Operating Systems

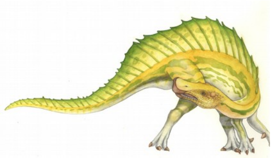
Isfahan University of Technology
Electrical and Computer Engineering Department
1400-1 semester

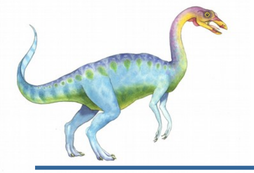
Zeinab Zali

Session 3: Operating System Design and Implementation

Design and Implementation

- Design and Implementation of OS is 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
- Specifying and designing an OS is highly creative task of **software engineering**



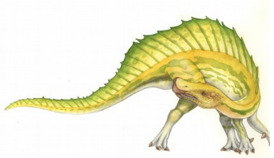


Policy and Mechanism

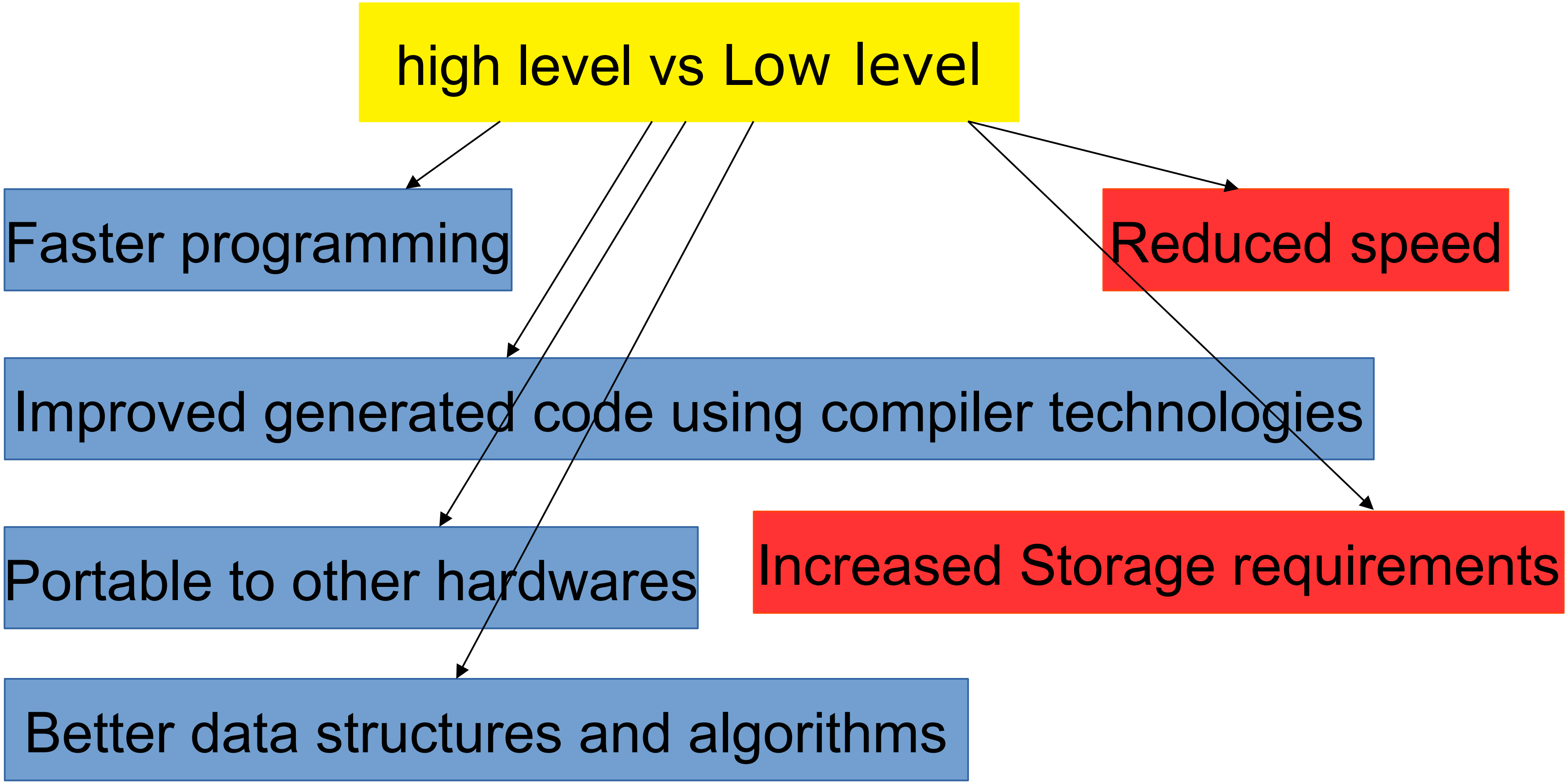
- **Policy**: **What** needs to be done?
  - Example: Interrupt after every 100 seconds
- **Mechanism**: **How** to do something?
  - Example: timer
- Important principle: separate policy from mechanism
- The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later.
  - Example: change 100 to 200

Implementation

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



OS Implementation



high level vs Low level

Faster programming

Reduced speed

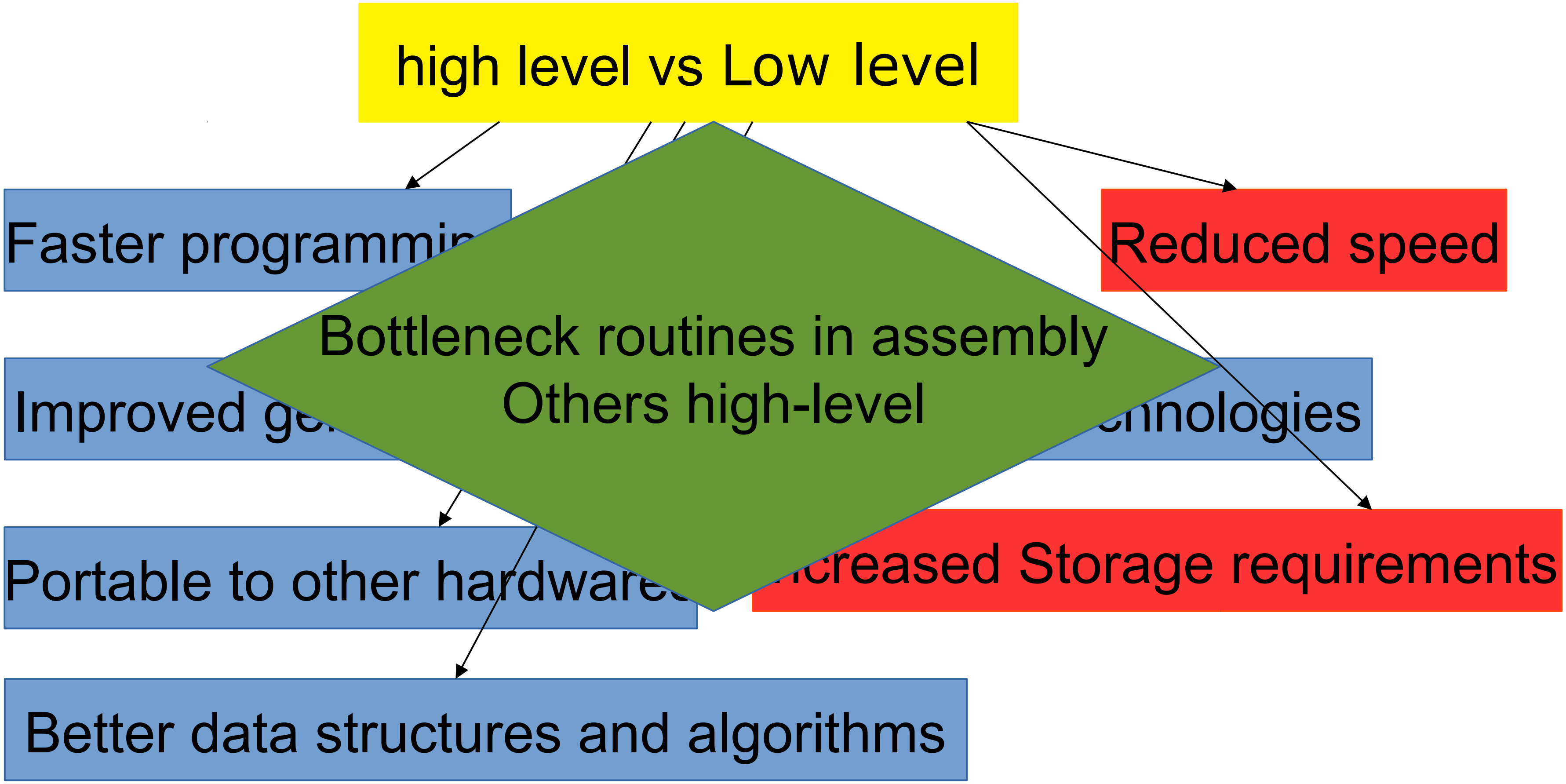
Improved generated code using compiler technologies

Portable to other hardwares

Increased Storage requirements

Better data structures and algorithms

OS Implementation



high level vs Low level

Faster programmin

Reduced speed

Bottleneck routines in assembly

Others high-level

Improved ge

chnologies

Portable to other hardware

creased Storage requirements

Better data structures and algorithms

Operating System Structure

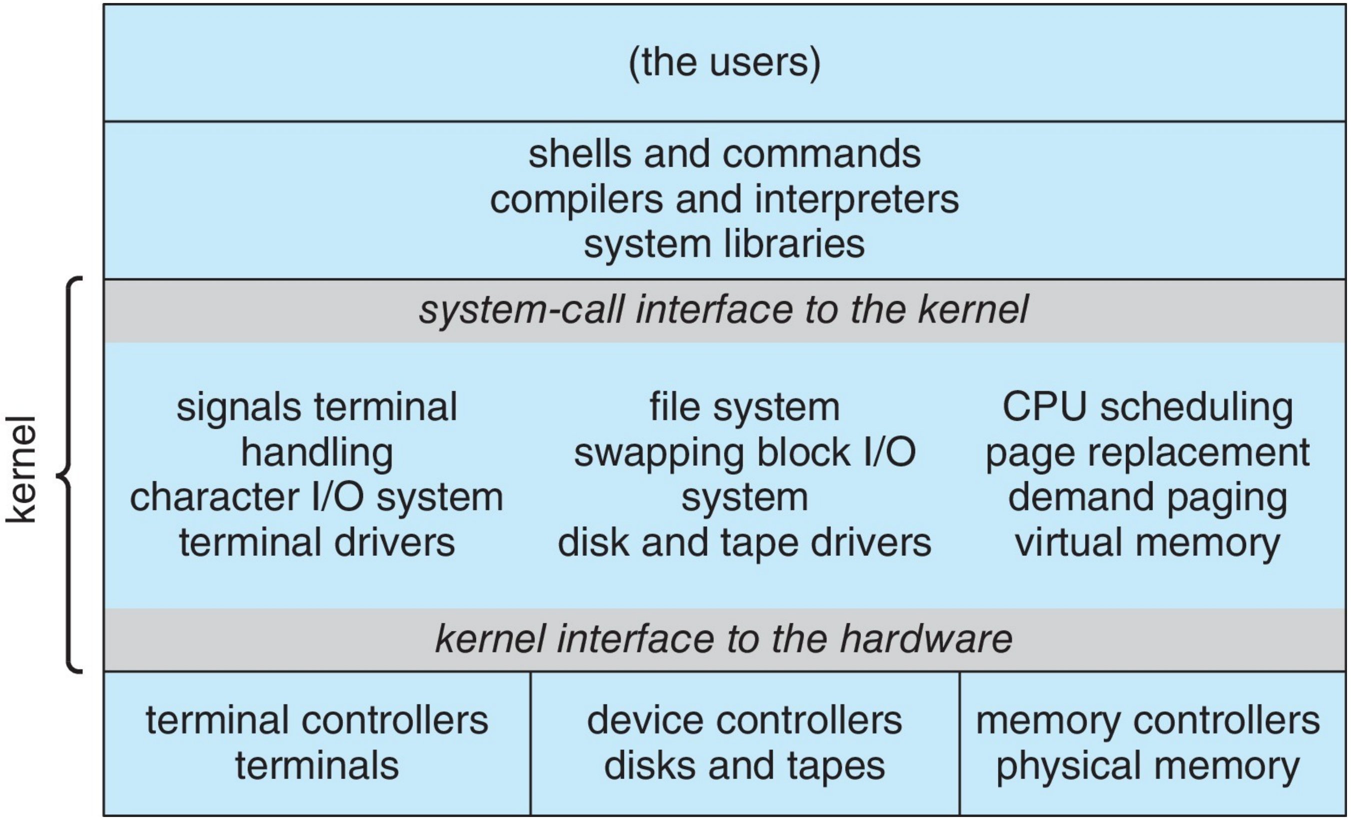
- **General-purpose** OS is very large program
- Various ways to structure ones
  - Simple structure – MS-DOS
  - More complex – UNIX
  - Layered – an abstraction
  - Microkernel – Mach

Monolithic Structure – Original UNIX

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

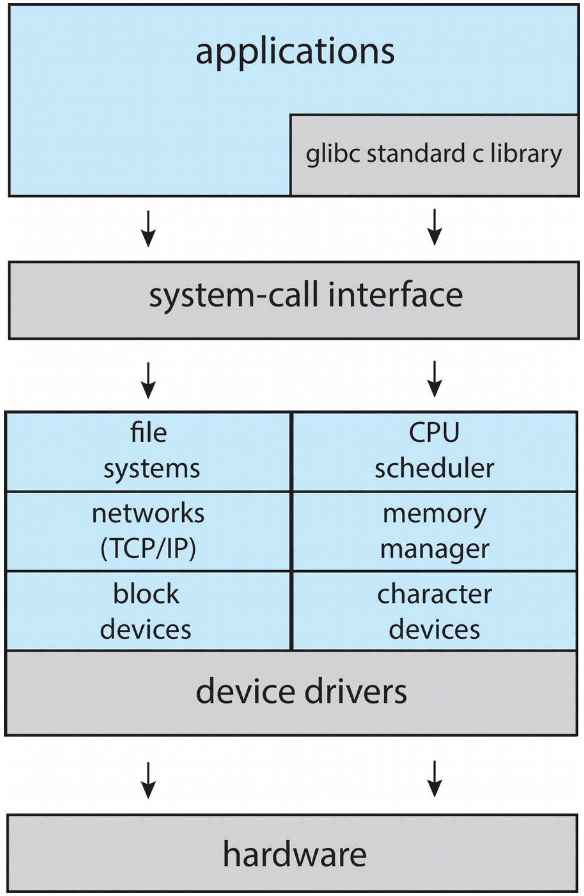
Traditional UNIX System Structure

Beyond simple but not fully layered



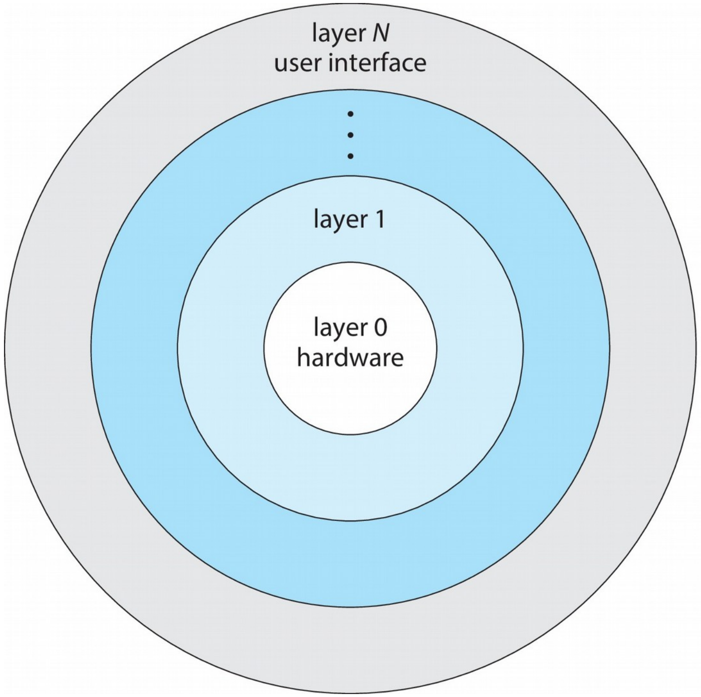
Linux System Structure

Monolithic plus **modular design**

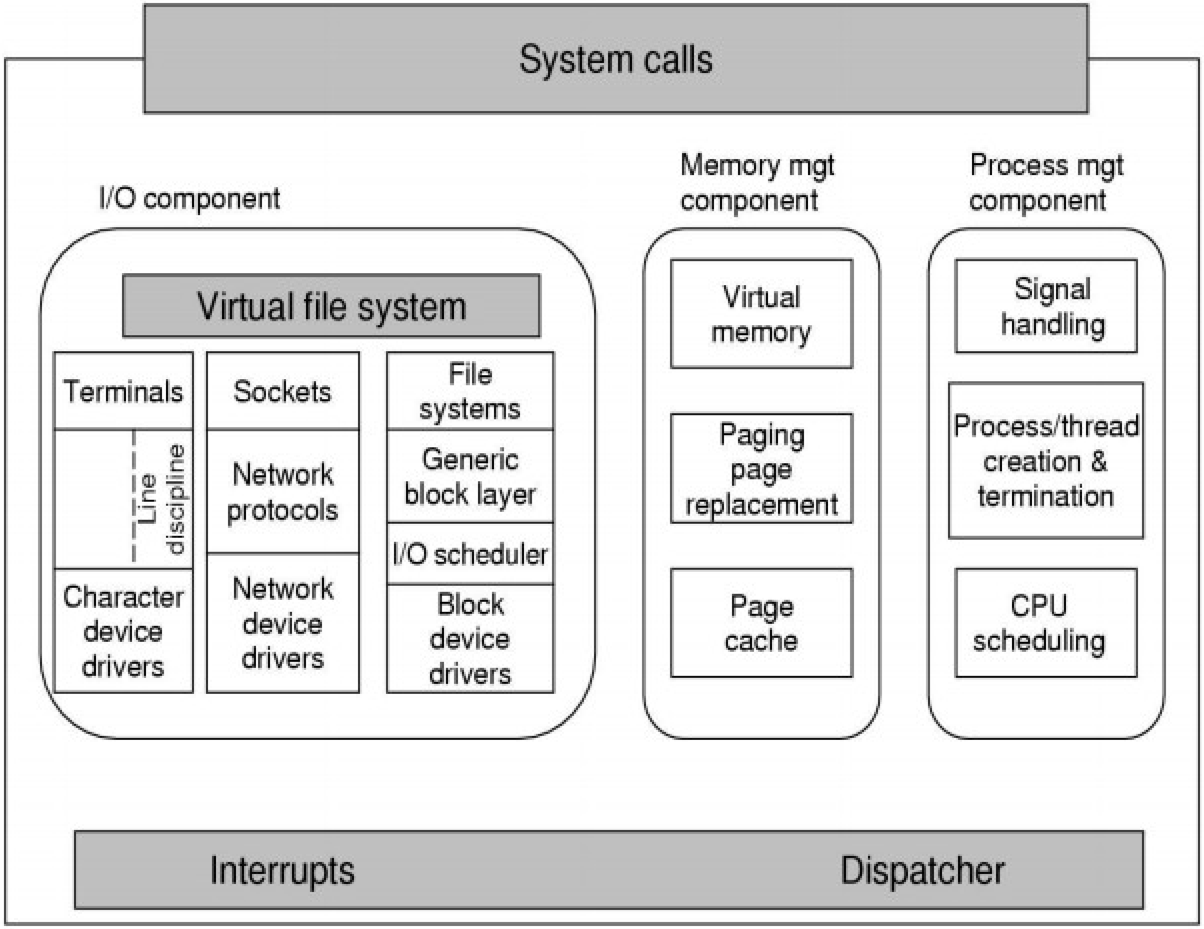


Layered Approach

- 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



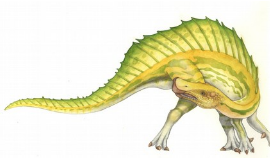
Linux kernel structure



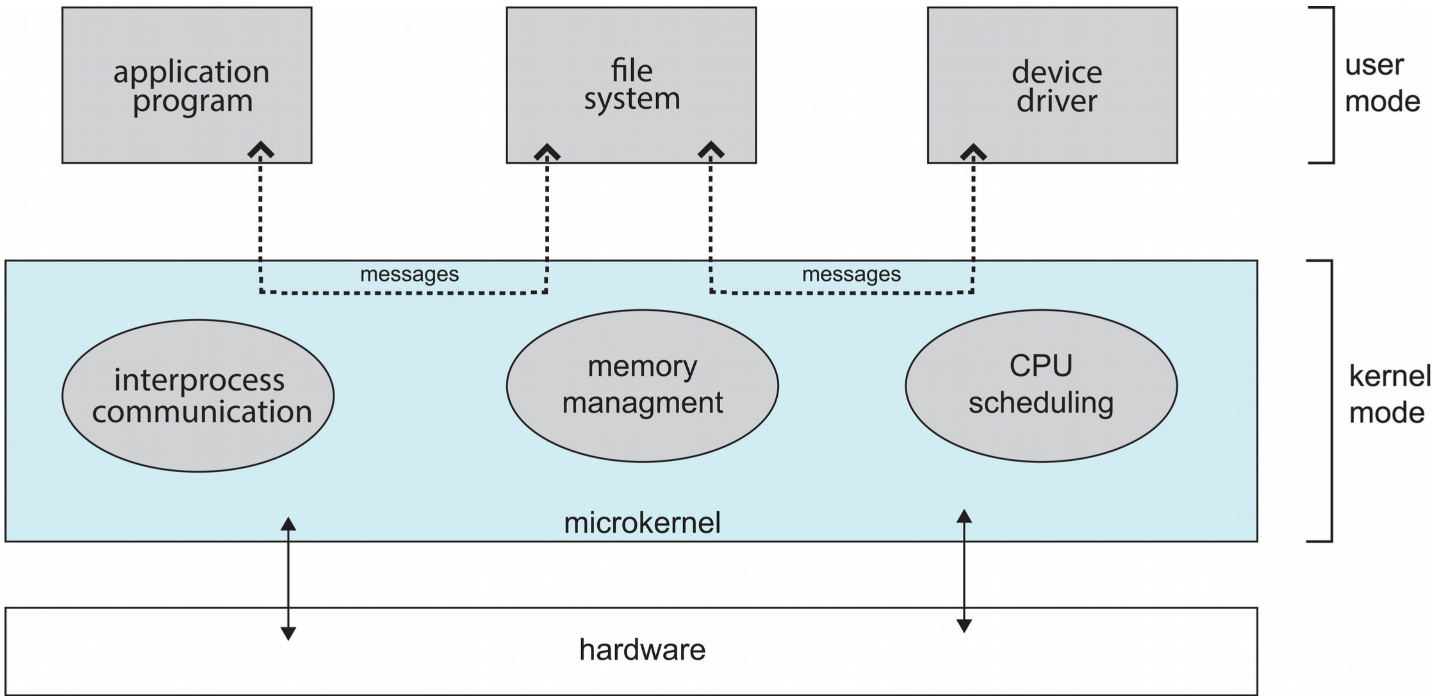
Structure of the Linux kernel

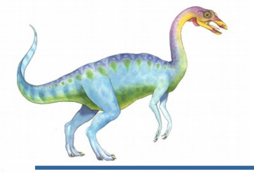
Microkernels

- Moves as much from the kernel into user space
- **Mach** is an 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



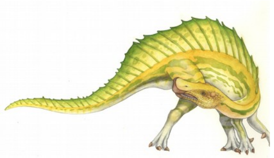
Microkernel System Structure





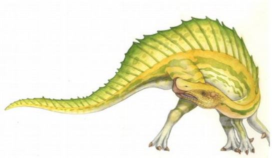
Modules

- Many modern operating systems implement **loadable kernel** mo**dules** (**LKMs**)
  - 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.



Hybrid Systems

- Most modern operating systems are 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**)



Building and Booting an Operating System

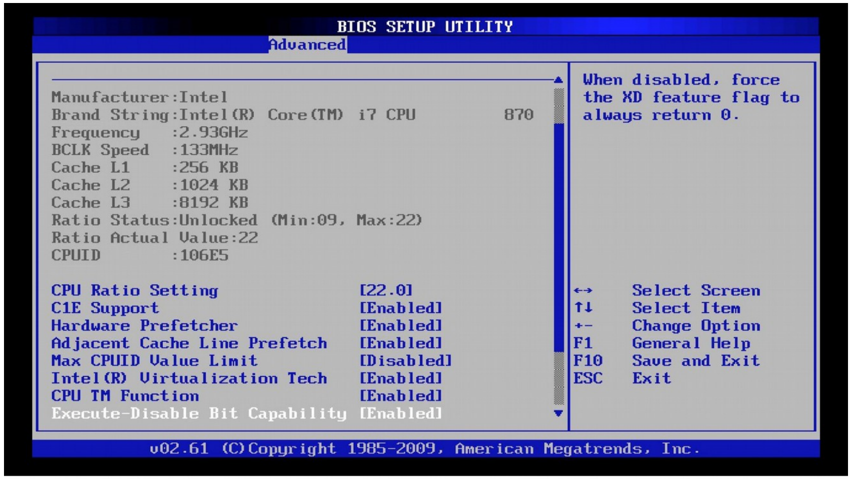
- Operating systems generally designed to run on a class of systems with variety of peripherals
- Commonly, operating system already installed on purchased computer
  - But can build and install some other operating systems
  - If generating an operating system from scratch
    - Write the operating system source code
    - Configure the operating system for the system on which it will run
    - Compile the operating system
    - Install the operating system
    - Boot the computer and its new operating system

Building and Booting Linux

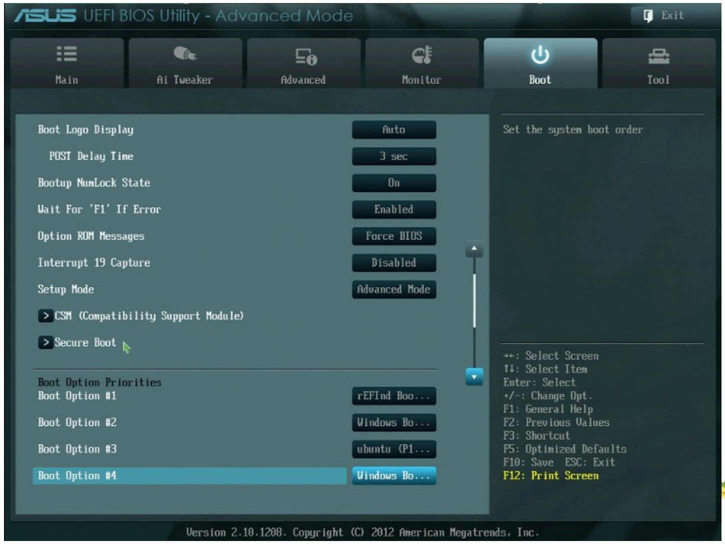
- Download Linux source code (http://www.kernel.org)
- Configure kernel via “`make menuconfig`”
- Compile the kernel using “`make`”
  - Produces `vmlinuz`, the kernel image
  - Compile kernel modules via “`make modules`”
  - Install kernel modules into `vmlinuz` via “`make modules_install`”
  - Install new kernel on the system via “`make install`”

System Boot

- When power initialized on system, execution starts at a fixed memory location
- Operating system must be made available to hardware so hardware can start it
  - Small piece of code – **bootstrap loader**, **BIOS**, 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
  - Modern systems replace BIOS with **Unified Extensible Firmware Interface** (**UEFI**)



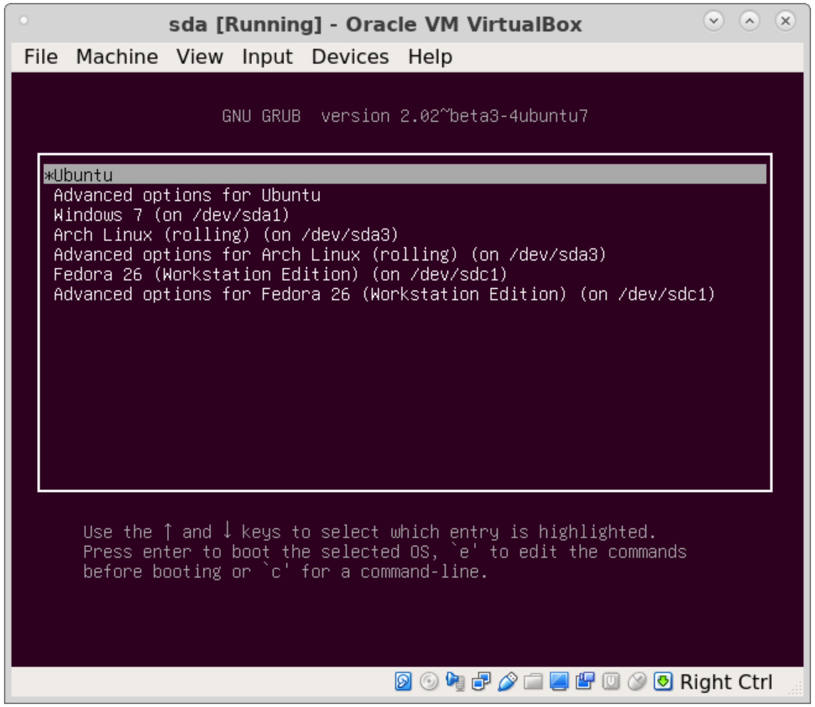
```
                    BIOS SETUP UTILITY
          Advanced

  Manufacturer:Intel                                  When disabled, force
  Brand String:Intel(R) Core(TM) i7 CPU       870    the XD feature flag to
  Frequency    :2.93GHz                               always return 0.
  BCLK Speed   :133MHz
  Cache L1     :256 KB
  Cache L2     :1024 KB
  Cache L3     :8192 KB
  Ratio Status:Unlocked (Min:09, Max:22)
  Ratio Actual Value:22
  CPUID        :106E5

  CPU Ratio Setting                  [22.0]          ←→   Select Screen
  C1E Support                        [Enabled]       ↑↓   Select Item
  Hardware Prefetcher                [Enabled]       +-   Change Option
  Adjacent Cache Line Prefetch       [Enabled]       F1   General Help
  Max CPUID Value Limit              [Disabled]      F10  Save and Exit
  Intel(R) Virtualization Tech       [Enabled]       ESC  Exit
  CPU TM Function                    [Enabled]
  Execute-Disable Bit Capability     [Enabled]

          v02.61 (C)Copyright 1985-2009, American Megatrends, Inc.
```



```
ASUS UEFI BIOS Utility - Advanced Mode                                  Exit

  Main      Ai Tweaker      Advanced      Monitor      Boot      Tool

  Boot Logo Display                     Auto            Set the system boot order
    POST Delay Time                     3 sec
  Bootup NumLock State                  On
  Wait For 'F1' If Error                Enabled
  Option ROM Messages                   Force BIOS
  Interrupt 19 Capture                  Disabled
  Setup Mode                            Advanced Mode
  > CSM (Compatibility Support Module)
  > Secure Boot
                                                        →←: Select Screen
  Boot Option Priorities                                ↑↓: Select Item
  Boot Option #1                        rEFInd Boo...   Enter: Select
  Boot Option #2                        Windows Bo...   +/-: Change Opt.
  Boot Option #3                        ubuntu (P1...   F1: General Help
  Boot Option #4                        Windows Bo...   F2: Previous Values
                                                        F3: Shortcut
                                                        F5: Optimized Defaults
                                                        F10: Save  ESC: Exit
                                                        F12: Print Screen

          Version 2.10.1208. Copyright (C) 2012 American Megatrends, Inc.
```

System Boot

- Common bootstrap loader, **GRUB**, allows selection of kernel from multiple disks, versions, kernel options
- Kernel loads and system is then **running**
- Boot loaders frequently allow various boot states, such as single user mode

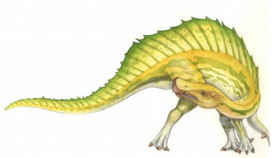

sda [Running] - Oracle VM VirtualBox
File Machine View Input Devices Help
Right Ctrl

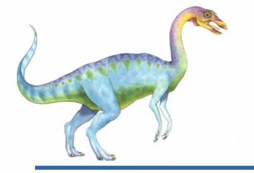
```
                GNU GRUB  version 2.02~beta3-4ubuntu7

*Ubuntu
 Advanced options for Ubuntu
 Windows 7 (on /dev/sda1)
 Arch Linux (rolling) (on /dev/sda3)
 Advanced options for Arch Linux (rolling) (on /dev/sda3)
 Fedora 26 (Workstation Edition) (on /dev/sdc1)
 Advanced options for Fedora 26 (Workstation Edition) (on /dev/sdc1)

     Use the ↑ and ↓ keys to select which entry is highlighted.
     Press enter to boot the selected OS, `e' to edit the commands
     before booting or `c' for a command-line.
```

Operating-System Debugging

- **Debugging** is finding and fixing errors, or **bugs**
- Also **performance tuning**
- 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.”





Operating-System Debugging

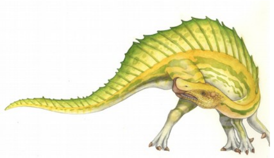
- **Debugging** is finding and fixing errors, or **bugs**
- Also **performance tuning**
- OS generate **log files** containing error information
- Failure of an application can generate **core dump** file capturing memory of the process
- Operating system failure can generate **crash dump** file containing

Dump: The act of copying raw data from one place to another with little or no formatting for readability.

Usually dump refers to copying data from main memory to display screen or a printer

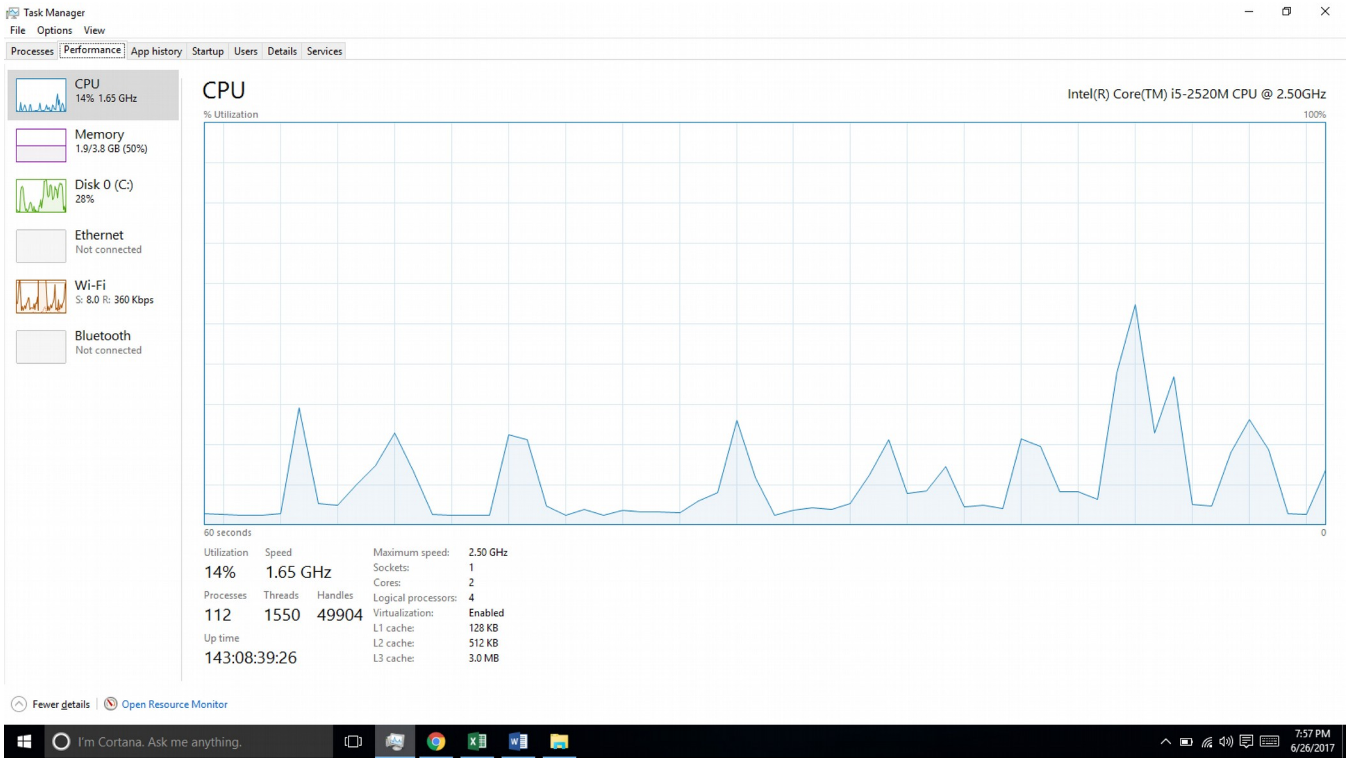
  - **Profiling** is periodic sampling of instruction pointer to look for statistical trends

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



CPU
14% 1.65 GHz

Memory
1.9/3.8 GB (50%)

Disk 0 (C:)
28%

Ethernet
Not connected

Wi-Fi
S: 8.0 R: 360 Kbps

Bluetooth
Not connected

CPU

Intel(R) Core(TM) i5-2520M CPU @ 2.50GHz

Utilization 14%

Speed 1.65 GHz

Processes 112

Threads 1550

Handles 49904

Up time 143:08:39:26

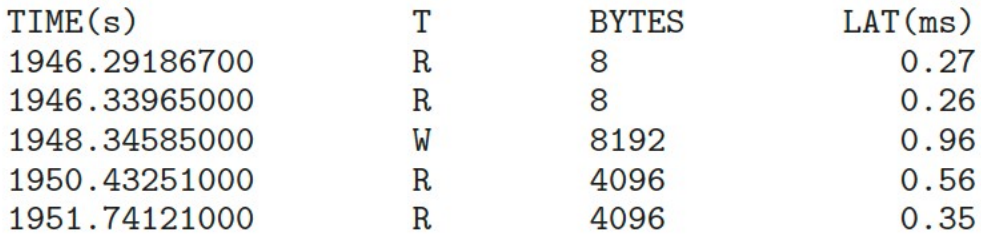
Maximum speed:	2.50 GHz
Sockets:	1
Cores:	2
Logical processors:	4
Virtualization:	Enabled
L1 cache:	128 KB
L2 cache:	512 KB
L3 cache:	3.0 MB

Tracing

- Collects data for a specific event, such as steps involved in a system call invocation
- Tools include
  - strace – trace system calls invoked by a process
  - gdb – source-level debugger
  - perf – collection of Linux performance tools
  - tcpdump – collects network packets

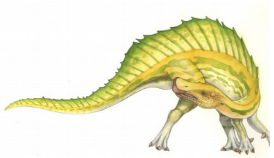
BCC

- Debugging interactions between user-level and kernel code nearly impossible without toolset that understands both and an instrument their actions
- BCC (BPF Compiler Collection) is a rich toolkit providing tracing features for Linux
  - See also the original DTrace
- For example, disksnoop.py traces disk I/O activity

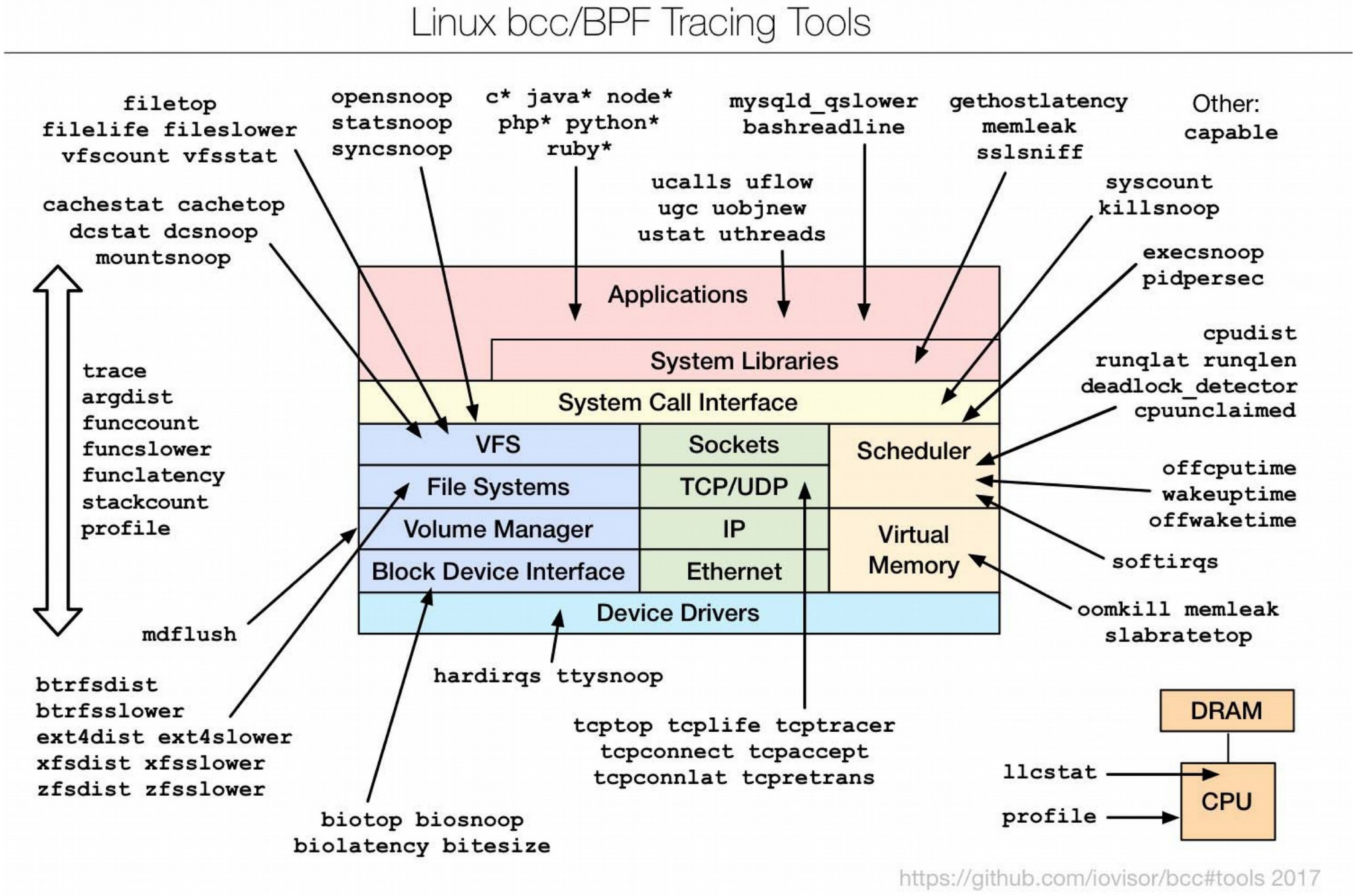


```
TIME(s)            T      BYTES      LAT(ms)
1946.29186700      R      8             0.27
1946.33965000      R      8             0.26
1948.34585000      W      8192          0.96
1950.43251000      R      4096          0.56
1951.74121000      R      4096          0.35
```

- Many other tools (next slide)



Linux bcc/BPF Tracing Tools



https://github.com/iovisor/bcc#tools 2017

Free and Open-Source Operating Systems

- Operating systems made available in source-code format rather than just binary **closed-source** and **proprietary**
- Counter to the **copy protection** and **Digital Rights Management** (**DRM**) movement
- Started by **Free Software Foundation** (**FSF**), which has “copyleft” **GNU Public License** (**GPL**)
  - Free software and open-source software are two different ideas championed by different groups of people
    - **https://www.gnu.org/philosophy/open-source-misses-the-point.en.html**
- Examples include **GNU/Linux** and **BSD UNIX** (including core of **Mac OS X**), and many more
- Can use VMM like VMware Player (Free on Windows), Virtualbox (open source and free on many platforms - http://www.virtualbox.com)
  - Use to run guest operating systems for exploration

Open Source film

تمرین

۱- هر یک از دسته مفاهیم زیر را با هم مقایسه کنید:

Device Driver- Device Controller

CPU scheduling- Job scheduling

۲- دو رویکرد متفاوت در برنامه نویسی CLI را بیان کرده و با هم مقایسه کنید

3- یکی از وظایف اصلی سیستم عامل، تخصیص منابع یا resource allocation است. در این رابطه دو منبع اصلی هر سیستم را نام ببرید.

تمرین

4- وظایف سیستم عامل عبارتند از
resource management، I/O handling، Process management، Memory management، .Storage management، Protection ، security

در مورد هر یک از تدابیر سخت افزاری یا نرم افزاری الف و ب، به این سؤالات پاسخ دهید

(۱) این تدبیر سخت افزاری یا نرم افزاری یا هردو است؟(توضیح مختصر) (۲) این تدبیر به منظور اجرای کدام یک از وظایف نامبرده در سیستم عامل به کار می‌رود؟ (۳) توضیح مختصر دهید که چگونه وظیفه موردنظر با تدبیر ذکرشده برآورده می‌شود.

الف) تعریف مدهای کرنل و کاربر

5- با ذکر حداقل دو مثال بنویسید در چه مواردی اپلیکیشنی که شما برنامه نویسی می کنید از سیستم عامل استفاده میکند؟ اپلیکیشن شما چگونه درخواست هایش را به سیستم عامل میفرستد؟ آیا در زبان‌های برنامه نویسی امکانی جهت ارسال دستور به سیستم عامل وجود دارد؟