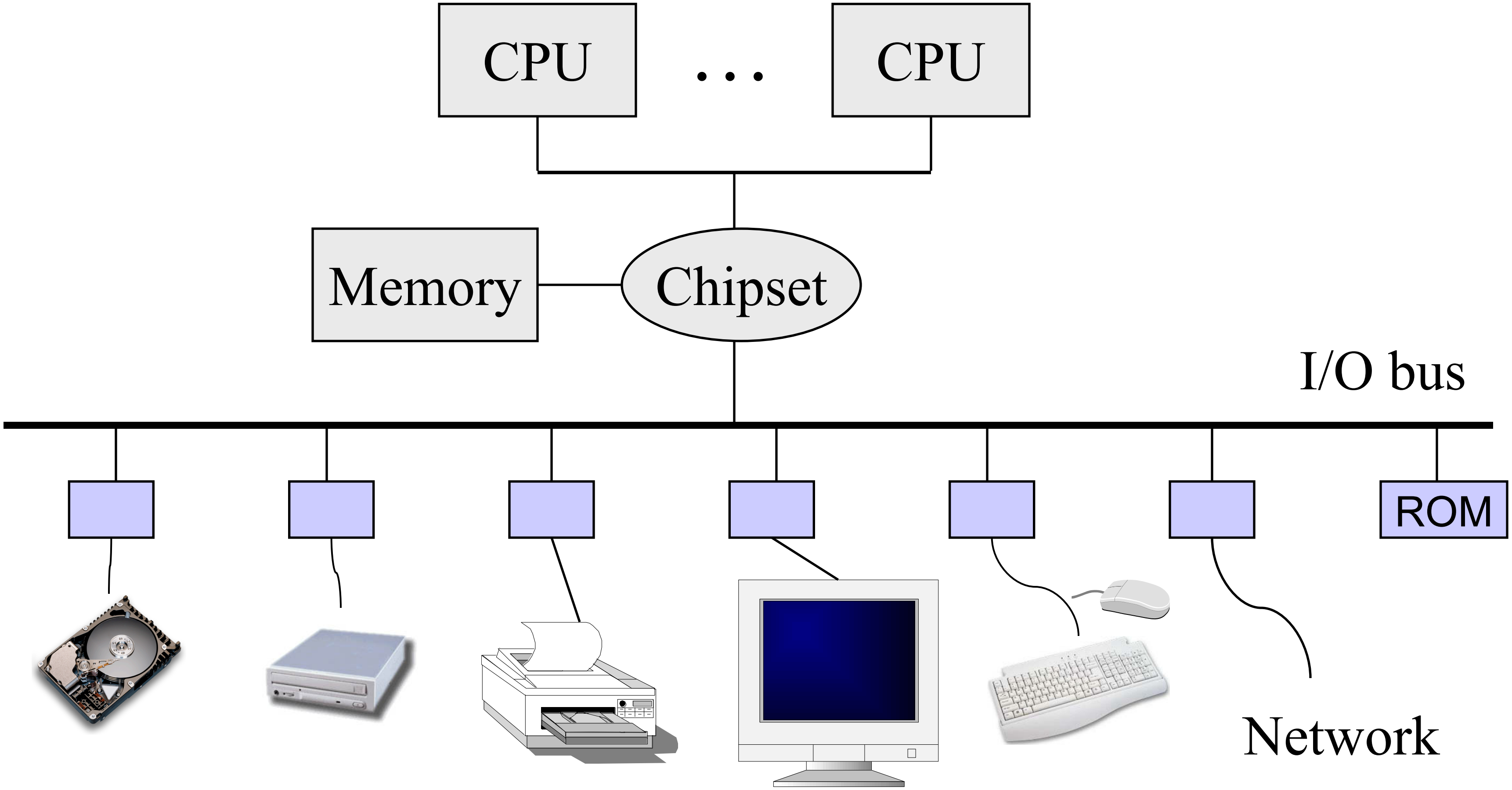
COS 318: Operating Systems

Overview

Today

- Overview of OS functionality
- Overview of OS components
- Interacting with the OS
- Booting a Computer

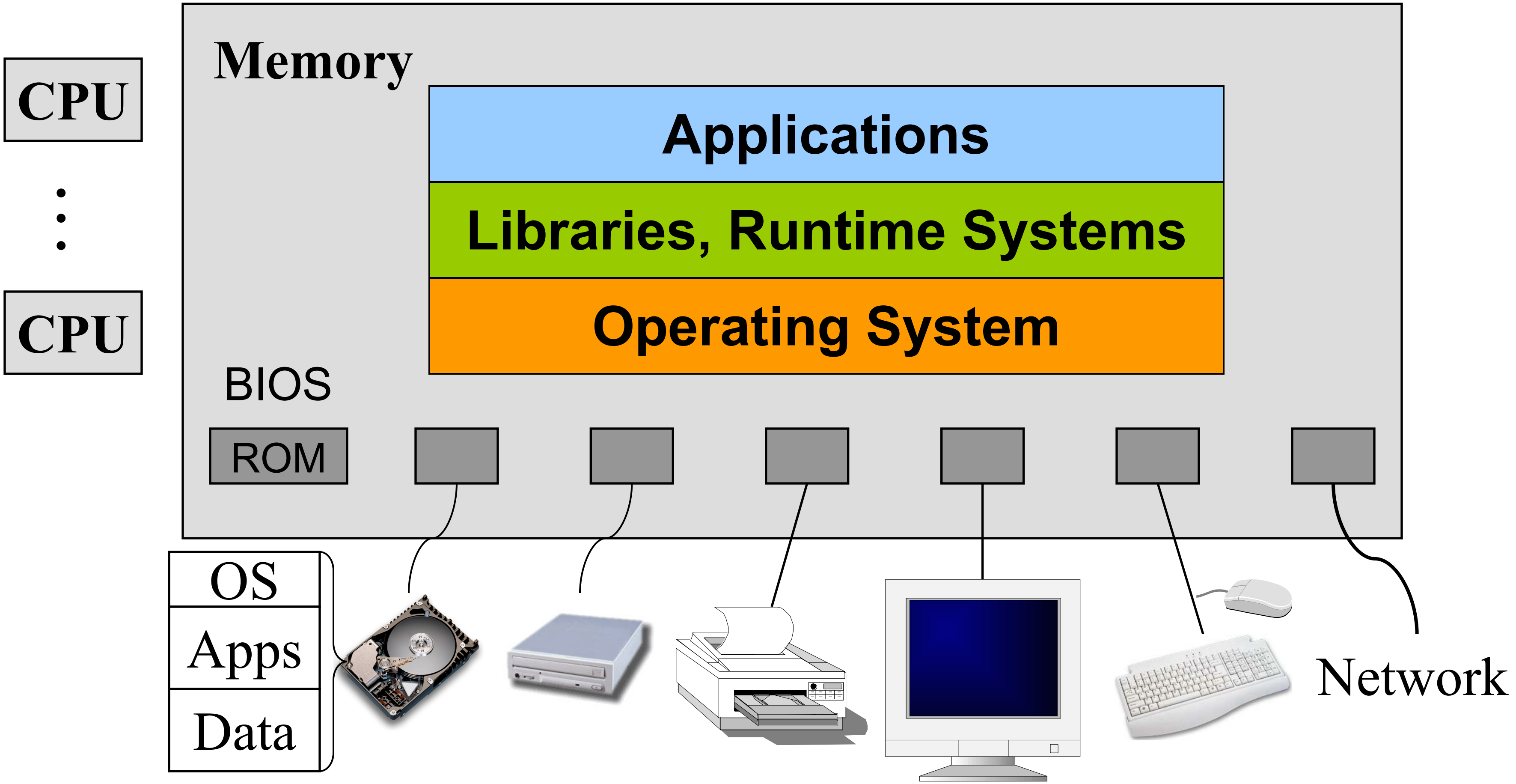
Hardware of A Typical Computer



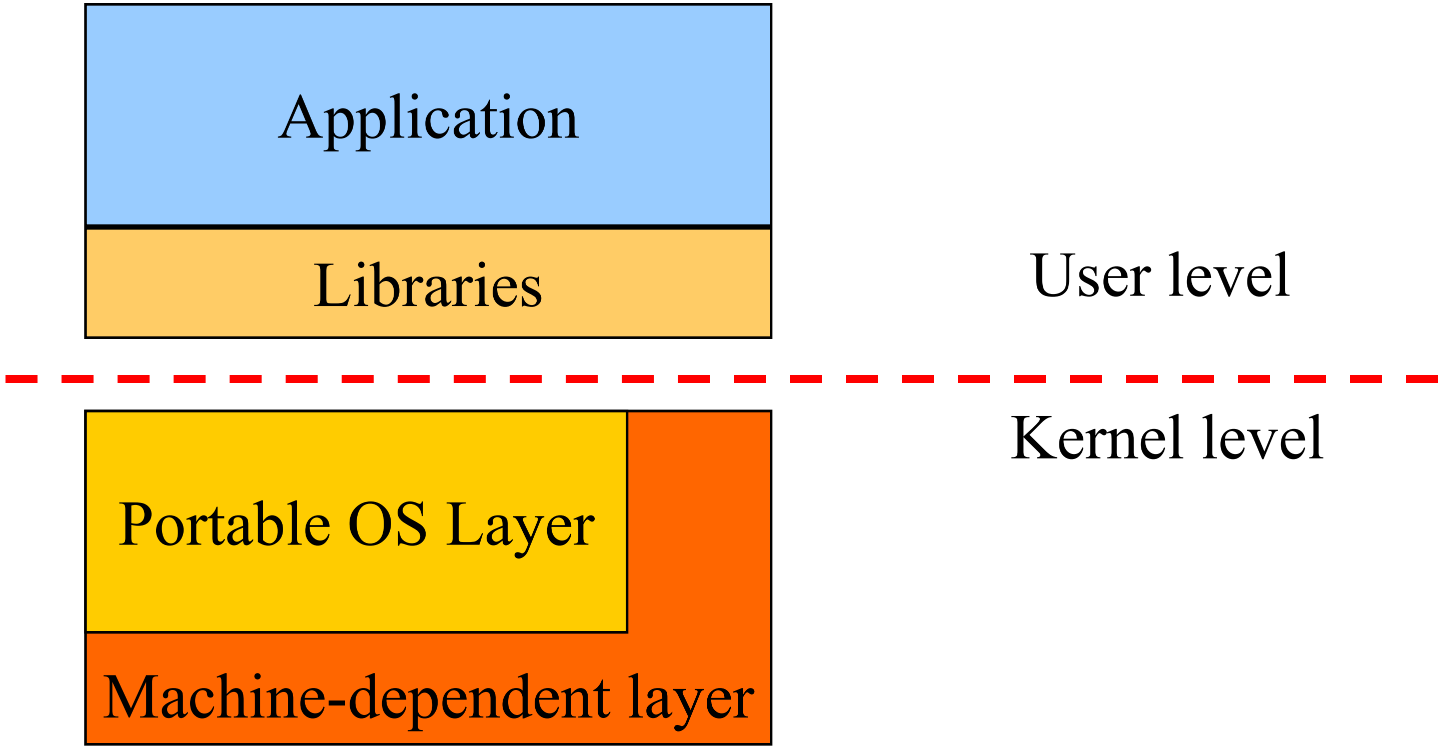
An Overview of HW Functionality

- **Executing machine code** (CPU, cache, memory)
  - Instructions for ALU, branch, memory operations
  - Instructions for communicating with I/O devices
- **Performing I/O operations**
  - I/O devices and the CPU can execute concurrently
  - Every device controller is in charge of one device type
  - Every device controller has a local buffer
  - CPU moves data btwn main memory and local buffers
  - I/O is btwn device and local buffer of device controller
  - Device controller uses **interrupt** to inform CPU it is done
- **Protection**
  - Timer, paging (e.g. TLB), mode bit (e.g. kernel/user)

Software in a Typical Computer



Typical Unix OS Structure



Application

Libraries

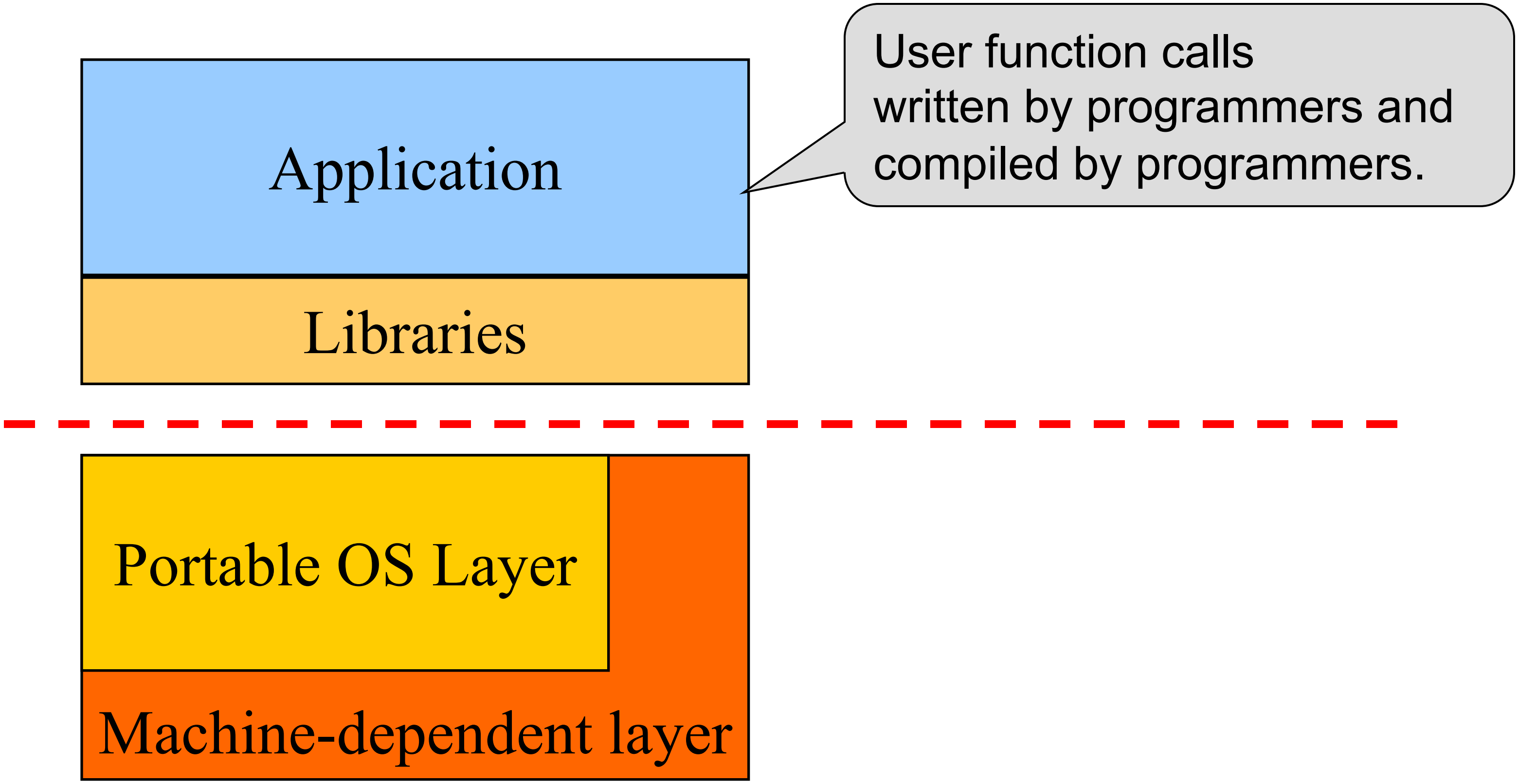
User level

Kernel level

Portable OS Layer

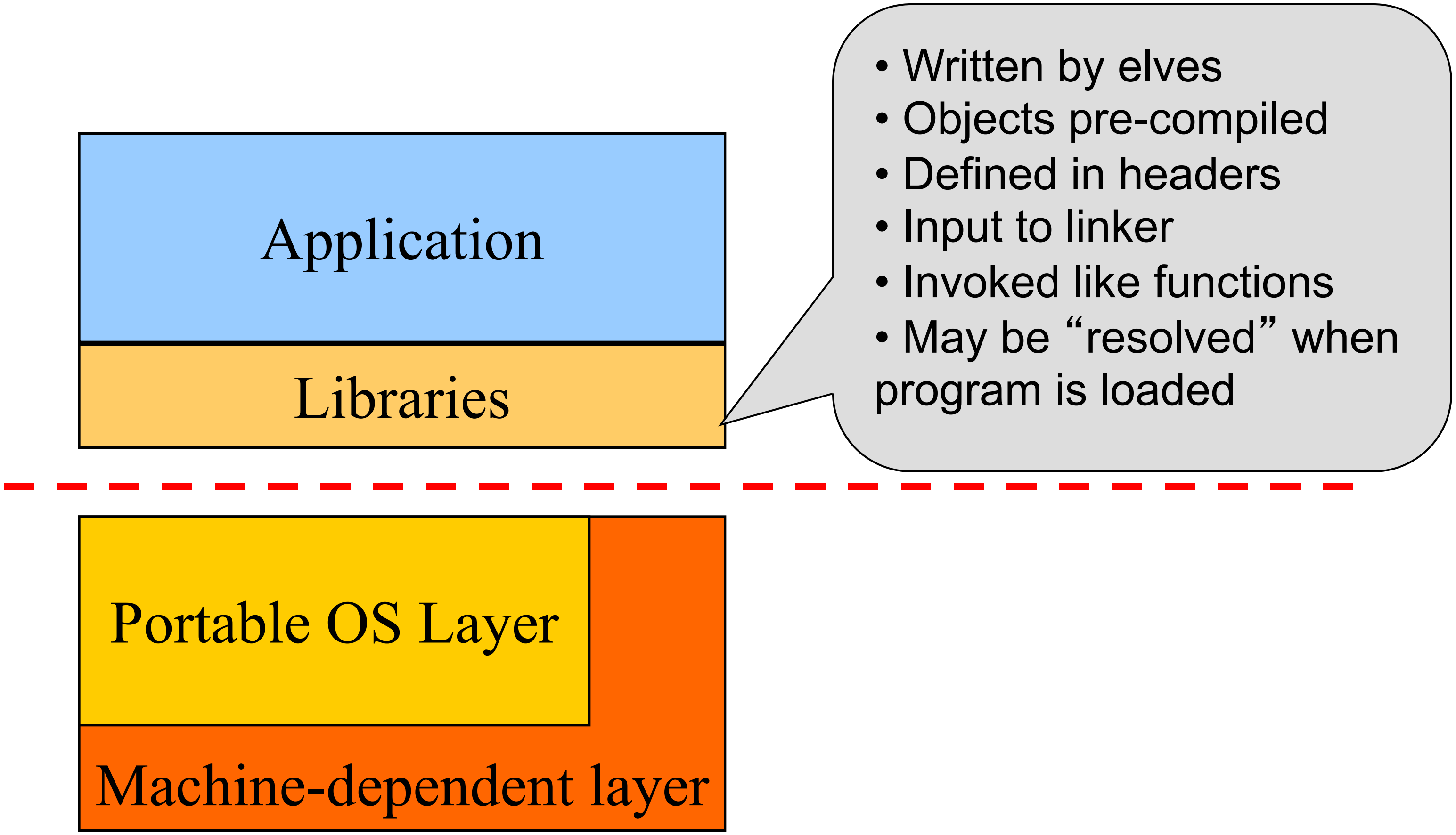
Machine-dependent layer

Typical Unix OS Structure



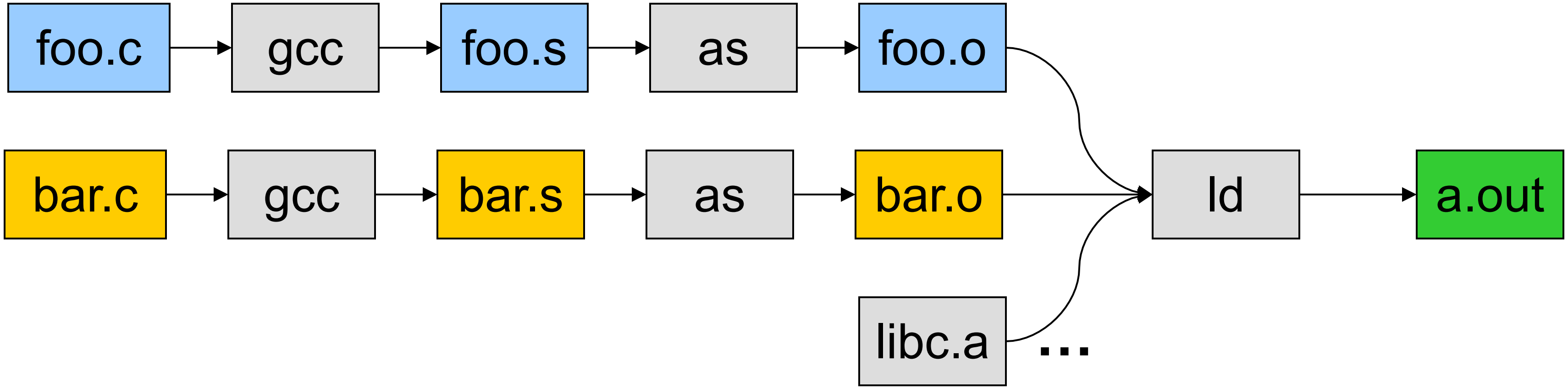
User function calls written by programmers and compiled by programmers.

Typical Unix OS Structure



- Written by elves
- Objects pre-compiled
- Defined in headers
- Input to linker
- Invoked like functions
- May be “resolved” when program is loaded

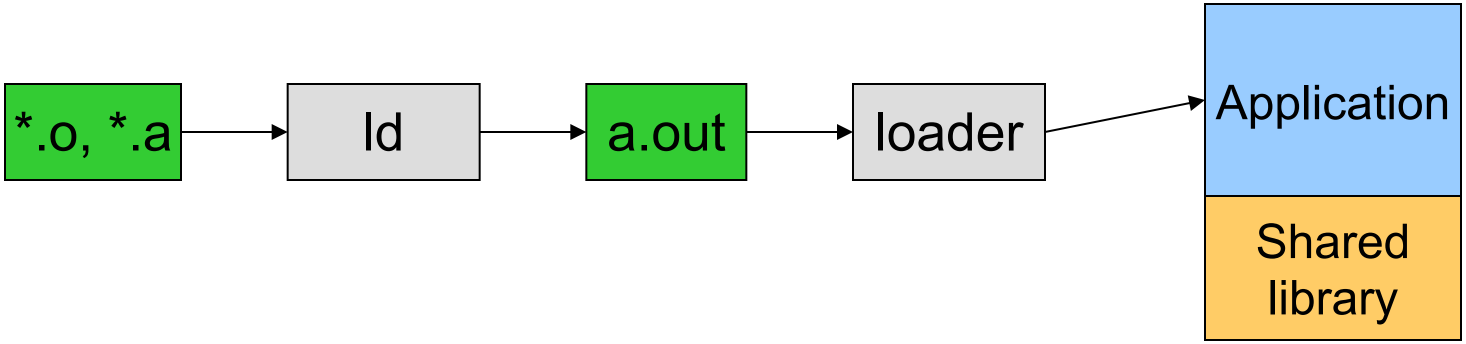
Quick Review: How Application is Created



- gcc can compile, assemble, and link together
- Compiler (part of gcc) compiles a program into assembly
- Assembler compiles assembly code into relocatable object file
- Linker links object files into an executable
- For more information:
  - Read man page of a.out, elf, ld, and nm
  - Read the document of ELF
- Q: What does the loader do?

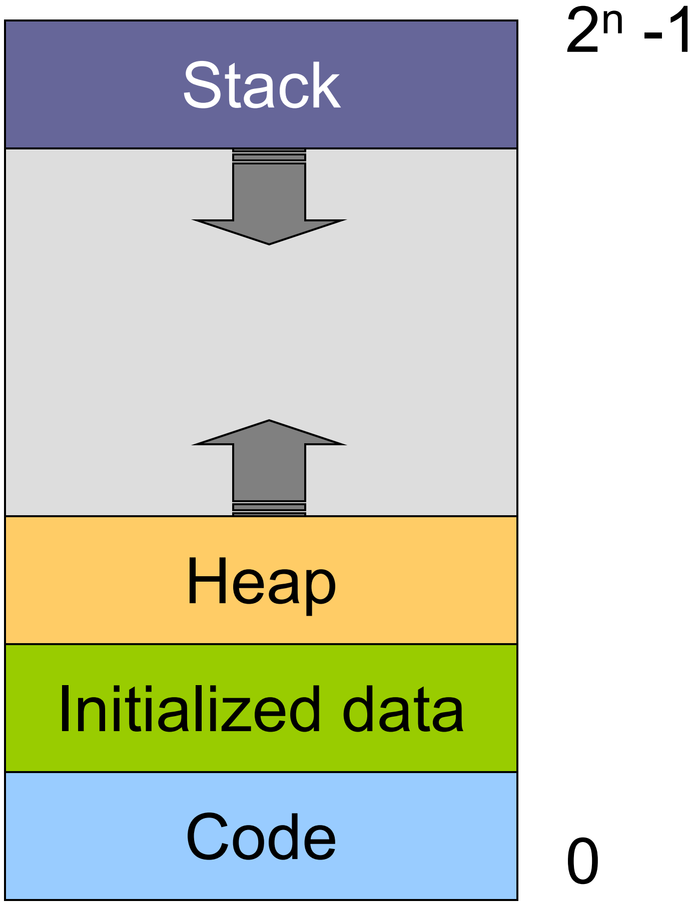
Application: How it's executed

- On Unix, "loader" does the job
  - Read an executable file
  - Layout the code, data, heap and stack
  - Dynamically link to shared libraries
  - Prepare for the OS kernel to run the application



What an executable application looks like

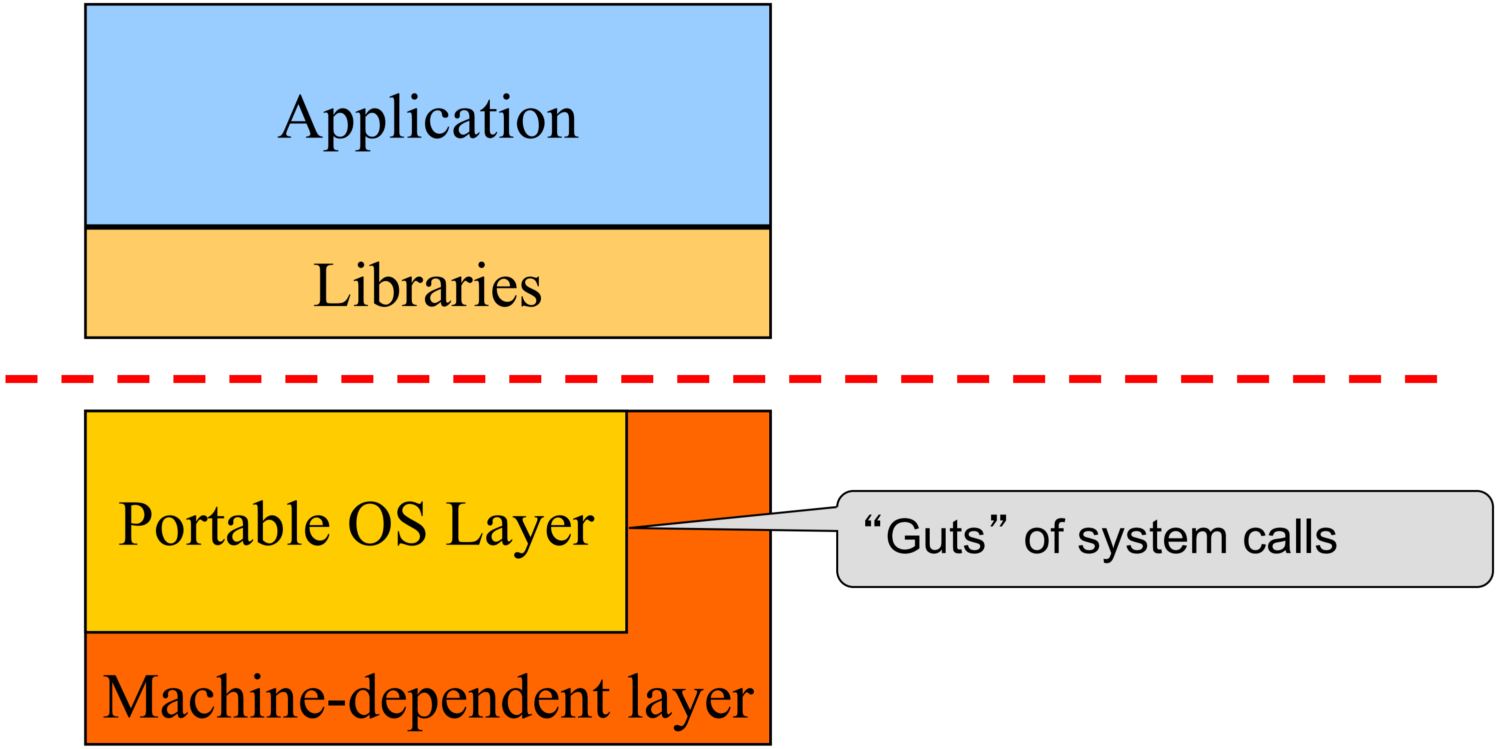
- Four segments
  - Code/Text – instructions
  - Data – global variables
  - Stack
  - Heap
- Why:
  - Separate code and data?
  - Have stack and heap go towards each other?



Responsibilities for the segments

- Stack
  - Layout by ?
  - Allocated/deallocated by ?
  - Local names are absolute/relative?
- Heap
  - Who sets the starting address?
  - Allocated/deallocated by ?
  - How do application programs manage it?
- Global data/code
  - Who allocates?
  - Who defines names and references?
  - Who translates references?
  - Who relocates addresses?
  - Who lays them out in memory?

Typical Unix OS Structure



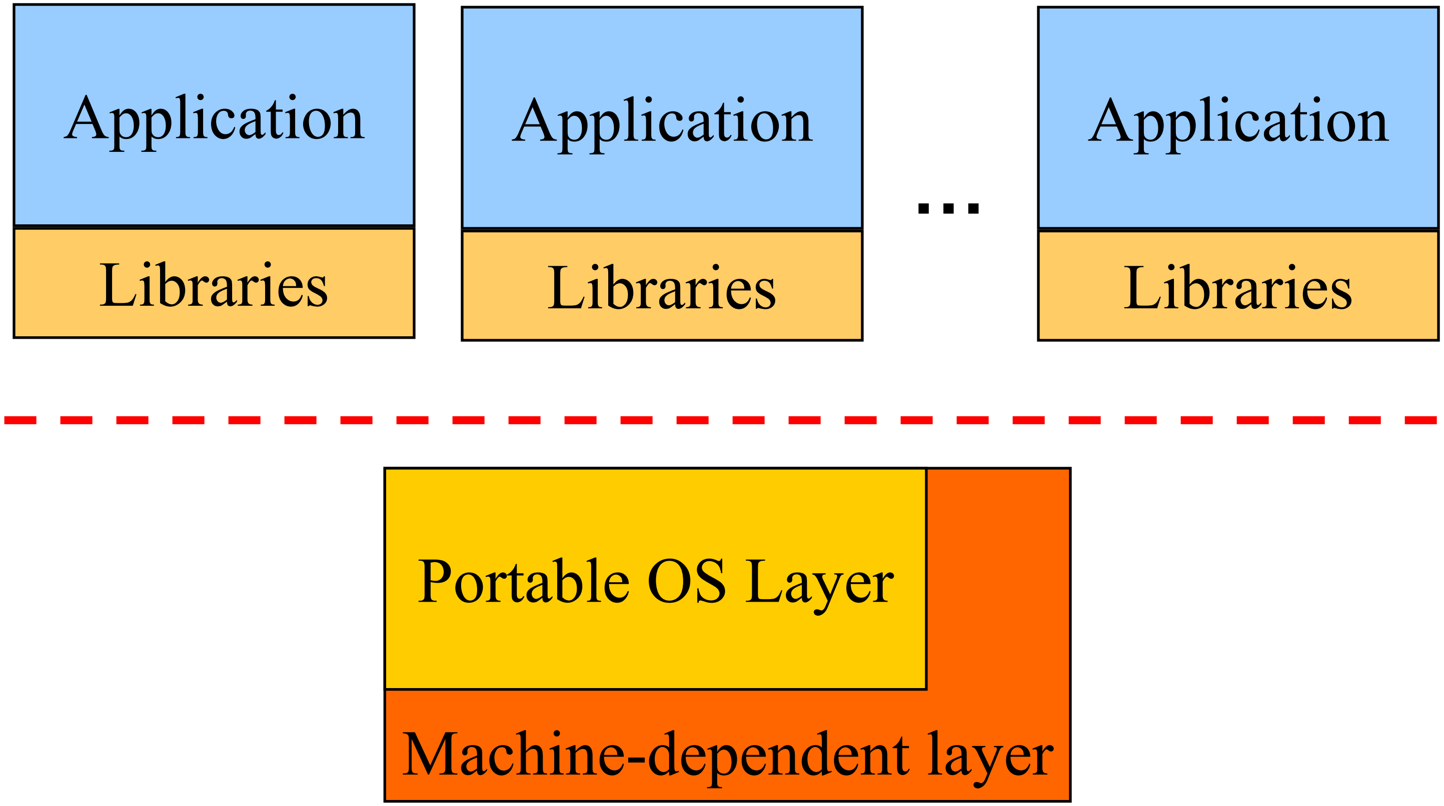
“Guts” of system calls

Must Support Multiple Applications

- In multiple windows
  - Browser, Zoom, shell, Powerpoint, Word, …
- Use command line to run multiple applications

```
% ls –al | grep ‘^d’
% foo &
% bar &
```

Multiple Application Processes



Application

Libraries

Application

Libraries

…

Application

Libraries

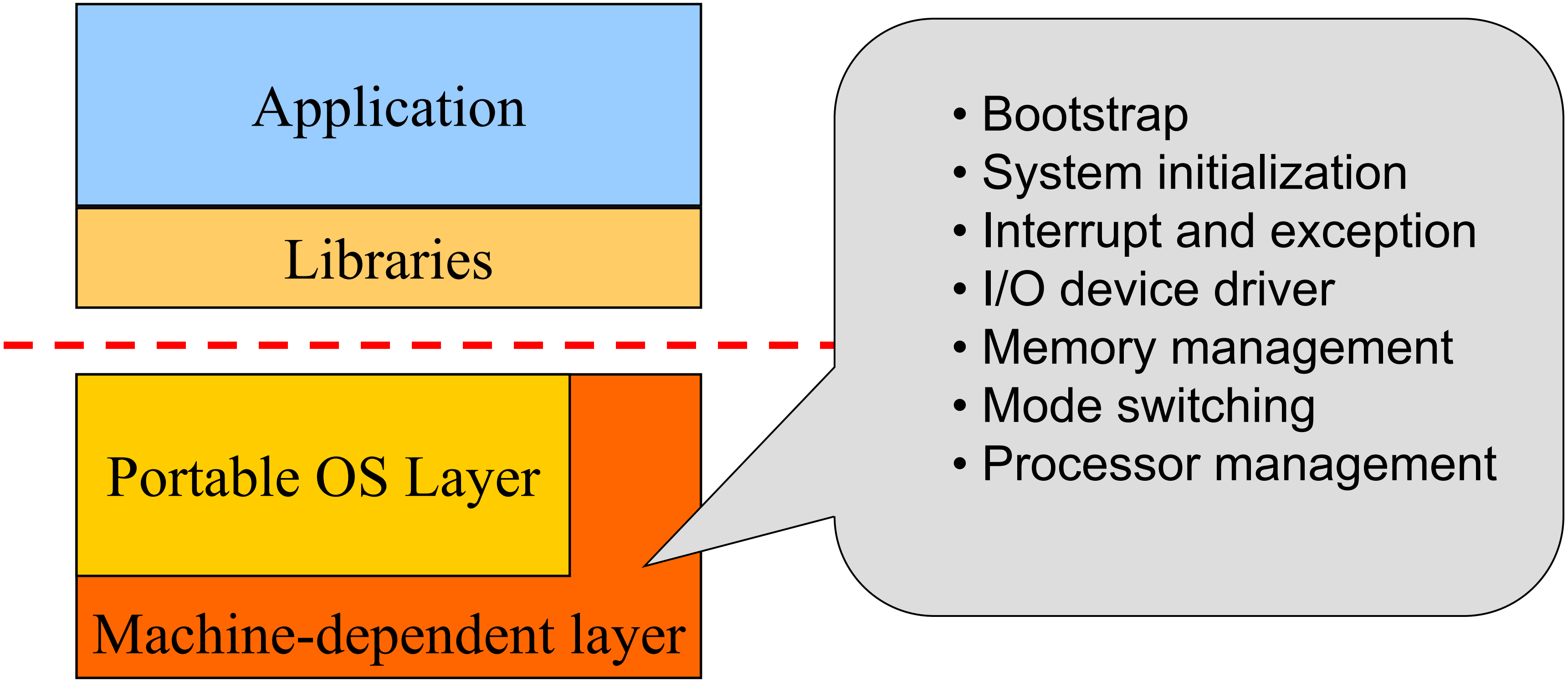
Portable OS Layer

Machine-dependent layer

OS Service Examples

- System calls: file open, close, read and write
- Control the CPU so that users won't cause problems
  - while (1) ;
- Protection:
  - Keep user programs from crashing OS
  - Keep user programs from crashing each other

Typical Unix OS Structure



- Bootstrap
- System initialization
- Interrupt and exception
- I/O device driver
- Memory management
- Mode switching
- Processor management

Today

- Overview of OS functionality
- Overview of OS components
- Interacting with the OS
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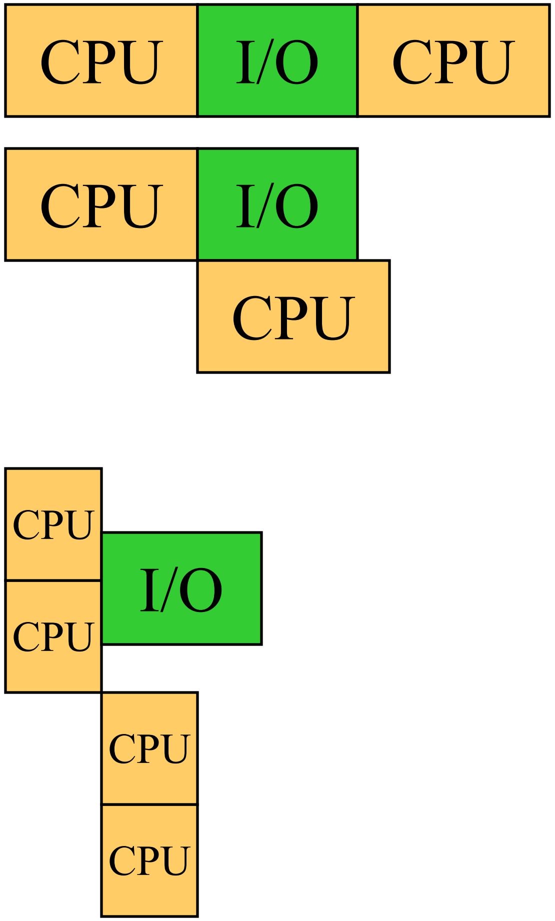
OS components

- Resource manager for each HW resource
  - CPU: processor management
  - RAM: memory management
  - Disk: file system and secondary-storage management
  - I/O device management (keyboards, mouse, network)
- Additional services:
  - window manager (GUI)
  - command-line interpreters (e.g., shell)
  - resource allocation and accounting
  - protection
    - Keep user programs from crashing OS
    - Keep user programs from crashing each other

Processor Management

- Goals
  - Overlap between I/O and computation
  - Time sharing
  - Allocation among Multiple CPUs
- Issues
  - Do not waste CPU resources
  - Synchronization and mutual exclusion
  - Fairness and deadlock



Memory Management

- Goals
  - Support for programs to run faster without complexity
  - Allocation and management
  - Implicit and explicit transfers among levels of hierarchy
- Issues
  - Efficiency & convenience
  - Fairness
  - Protection
- Q: Who/what manages registers, L1, L2, L3, DRAM?

Register: 1x

L1 cache: 2-4x

L2 cache: ~10x

L3 cache: ~50x

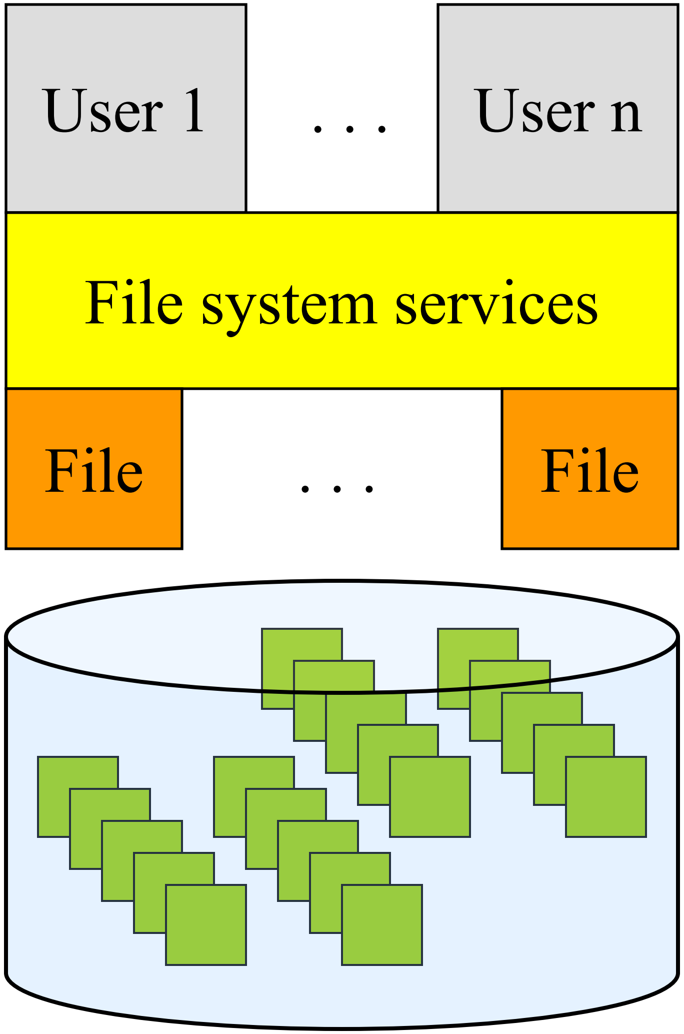
DRAM: ~200-500x

Disks: ~30M x

Archive storage: >1000M x

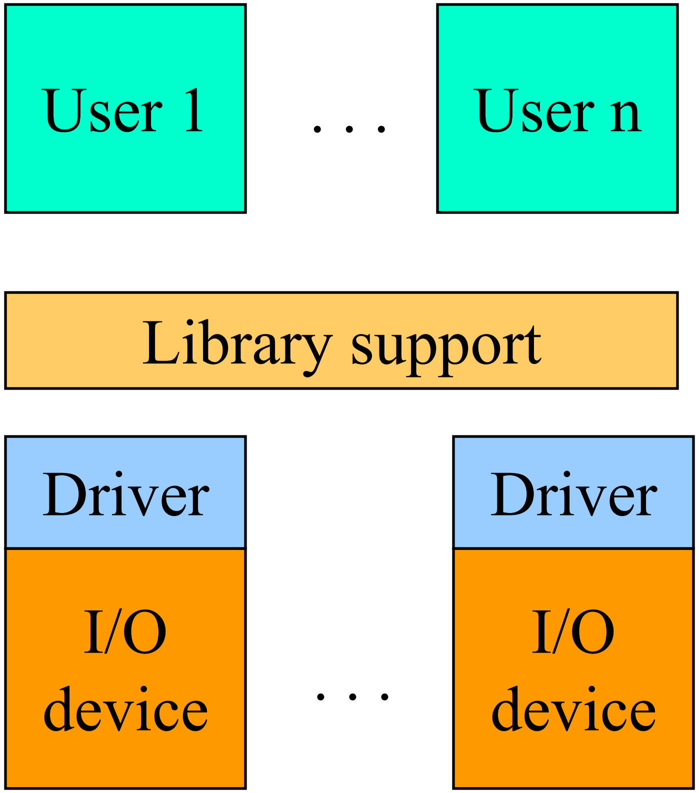
File System

- Goals:
  - Manage disk blocks
  - Map between files and disk blocks
- Typical file system calls
  - Open a file with authentication
  - Read/write data in files
  - Close a file
- Issues
  - Reliability
  - Safety
  - Efficiency
  - Manageability



I/O Device Management

- Goals
  - Interactions between devices and applications
  - Ability to plug in new devices
- Issues
  - Diversity of devices, third-party hardware
  - Efficiency
  - Fairness
  - Protection and sharing



Window Systems

- Goals
  - Interacting with a user
  - Interfaces to examine and manage apps and the system
- Issues
  - Inputs from keyboard, mouse, touch screen, …
  - Display output from applications and systems
  - Where is the Window System?
    - All in the kernel (Windows)
    - All at user level
    - Split between user and kernel (Unix)

Summary

- Overview of OS functionality
  - Layers of abstraction
  - Services to applications
  - Resource management
- Overview of OS components
  - Processor management
  - Memory management
  - I/O device management
  - File system
  - Window system
  - …

Outline

- Overview of OS functionality
- Overview of OS components
- Interacting with the OS
- Booting a Computer

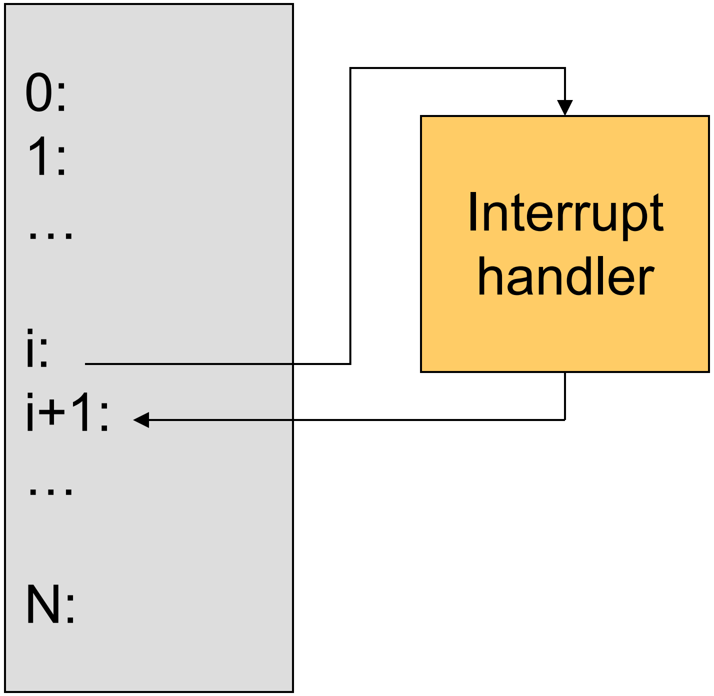
How the OS is Invoked

- Exceptions
  - Normal or program error: traps, faults, aborts
  - Special software generated: INT 3
  - Machine-check exceptions
- Interrupts
  - Hardware (by external devices)
  - Software: INT n
- System calls?
  - Generate a trap

- See Intel document volume 3 for details

Interrupts

- Raised by external events
- Interrupt handler is in kernel
- Eventually resume the interrupted process
- A way to
  - Switch CPU to another process
  - Overlap I/O with CPU
  - Handle other long-latency events



Interrupt and Exceptions (1)

Vector #	Mnemonic	Description	Type
0	#DE	Divide error (by zero)	Fault
1	#DB	Debug	Fault/trap
2		NMI interrupt	Interrupt
3	#BP	Breakpoint	Trap
4	#OF	Overflow	Trap
5	#BR	BOUND range exceeded	Trap
6	#UD	Invalid opcode	Fault
7	#NM	Device not available	Fault
8	#DF	Double fault	Abort
9		Coprocessor segment overrun	Fault
10	#TS	Invalid TSS (Task State Segment). Kernel/HW bug.	

Interrupt and Exceptions (2)

Vector #	Mnemonic	Description	Type
11	#NP	Segment not present	Fault
12	#SS	Stack-segment fault	Fault
13	#GP	General protection	Fault
14	#PF	Page fault	Fault
15		Reserved	Fault
16	#MF	Floating-point error (math fault)	Fault
17	#AC	Alignment check	Fault
18	#MC	Machine check	Abort
19-31		Reserved	
32-255		User defined	Interrupt

System Calls

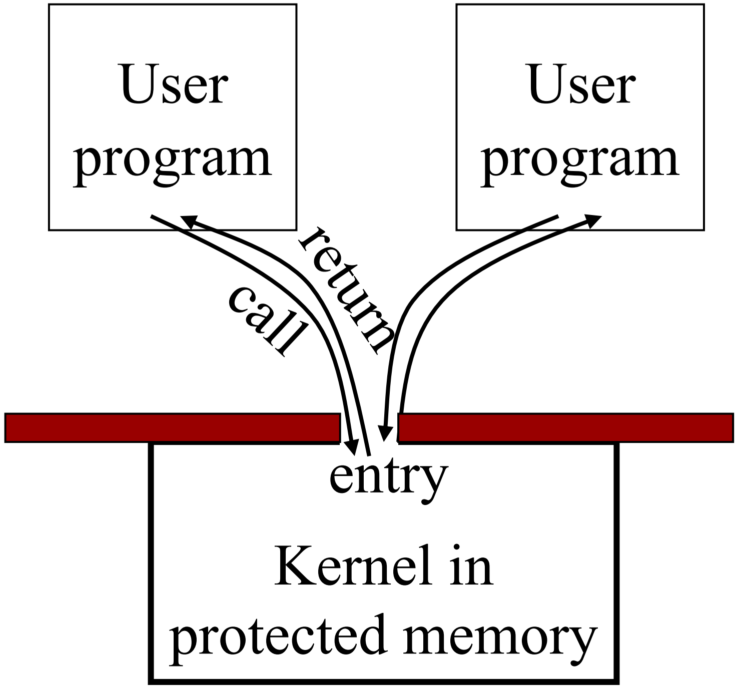
- Operating system API
  - Interface between an application and the operating system kernel
- Categories of system calls
  - Process management
  - Memory management
  - File management
  - Device management
  - Communication

How many system calls?

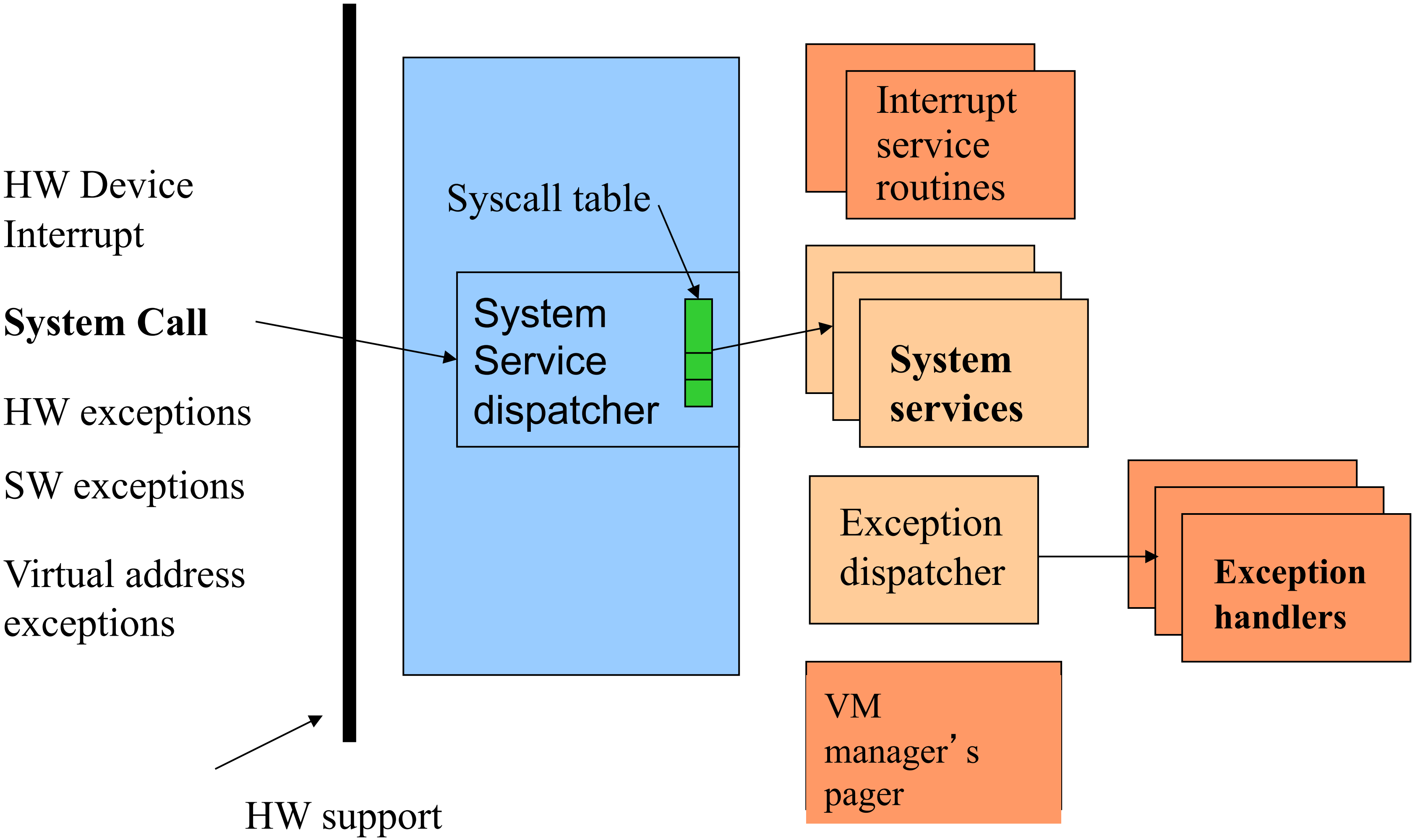
6th Edition Unix:	~45
POSIX:	~130
FreeBSD:	~130
Linux:	~250
Windows 7:	> 900

System Call Mechanism

- Assumptions
  - User code can be arbitrary
  - User code cannot modify kernel memory
- Design Issues
  - User makes a system call with parameters
  - The call mechanism switches code to kernel mode
  - Execute system call
  - Return with results



OS Kernel: Trap Handler



HW Device Interrupt

System Call

HW exceptions

SW exceptions

Virtual address exceptions

HW support

Syscall table

System Service dispatcher

Interrupt service routines

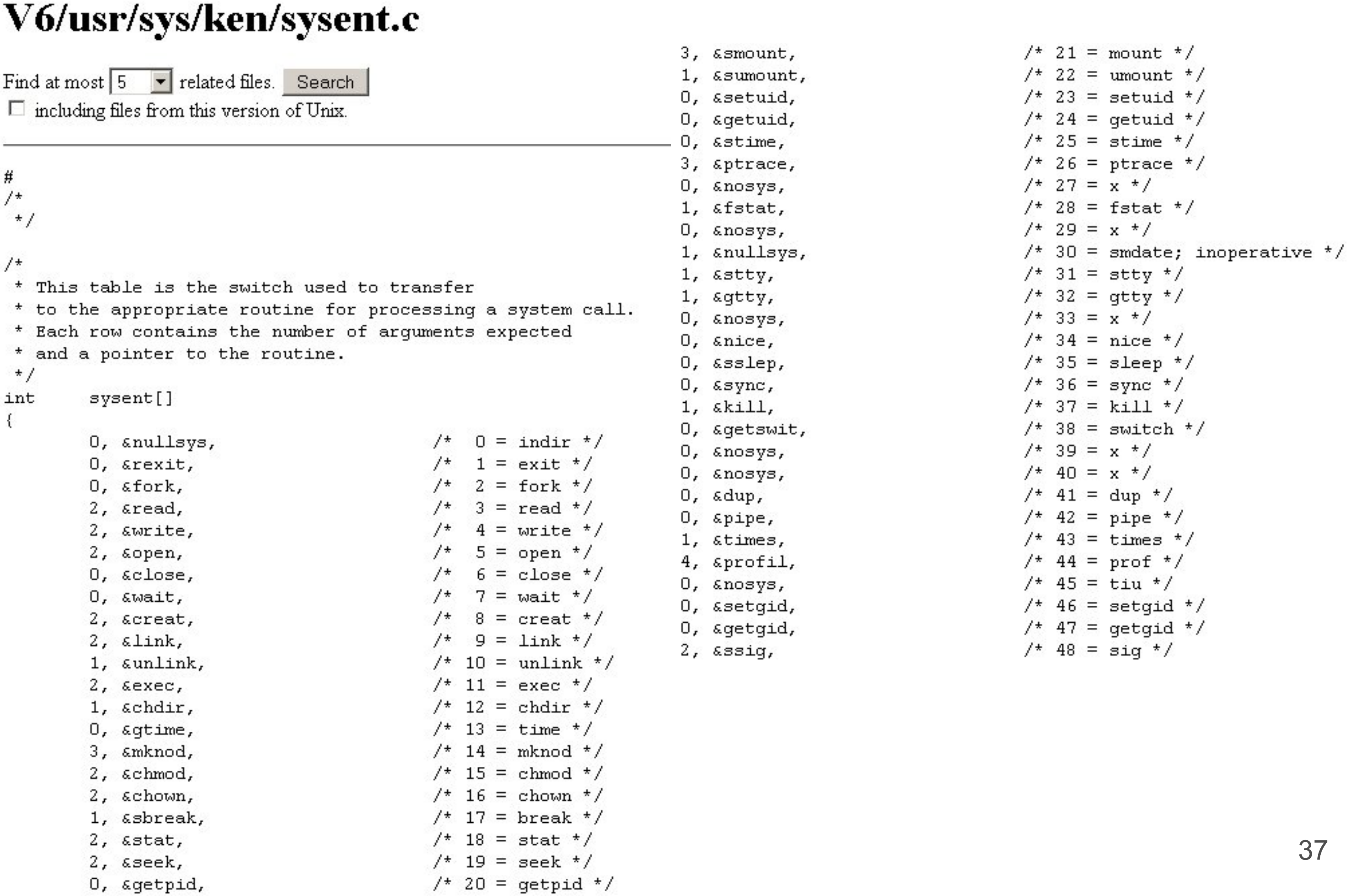
System services

Exception dispatcher

Exception handlers

VM manager’s pager

From http://minnie.tuhs.org/UnixTree/V6



V6/usr/sys/ken/sysent.c

```
#
/*
 */

/*
 * This table is the switch used to transfer
 * to the appropriate routine for processing a system call.
 * Each row contains the number of arguments expected
 * and a pointer to the routine.
 */
int     sysent[]
{
        0, &nullsys,                    /*  0 = indir */
        0, &rexit,                      /*  1 = exit */
        0, &fork,                       /*  2 = fork */
        2, &read,                       /*  3 = read */
        2, &write,                      /*  4 = write */
        2, &open,                       /*  5 = open */
        0, &close,                      /*  6 = close */
        0, &wait,                       /*  7 = wait */
        2, &creat,                      /*  8 = creat */
        2, &link,                       /*  9 = link */
        1, &unlink,                     /* 10 = unlink */
        2, &exec,                       /* 11 = exec */
        1, &chdir,                      /* 12 = chdir */
        0, &gtime,                      /* 13 = time */
        3, &mknod,                      /* 14 = mknod */
        2, &chmod,                      /* 15 = chmod */
        2, &chown,                      /* 16 = chown */
        1, &sbreak,                     /* 17 = break */
        2, &stat,                       /* 18 = stat */
        2, &seek,                       /* 19 = seek */
        0, &getpid,                     /* 20 = getpid */
        3, &smount,                     /* 21 = mount */
        1, &sumount,                    /* 22 = umount */
        0, &setuid,                     /* 23 = setuid */
        0, &getuid,                     /* 24 = getuid */
        0, &stime,                      /* 25 = stime */
        3, &ptrace,                     /* 26 = ptrace */
        0, &nosys,                      /* 27 = x */
        1, &fstat,                      /* 28 = fstat */
        0, &nosys,                      /* 29 = x */
        1, &nullsys,                    /* 30 = smdate; inoperative */
        1, &stty,                       /* 31 = stty */
        1, &gtty,                       /* 32 = gtty */
        0, &nosys,                      /* 33 = x */
        0, &nice,                       /* 34 = nice */
        0, &sslep,                      /* 35 = sleep */
        0, &sync,                       /* 36 = sync */
        1, &kill,                       /* 37 = kill */
        0, &getswit,                    /* 38 = switch */
        0, &nosys,                      /* 39 = x */
        0, &nosys,                      /* 40 = x */
        0, &dup,                        /* 41 = dup */
        0, &pipe,                       /* 42 = pipe */
        1, &times,                      /* 43 = times */
        4, &profil,                     /* 44 = prof */
        0, &nosys,                      /* 45 = tiu */
        0, &setgid,                     /* 46 = setgid */
        0, &getgid,                     /* 47 = getgid */
        2, &ssig,                       /* 48 = sig */
```

Passing Parameters

- Pass by registers
  - # of registers
  - # of usable registers
  - # of parameters in system call
  - Spill/fill code in compiler
- Pass by a memory vector (list)
  - Single register for starting address
  - Vector in user’s memory
- Pass by stack
  - Similar to the memory vector
  - Procedure call convention

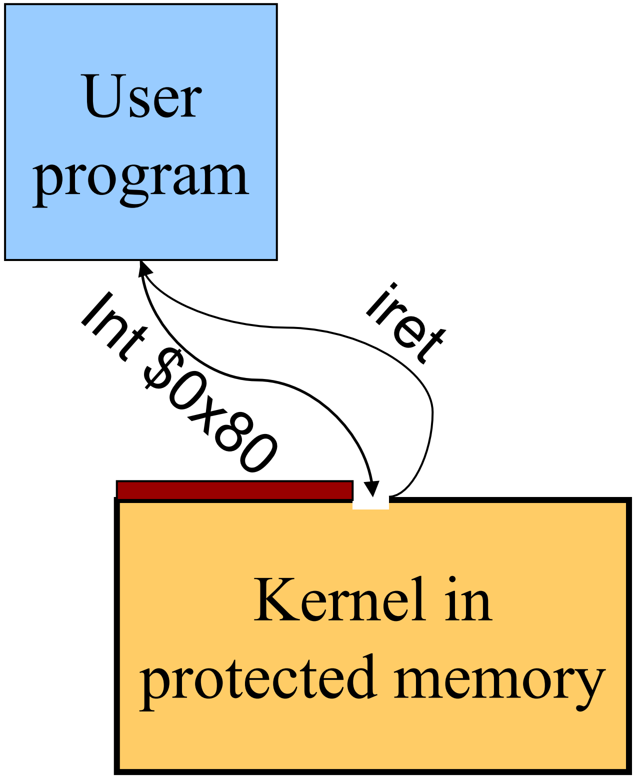
Library Stubs for System Calls

- Example:

```
int read( int fd, char * buf, int size)
{
    move fd, buf, size to $R_1$, $R_2$, $R_3$
    move READ to $R_0$
    int $0x80
    move result to $R_{result}$
}
```

Linux: 80
NT: 2E

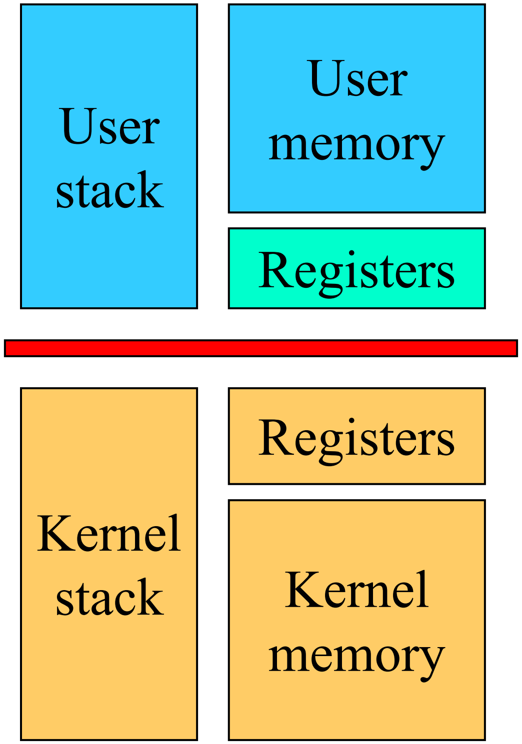
Q. What system call does int $0x80 correspond to?



System Call Entry Point

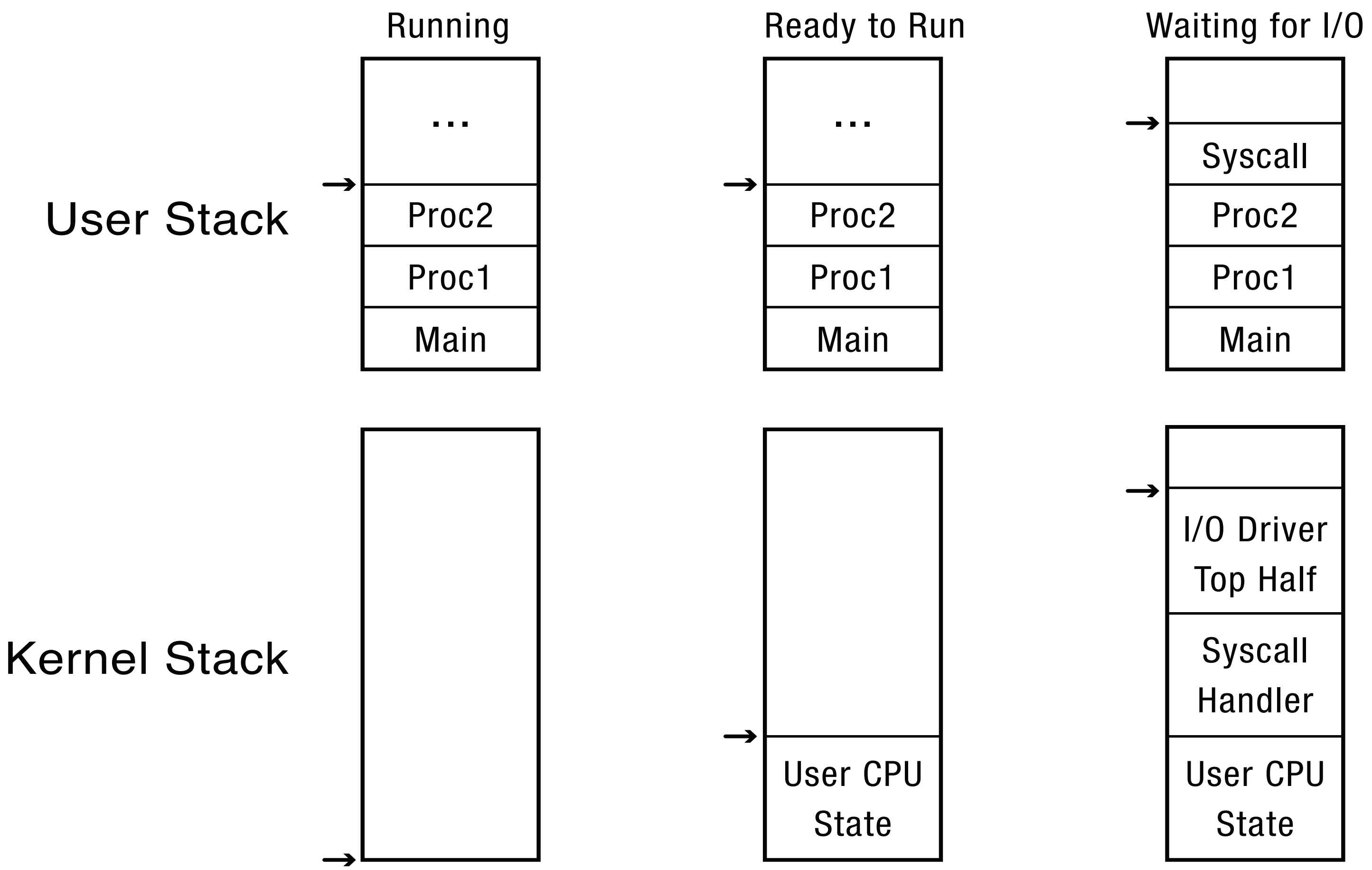
```
EntryPoint:
    switch to kernel stack
    save context
    check $R_0$
    call the real code pointed by $R_0$
    place result in $R_{result}$
    restore context
    switch to user stack
    iret (change to user mode and return)
```

(Assumes passing parameters in registers)



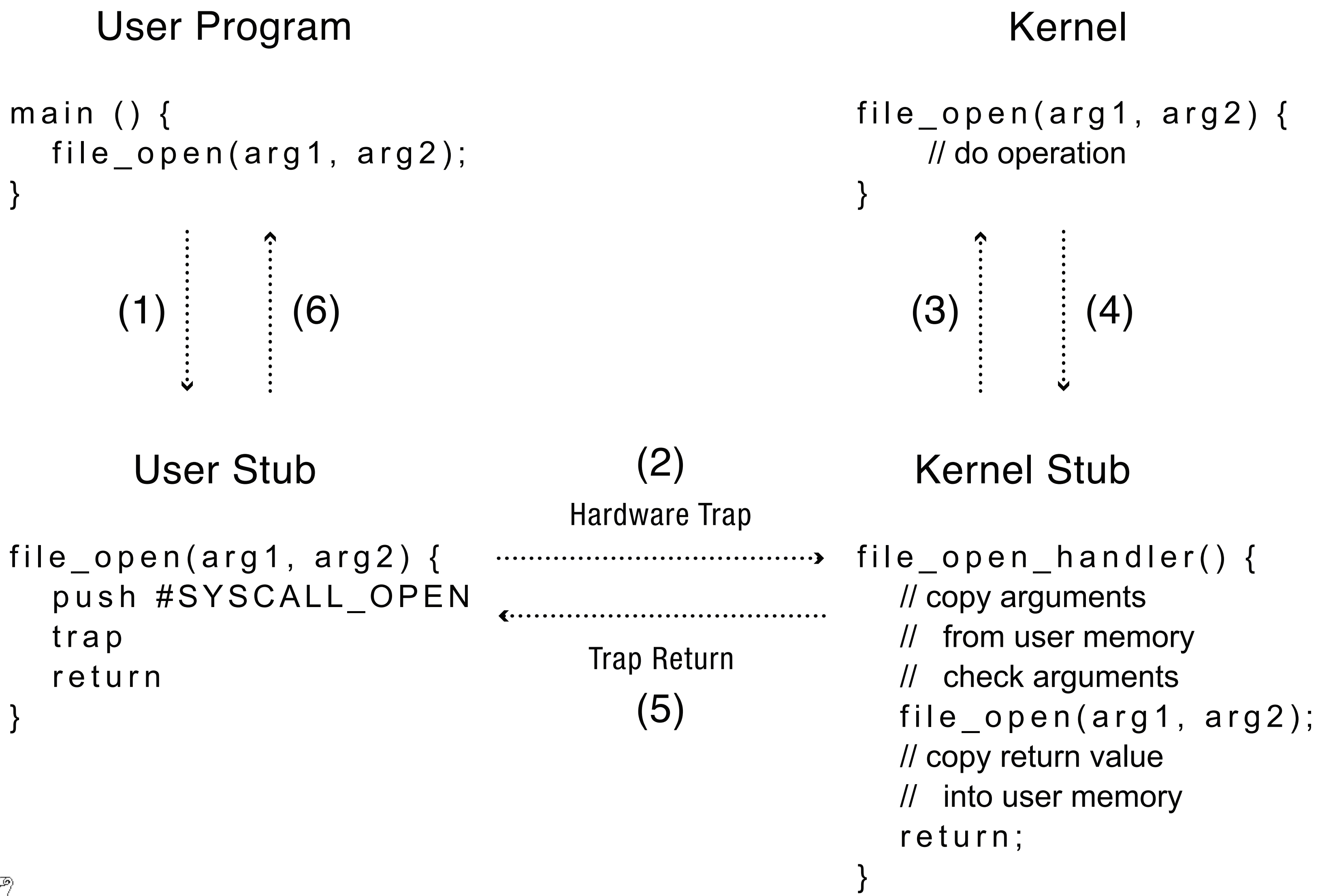
Kernel stacks

Per-processor, located in kernel memory. Why can't the interrupt handler run on the stack of the interrupted user process?



	Running	Ready to Run	Waiting for I/O
User Stack	… Proc2 Proc1 Main	… Proc2 Proc1 Main	Syscall Proc2 Proc1 Main
Kernel Stack		User CPU State	I/O Driver Top Half Syscall Handler User CPU State

System call stubs



User Program

```
main () {
   file_open(arg1, arg2);
}
```

(1) (6)

Kernel

```
file_open(arg1, arg2) {
      // do operation
}
```

(3) (4)

User Stub

```
file_open(arg1, arg2) {
   push #SYSCALL_OPEN
   trap
   return
}
```

(2)

Hardware Trap

Trap Return

(5)

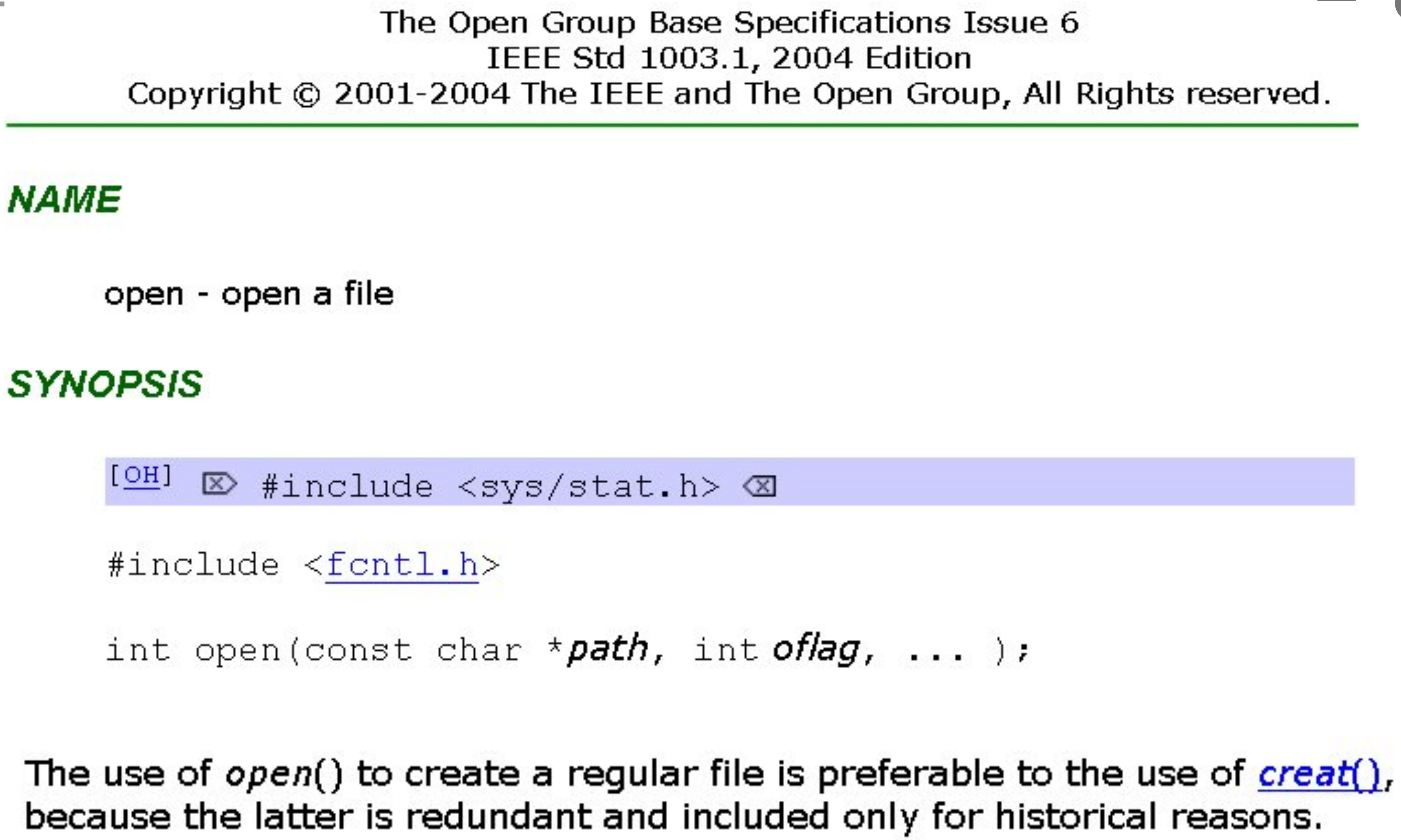
Kernel Stub

```
file_open_handler() {
   // copy arguments
   //   from user memory
   //   check arguments
   file_open(arg1, arg2);
   // copy return value
   //   into user memory
   return;
}
```

Design Issues

- System calls
  - There is one result register; what about more results?
  - How do we pass errors back to the caller?
- Q. What criteria should you use to decide what should be a system call versus a library call? What are the most important goals for each?

Backward compatibility...



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IEEE Std 1003.1, 2004 Edition
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NAME

open - open a file

SYNOPSIS

```
[OH] ⌦ #include <sys/stat.h> ⌫

#include <fcntl.h>

int open(const char *path, int oflag, ... );
```

The use of *open*() to create a regular file is preferable to the use of *creat()*, because the latter is redundant and included only for historical reasons.

Division of Labor (Separation Of Concerns)

Memory management example

- Kernel
  - Allocates “pages” with protection
  - Allocates a big chunk (many pages) to library
  - Does not care about small allocations
- Library
  - Provides malloc/free for allocation and deallocation
  - Applications use them to manage memory
  - When reaching the end, library asks kernel for more

Today

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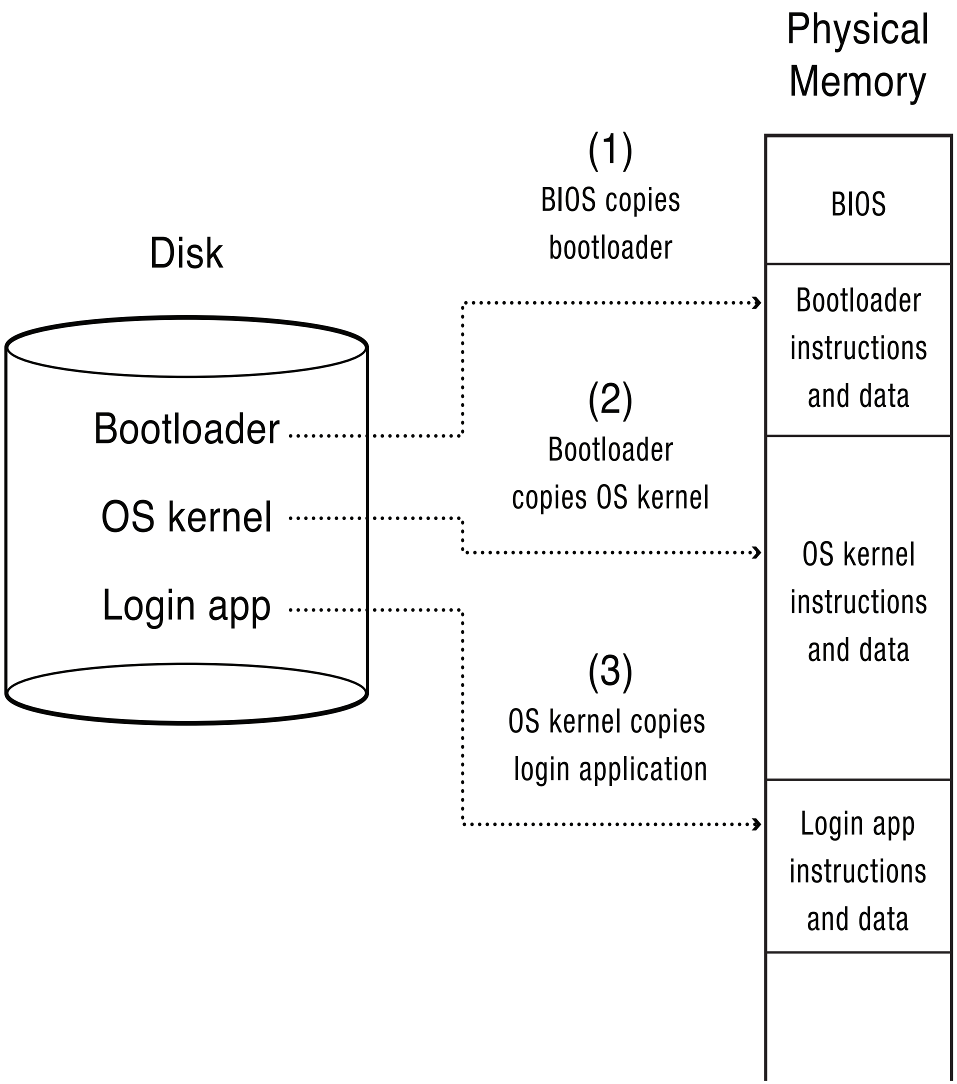
Booting a Computer

- Power up a computer
- Processor reset
  - Set to known state
  - Jump to ROM code (for x86, this is the BIOS)
- Load in the boot loader from stable storage
- Jump to the boot loader
- Load the rest of the operating system
- Initialize and run



System Boot

- Power on (processor waits until Power Good Signal)
- Processor jumps to a fixed address, which is the start of the ROM BIOS program

ROM Bios Startup Program (1)

- POST (Power-On Self-Test)
  - Stop booting if fatal errors, and report
- Look for video card and execute built-in BIOS code (normally at C000h)
- Look for other devices ROM BIOS code
  - IDE/ATA disk ROM BIOS at C8000h 9=818200d)
- Display startup screen
  - BIOS information
- Execute more tests
  - memory
  - system inventory

ROM BIOS startup program (2)

- Look for logical devices
  - Label them
    - Serial ports: COM 1, 2, 3, 4
    - Parallel ports: LPT 1, 2, 3
  - Assign each an I/O address and interrupt numbers
- Detect and configure Plug-and-Play (PnP) devices
- Display configuration information on screen

ROM BIOS startup program (3)

- Search for a drive to BOOT from
  - Hard disk or USB drive or CD/DVD
- Load code in boot sector
- Execute boot loader
- Boot loader loads program to be booted
  - If no OS: "Non-system disk or disk error - Replace and press any key when ready"
- Transfer control to loaded program
  - Could be OS or another feature-rich bootloader (e.g. GRUB), which then loads the actual OS

Summary

- Protection mechanism
  - Architecture support: two modes
  - Software traps (exceptions)
- OS structures
  - Monolithic, layered, microkernel and virtual machine
- System calls
  - Implementation
  - Design issues
  - Tradeoffs with library calls