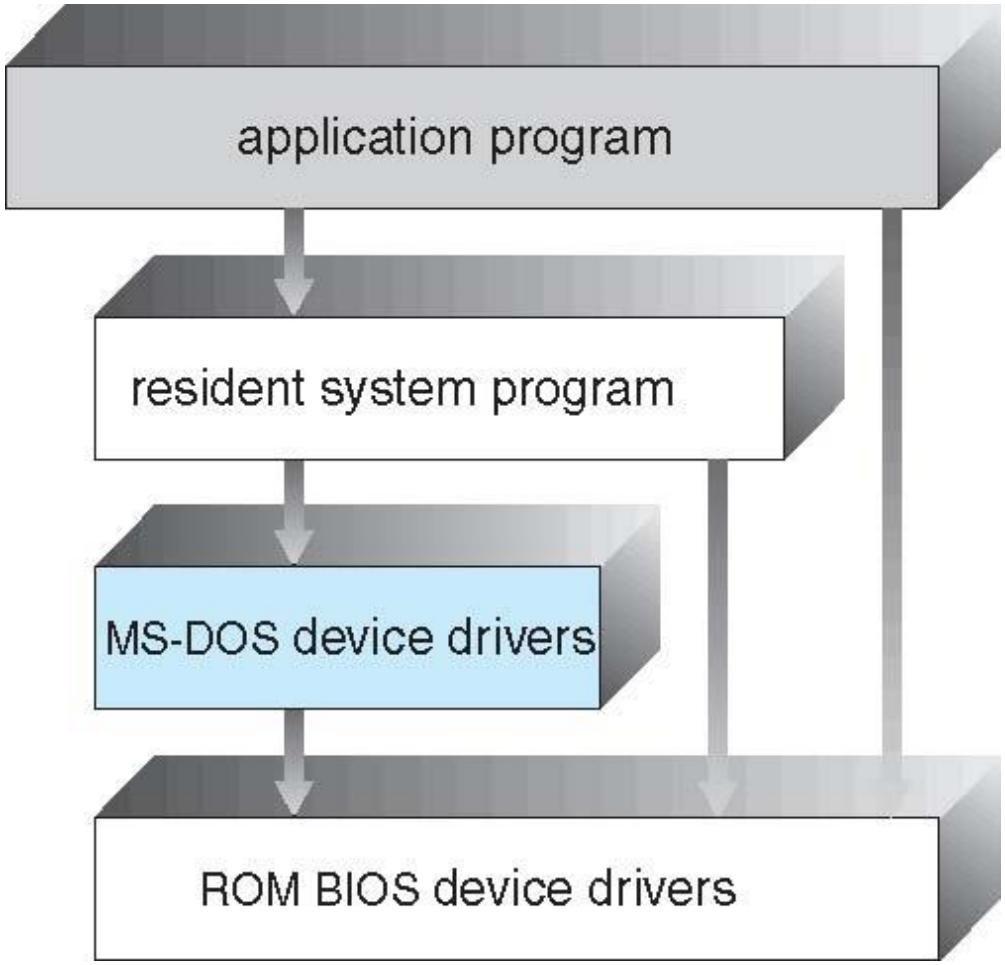
At system startup



(b)

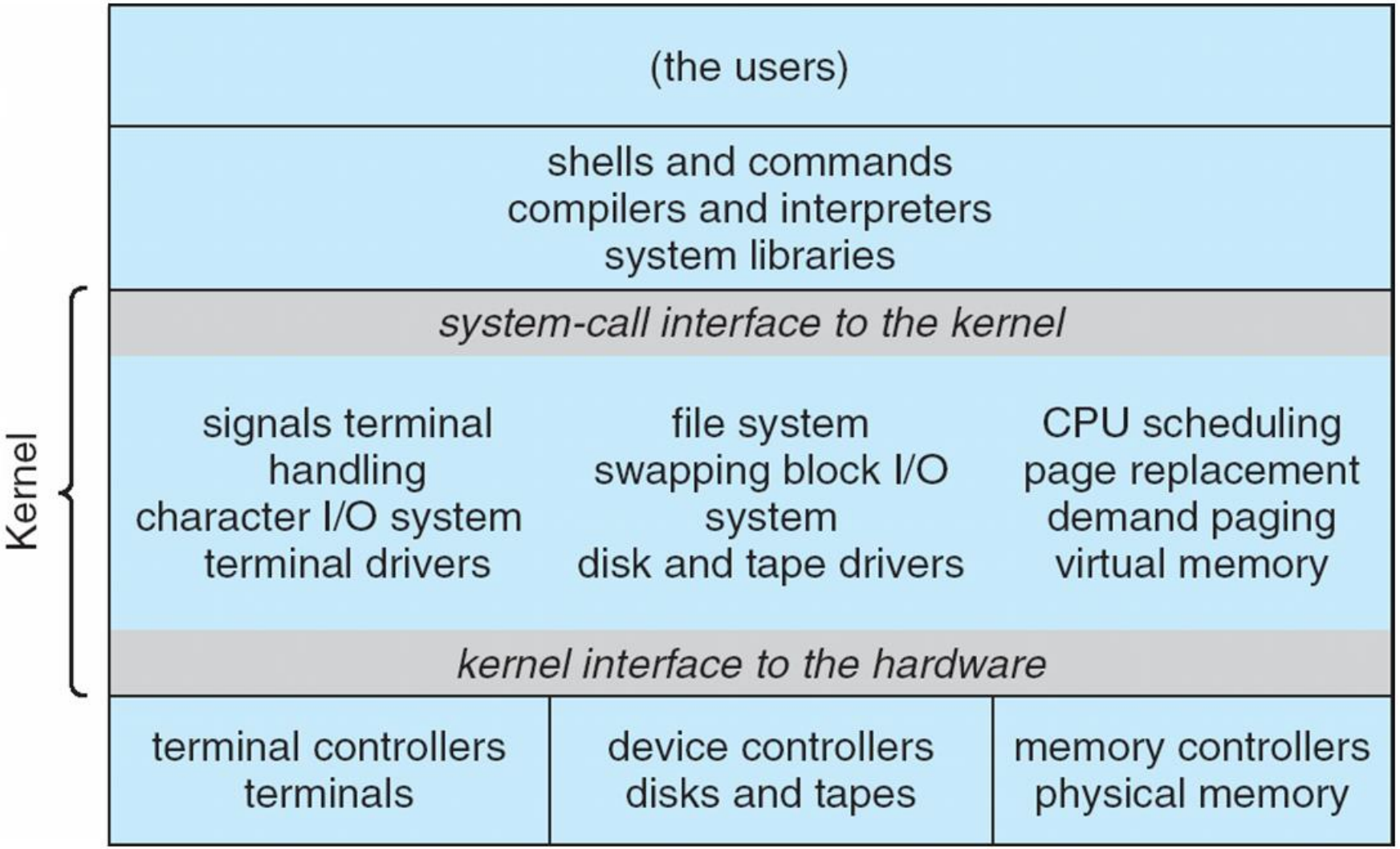
running a program

MS-DOS


application program
resident system program
MS-DOS device drivers
ROM BIOS device drivers

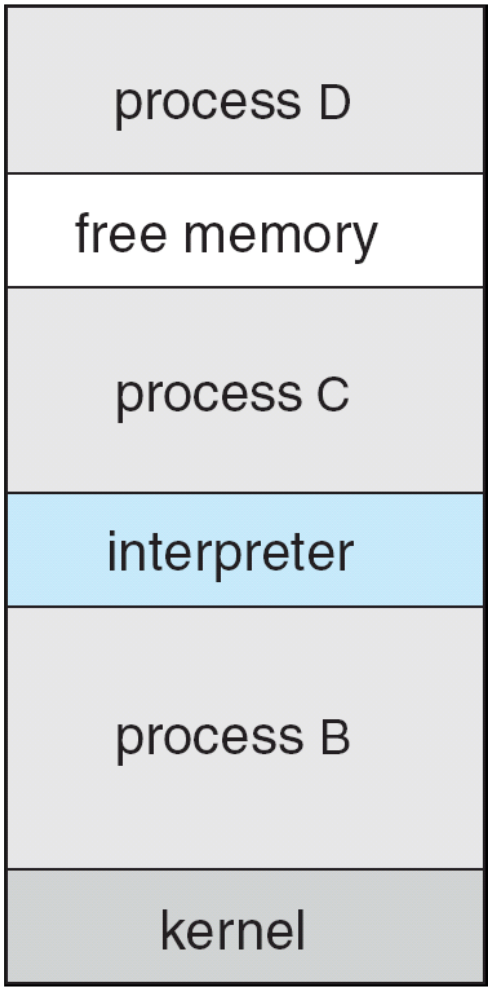
More Complex Structure: Traditional UNIX

- Limited by hardware functionality, the original UNIX operating system had limited structuring.
- Beyond simple but not fully layered
- 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


(the users)
shells and commands
compilers and interpreters
system libraries
system-call interface to the kernel
signals terminal handling
character I/O system
terminal drivers
file system
swapping block I/O system
disk and tape drivers
CPU scheduling
page replacement
demand paging
virtual memory
kernel interface to the hardware
terminal controllers
terminals
device controllers
disks and tapes
memory controllers
physical memory
Kernel

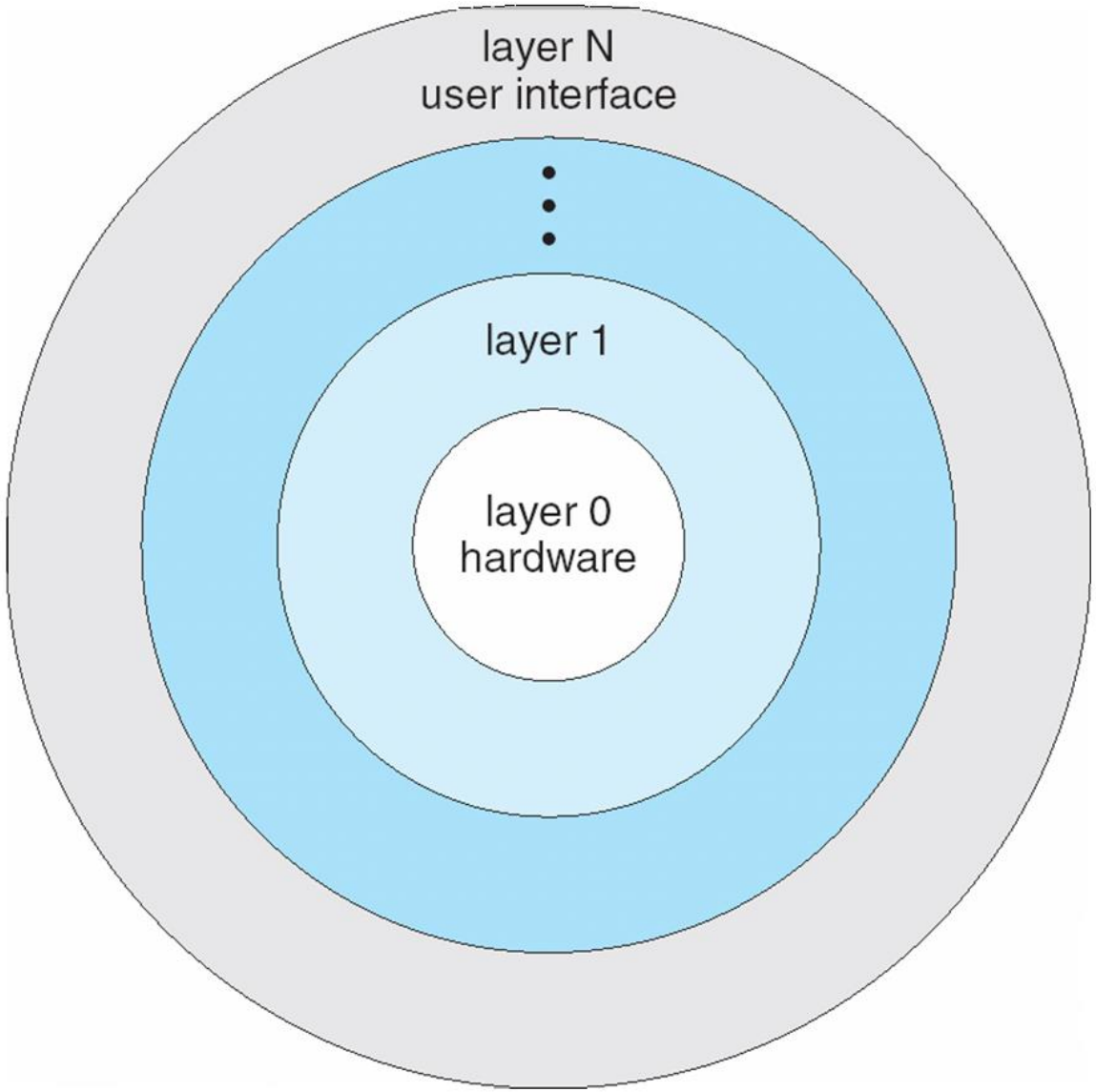
FreeBSD

- Unix variant
- Multitasking
- User login -> invoke user's choice of shell
- Shell executes fork() system call to create process
  - Executes exec() to load program into process
  - Shell waits for process to terminate or continues with user commands
- Process exits with:
  - code = 0 – no error
  - code > 0 – error code



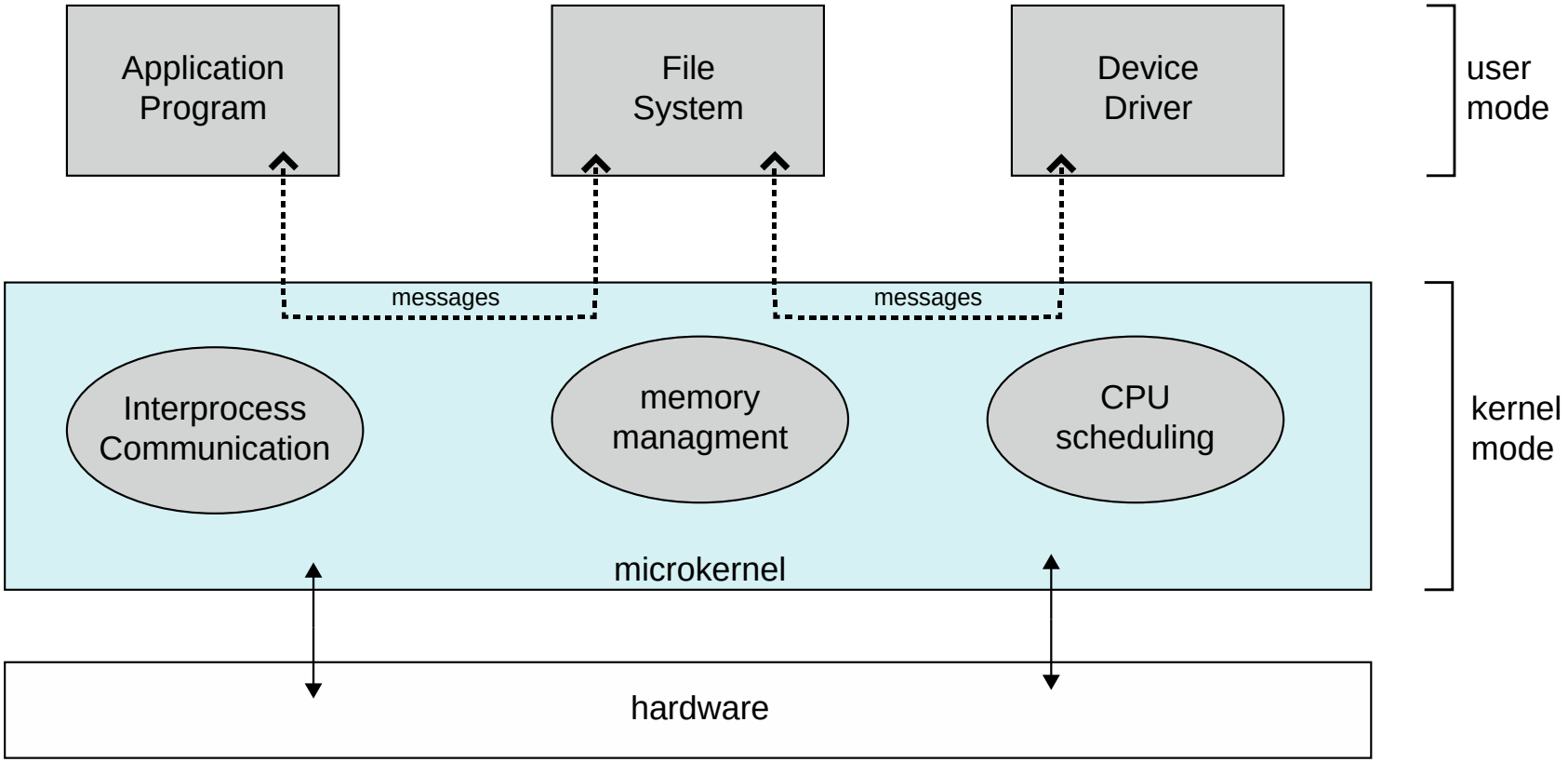
Layered Approach

- 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


layer N
user interface
layer 1
layer 0
hardware

Microkernel System Structure

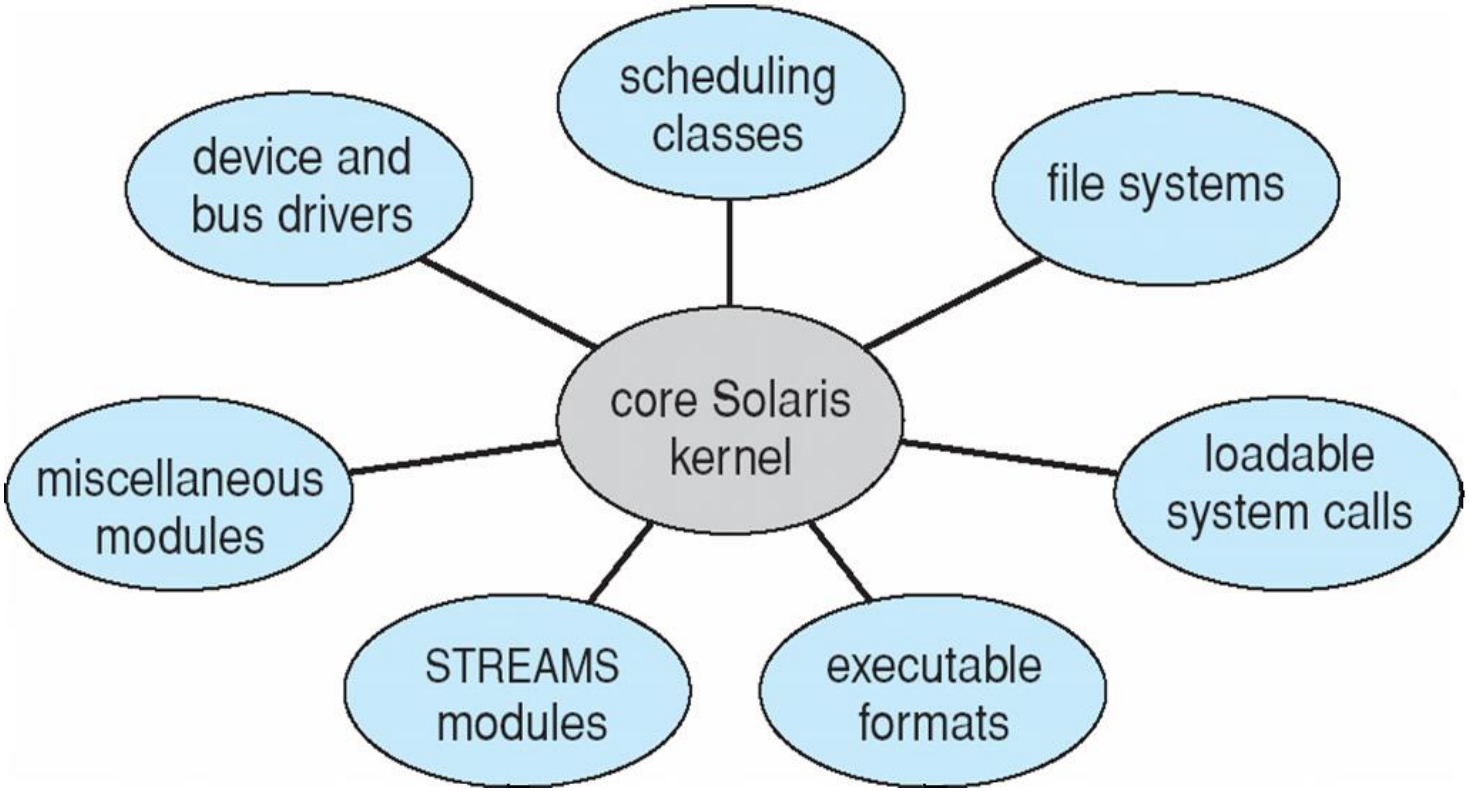
- Moves as much from the kernel into user space
  - Mach example of microkernel
    - Mac OS X kernel (Darwin) partly based on Mach
- Communication takes place between user modules using message passing
- Benefits:
  - Easier to extend a microkernel
  - Easier to port the operating system to new architectures
  - More reliable (less code is running in kernel mode)
  - More secure
- Detriments:
  - Performance overhead of user space to kernel space communication


Application Program
File System
Device Driver
user mode
messages
messages
Interprocess Communication
memory managment
CPU scheduling
kernel mode
microkernel
hardware

Modules

- Many modern operating systems implement loadable 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 with more flexible
  - Linux, Solaris, etc

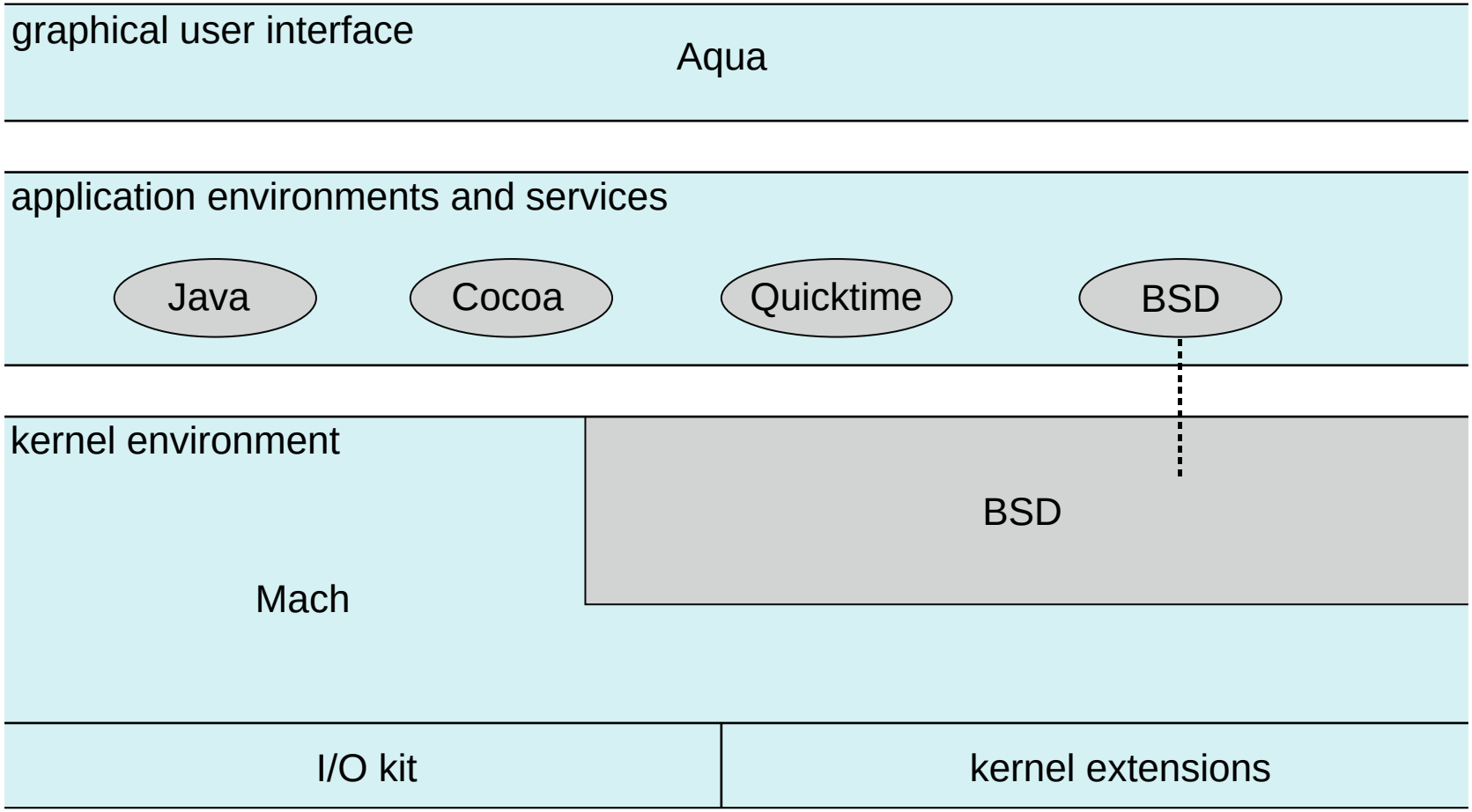
Solaris Modular Approach



Hybrid Systems

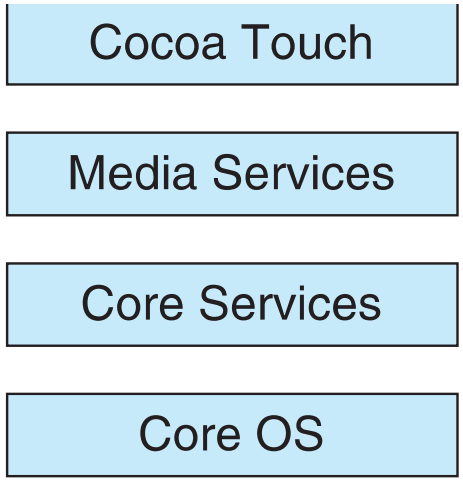
- Most modern operating systems are actually not one pure model
  - Hybrid combines multiple approaches to address performance, security, usability needs
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality
  - Windows mostly monolithic, plus microkernel for different subsystem personalities
- Apple Mac OS X hybrid, layered, Aqua UI plus Cocoa programming environment
  - Below is kernel consisting of Mach microkernel and BSD Unix parts, plus I/O kit and dynamically loadable modules (called kernel extensions)

Mac OS X Structure



iOS

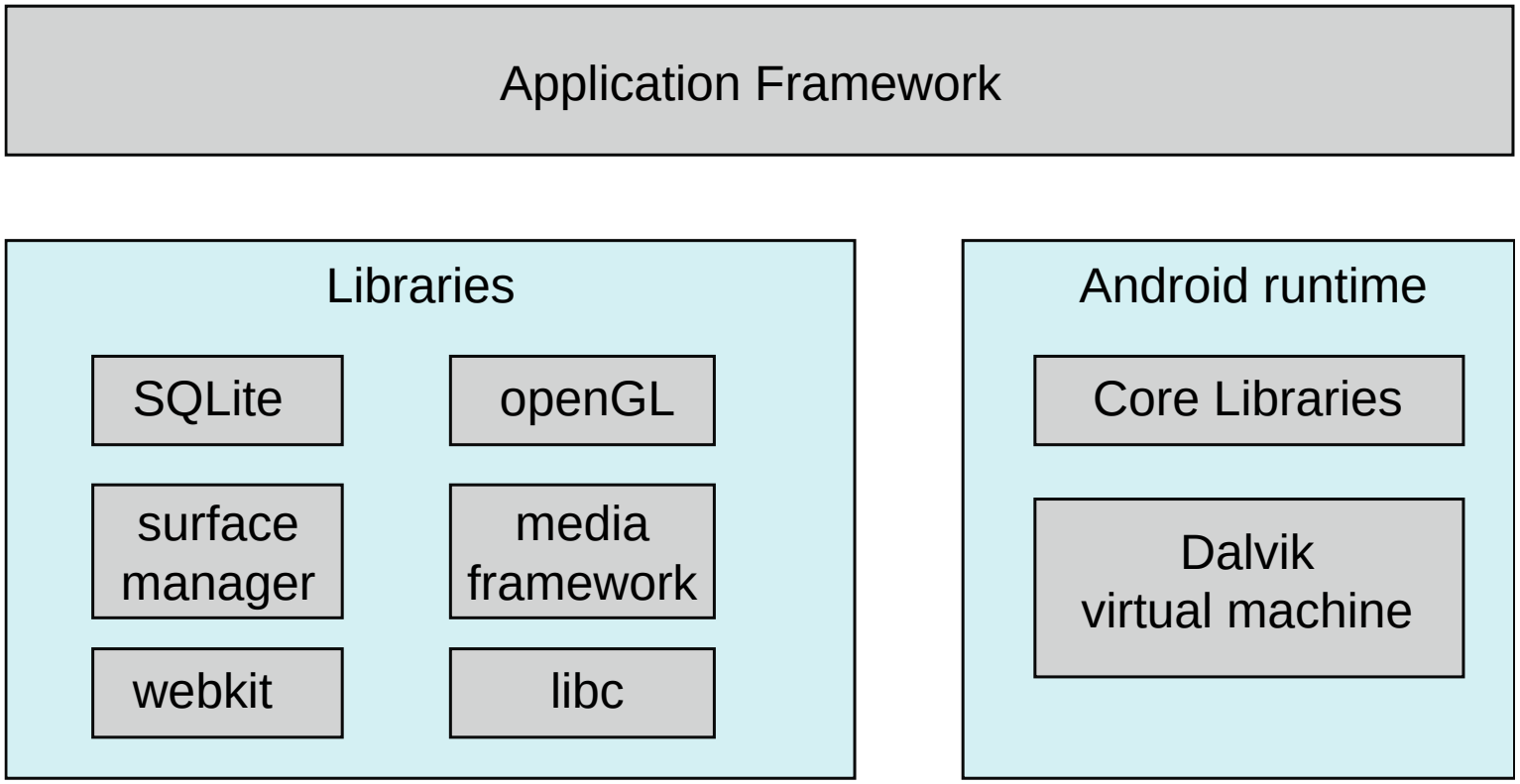
- Apple mobile OS for iPhone, iPad
  - Structured on Mac OS X, added functionality
  - Does not run OS X applications natively
  - Also runs on different CPU architecture (ARM vs. Intel)
  - Cocoa Touch Objective-C API for developing apps
  - Media services layer for graphics, audio, video
  - Core services provides cloud computing, databases
  - Core operating system, based on Mac OS X kernel



Android

- Developed by Open Handset Alliance (mostly Google)
  - Open Source
- Similar stack to IOS
- Based on Linux kernel but modified
  - Provides process, memory, device-driver management
  - Adds power management
- Runtime environment includes core set of libraries and Dalvik virtual machine
  - Apps developed in Java plus Android API
    - Java class files compiled to Java bytecode then translated to executable than runs in Dalvik VM
- Libraries include frameworks for web browser (webkit), database (SQLite), multimedia, smaller libc

Android Structure



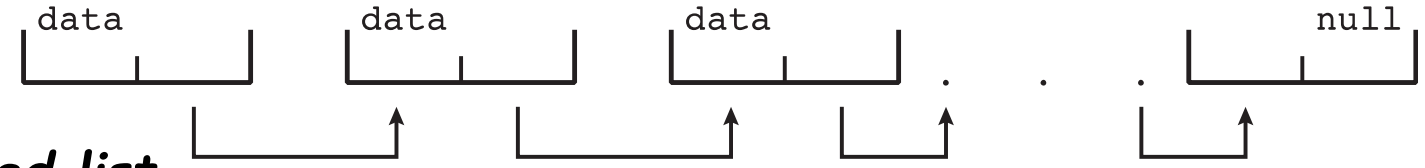
Questions?

- OS structure
  - Simple
  - Traditional
  - Layered
  - Microkernel
  - Hybrid

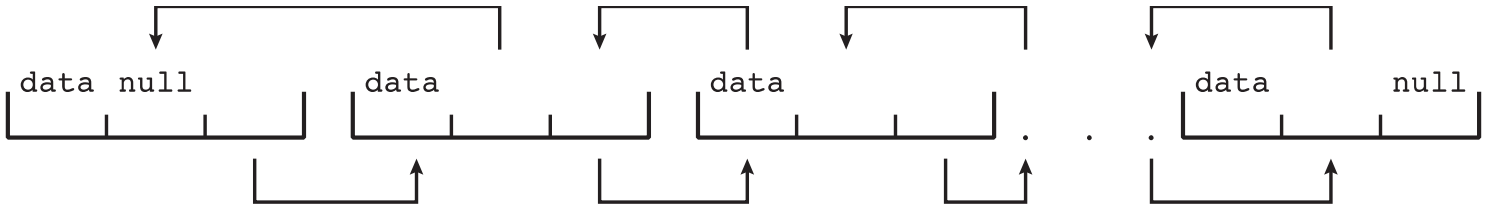
Implement OS: Kernel Data Structures

Many similar to standard programming data structures

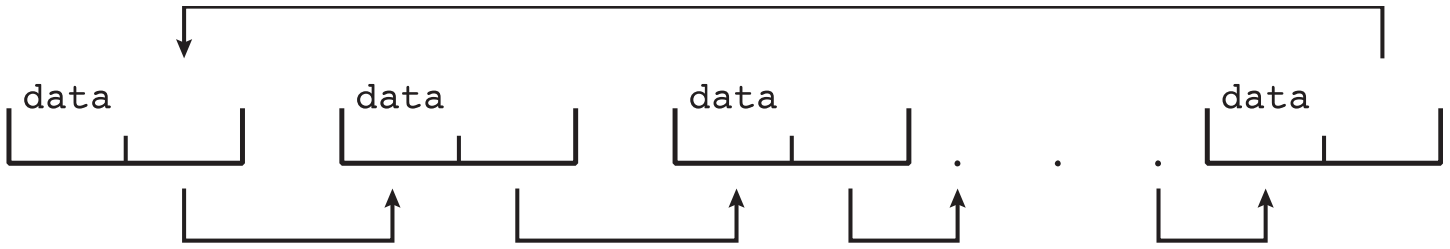
Singly linked list



Doubly linked list

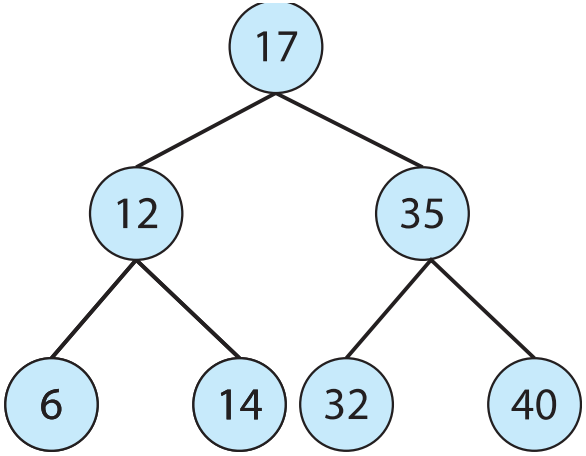


Circular linked list



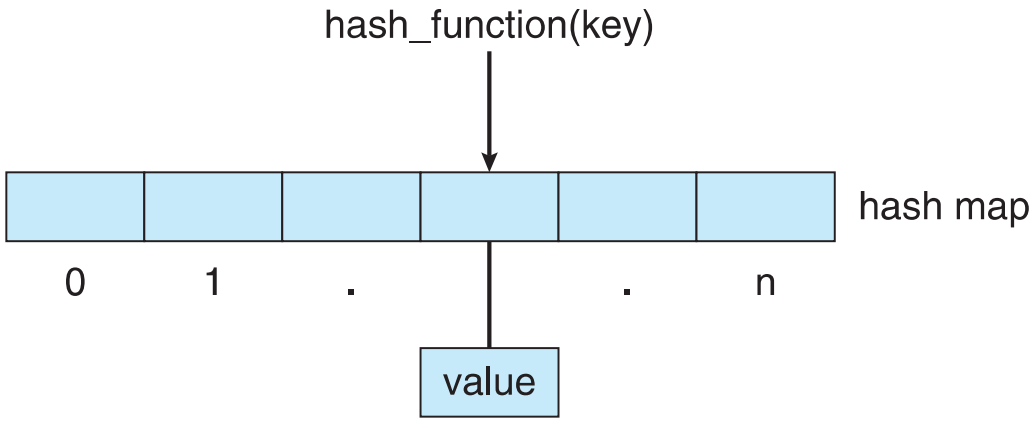
Kernel Data Structures: Binary Search Tree

- **Binary search tree:** left <= right
  - Search performance is *O(n)*
  - **Balanced binary search tree** is *O(lg n)*



Kernel Data Structures: Hash Map

- **Hash function** can create a **hash map**



- **Bitmap** – string of *n* binary digits representing the status of *n* items
- Linux data structures defined in

  include files `<linux/list.h>, <linux/kfifo.h>, <linux/rbtree.h>`

Questions?

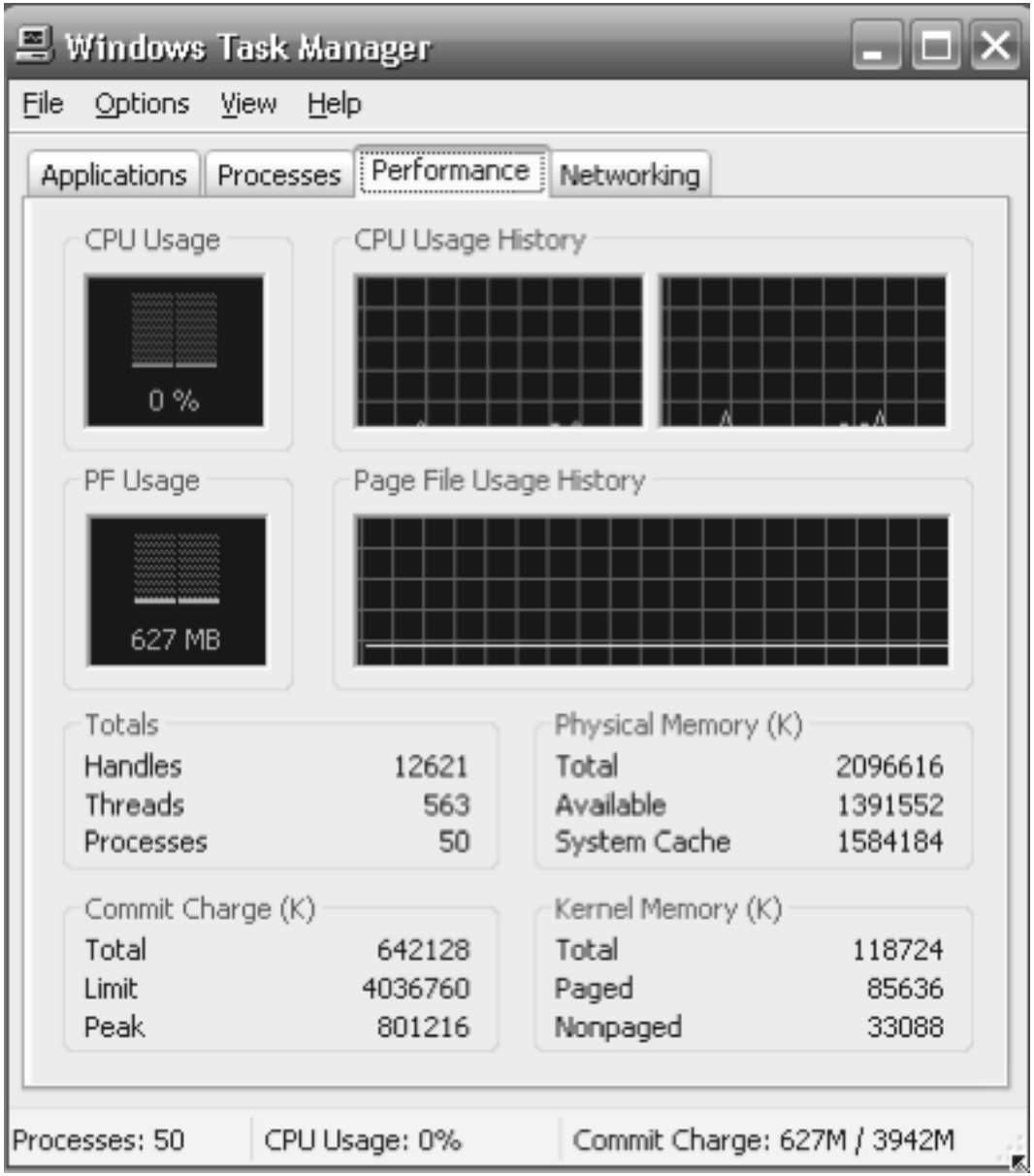
- Kernel data structures?

Operating System Debugging

- Debugging is finding and fixing errors, or bugs
- OS generate log files containing error information
- Failure of an application can generate core dump file capturing memory of the process
- Operating system failure can generate crash dump file containing kernel memory
- Beyond crashes, performance tuning can optimize system performance
  - Sometimes using trace listings of activities, recorded for analysis
  - Profiling is periodic sampling of instruction pointer to look for statistical trends
- Kernighan's Law: "Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it."

Performance Tuning

- Improve performance by removing bottlenecks
- OS must provide means of computing and displaying measures of system behavior
- For example, "top" program or Windows Task Manager


Windows Task Manager
File Options View Help
Applications Processes Performance Networking
CPU Usage
0 %
CPU Usage History
PF Usage
627 MB
Page File Usage History
Totals
Handles 12621
Threads 563
Processes 50
Physical Memory (K)
Total 2096616
Available 1391552
System Cache 1584184
Commit Charge (K)
Total 642128
Limit 4036760
Peak 801216
Kernel Memory (K)
Total 118724
Paged 85636
Nonpaged 33088
Processes: 50
CPU Usage: 0%
Commit Charge: 627M / 3942M

DTrace

- DTrace tool in Solaris, FreeBSD, Mac OS X allows live instrumentation on production systems
- Probes fire when code is executed within a provider, capturing state data and sending it to consumers of those probes
  Example of following XEventsQueued system call move from libc library to kernel and back

```
# ./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
```

Example: Record Process Running Time

- Using DTrace to record amount of time each process with UserID 101 is in running mode (on CPU) in nanoseconds

Example: DTrace Code

```
sched:::on-cpu
uid == 101
{
   self->ts = timestamp;
}

sched:::off-cpu
self->ts
{
   @time[execname] = sum(timestamp - self->ts);
   self->ts = 0;
}
```

Example: Running the DTrace Code

```
# dtrace -s sched.d
dtrace: script 'sched.d' matched 6 probes
^C
        gnome-settings-d              142354
        gnome-vfs-daemon              158243
        dsdm                          189804
        wnck-applet                   200030
        gnome-panel                   277864
        clock-applet                  374916
        mapping-daemon                385475
        xscreensaver                  514177
        metacity                      539281
        Xorg                         2579646
        gnome-terminal               5007269
        mixer_applet2                7388447
        java                        10769137
```

Figure 2.21 Output of the D code.

Questions

- OS debugging

Operating System Generations

- Operating systems are designed to run on any of a class of machines; the system must be configured for each specific computer site
- SYSGEN program obtains information concerning the specific configuration of the hardware system
  - Used to build system-specific compiled kernel or system-tuned
  - Can general more efficient code than one general kernel

System Boot

- When power initialized on system, execution starts at a fixed memory location
  - Firmware ROM used to hold initial boot code
- Operating system must be made available to hardware so hardware can start it
  - Small piece of code – bootstrap loader, stored in ROM or EEPROM locates the kernel, loads it into memory, and starts it
  - Sometimes two-step process where boot block at fixed location loaded by ROM code, which loads bootstrap loader from disk
- Common bootstrap loader, GRUB, allows selection of kernel from multiple disks, versions, kernel options
- Kernel loads and system is then running

Questions

- Concept of system generation
- System boot