Introduction

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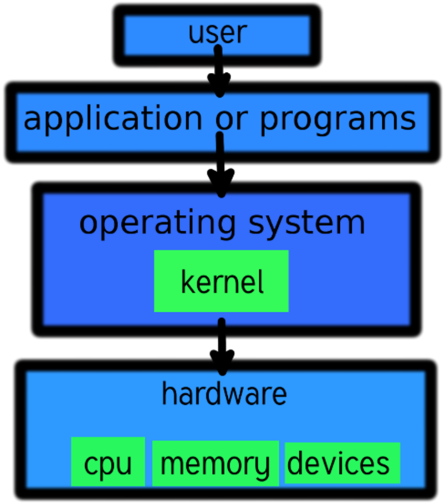
What is Linux?

- **Like Windows, iOS, and Mac OS, Linux is an operating system**
  - Linux is a family of open source operating systems based on the Linux kernel
  - An operating system is software that manages all of the hardware resources associated with your desktop or laptop
    - The operating system manages the communication between your software and your hardware



What is Linux Kernel?

- The Linux kernel is the main component of a Linux operating system (OS) and is the core interface between hardware and its processes
- The Linux kernel is charged with managing the hardware, running user programs, and maintaining the security and integrity of the whole system
- The kernel is so named like a seed inside a hard shell
  - The kernel exists within the OS and controls all the major functions of the hardware

Why Linux is very important

- A thriving commercial ecosystem
  - 80%+ of smartphones run Android (based on the Linux kernel)
  - 98%+ of the top 500 fastest supercomputers in the world
  - Most of the global markets, including NYSE, NASDAQ, London Exchange, Tokyo Stock Exchange
  - The majority of consumer electronic devices
  - 75%+ of cloud-enabled enterprises report using Linux as their primary cloud platform
  - E-commerce giants Amazon, Ebay, Paypal, Walmart, and more run on Linux

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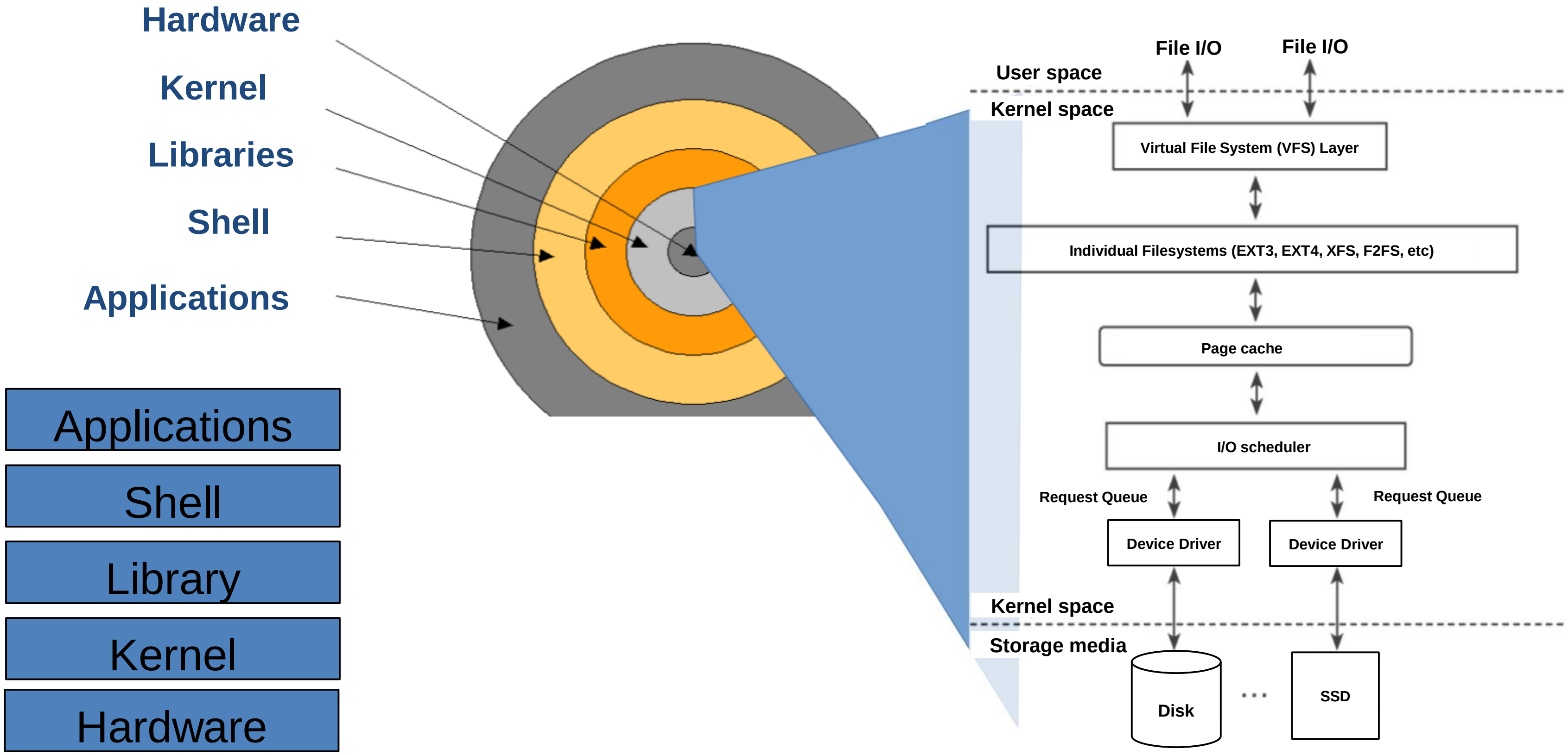
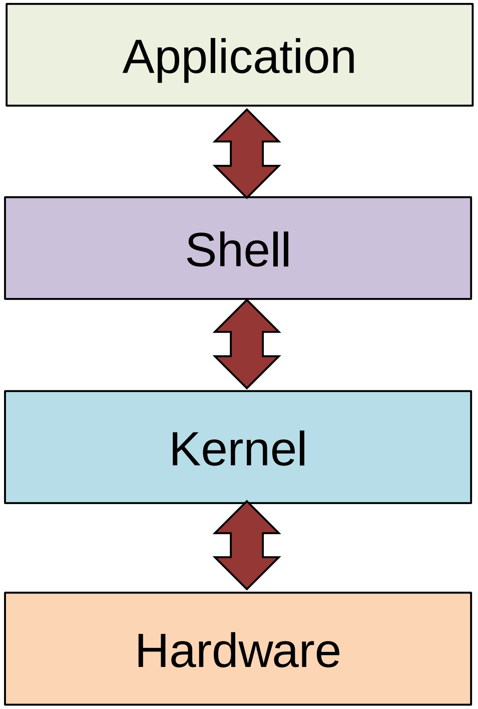
Ex) Linux storage stack



What is Linux Kernel?

- Central module of an operating system (OS)
- The part of the operating system that loads first, and it remains in main memory
- Kernel can be contrasted with a shell, the outermost part of an operating system that interacts with user commands
- Kernel manages your hardware and system resources



What is Linux Kernel?

- **What the kernel does**
  - The kernel has main 4 jobs
    - **Process management**
      - Determine which processes can use the CPU, when, and for how long
    - **Memory/Storage management**
      - Keep track of how much memory/storage is used to store what, and where
    - **Device drivers**
      - Act as mediator/interpreter between the hardware and processes
    - **System calls and security**
      - Receive requests for service from the proceeses

What does an OS do for you?

- **Abstract**
  - Abstract the hardware for convenience and portability
- **Multiplex**
  - Multiplex the hardware among multiple applications
- **Isolation**
  - Isolate applications to contain bugs
- **Share**
  - Allow sharing among applications

Research on Linux Kernel

- **Manycore performance/scalability of operating system**
  - What happen if we run Linux on manycore machine (72cores)?
  - Will your application run 72 times faster?
- **Non-volatile memory systems**
  - What happen if storage performance is becoming closer to DRAM performance?
  - Will your application achieve DRAM-like I/O performance?
- **System security**
  - How operating system should be designed to avoid security holes?

Core Services in Linux

- **Abstraction for applications**
  - Process and Thread
  - Memory management
  - File services and contents
  - Directoris and file names
  - Security
  - Many others: users, IPC, network, time, terminals, etc

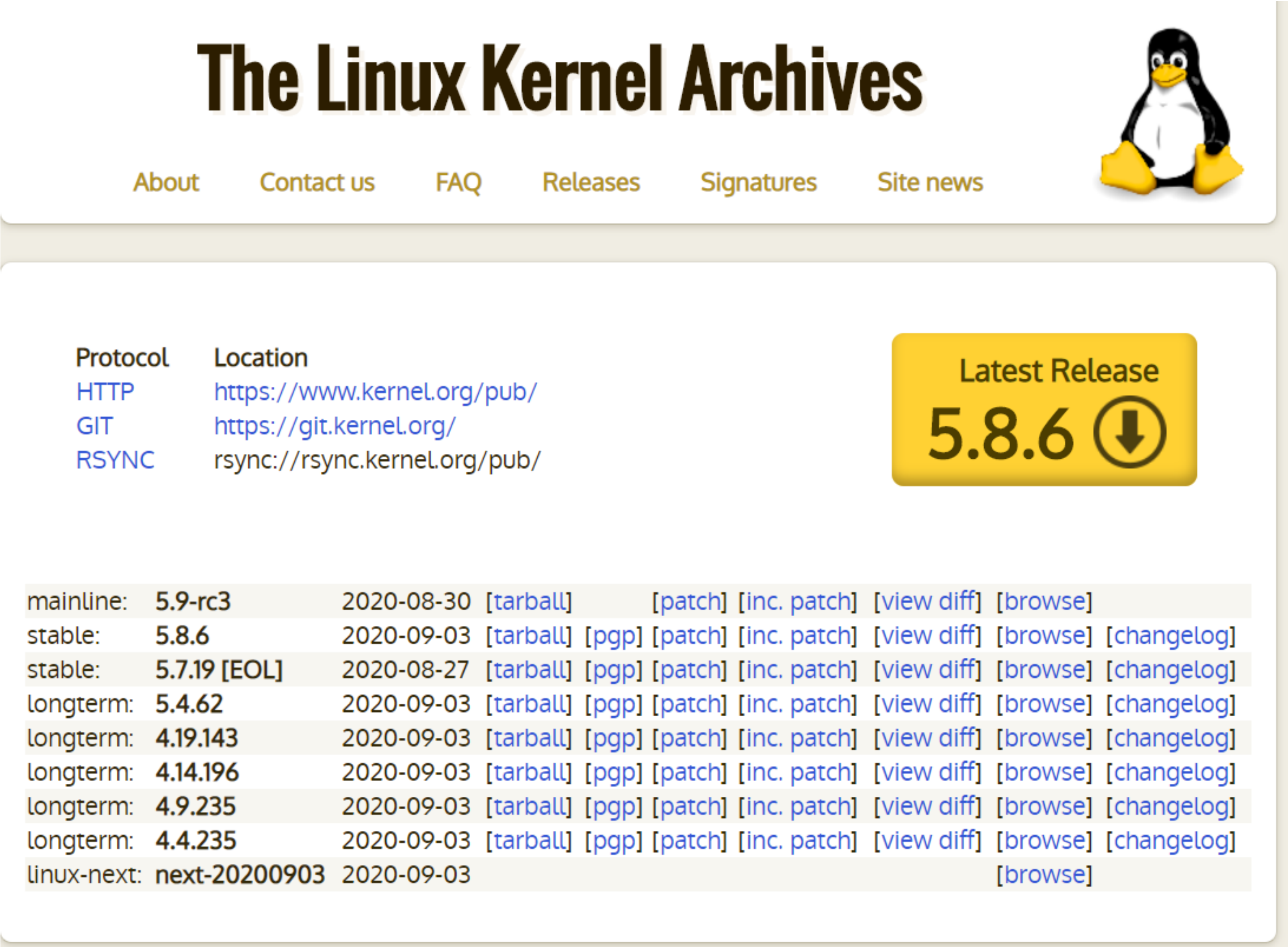
Example: system calls

- **The system call is the fundamental interface between an application and the Linux kernel**
  - A system call is the programmatic way in which a program requests a service from the Linux kernel
  - Applications talk to an OS via system calls

```
fd = open(“file”, flag); //open system call
write(fd, “hello”, count); //write system call
```

How can we get Linux kernel source code

- **www.kernel.org**



Protocol	Location
HTTP	https://www.kernel.org/pub/
GIT	https://git.kernel.org/
RSYNC	rsync://rsync.kernel.org/pub/

mainline:	5.9-rc3	2020-08-30	[tarball]		[patch]	[inc. patch]	[view diff]	[browse]	
stable:	5.8.6	2020-09-03	[tarball]	[pgp]	[patch]	[inc. patch]	[view diff]	[browse]	[changelog]
stable:	5.7.19 [EOL]	2020-08-27	[tarball]	[pgp]	[patch]	[inc. patch]	[view diff]	[browse]	[changelog]
longterm:	5.4.62	2020-09-03	[tarball]	[pgp]	[patch]	[inc. patch]	[view diff]	[browse]	[changelog]
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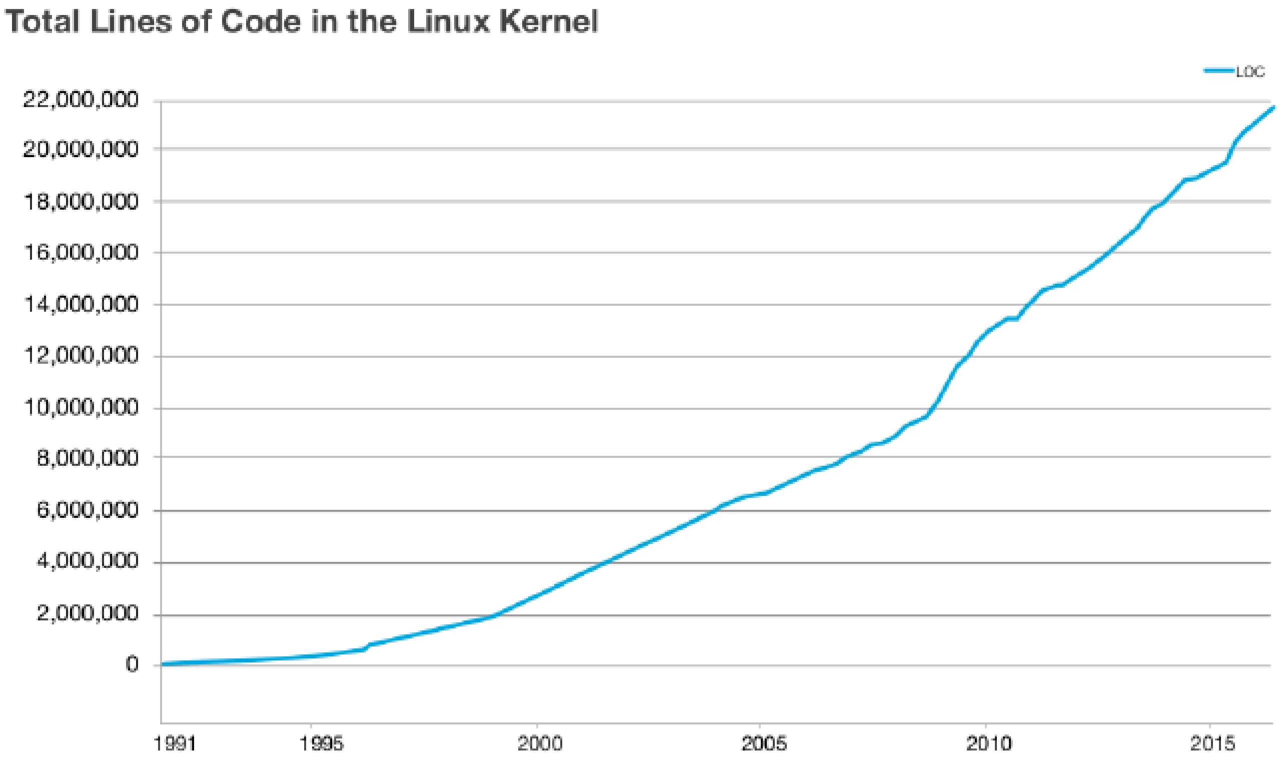
linux-next:	next-20200903	2020-09-03						[browse]	

Why is Linux kernel interesting?

- **OS design deals with conflicting goals and trade-offs**
  - Efficient yet portable
  - Powerful yet simple
  - Isolated yet interactable
  - General yet performant
- **Open problems: multi-core, non-volatile memory, security**
- **How does a state-of-the-art OS deal with above issues?**
  - Hack the Linux kernel!

Why is Linux kernel interesting?

- **Extremely large software project**
  - More than 24 million lines of code
  - 7,500 lines of code are added every day

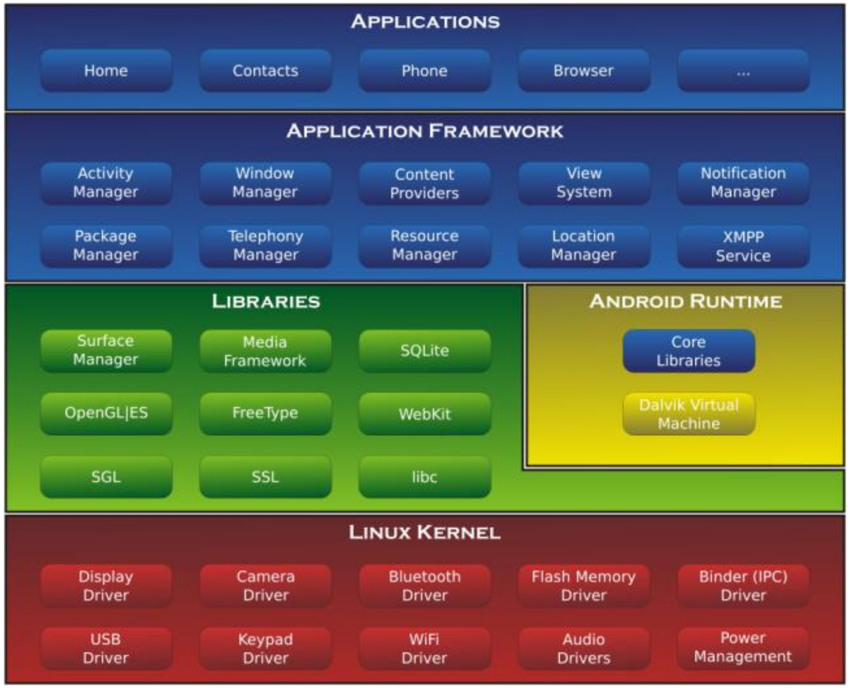


Why is Linux kernel interesting?

- **Very fast development cycles**
  - Release about every 70 days
  - 13,000 patches / release
  - 225 companies / release (or 1,600 developers)
- **One of the most well-written/designed/maintained C code**
  - Ref: https://www.linuxfoundation.org/2017-linux-kernel-report-landing-page/

Linux is eating the world

- **68% of smartphones and tablets run Linux**
  - iOS: 24%
- **98% of top 1 million web servers run Linux**
- **99% of super computers run Linux**



APPLICATIONS

Home | Contacts | Phone | Browser | ...

APPLICATION FRAMEWORK

Activity Manager | Window Manager | Content Providers | View System | Notification Manager

Package Manager | Telephony Manager | Resource Manager | Location Manager | XMPP Service

LIBRARIES

Surface Manager | Media Framework | SQLite

OpenGL|ES | FreeType | WebKit

SGL | SSL | libc

ANDROID RUNTIME

Core Libraries

Dalvik Virtual Machine

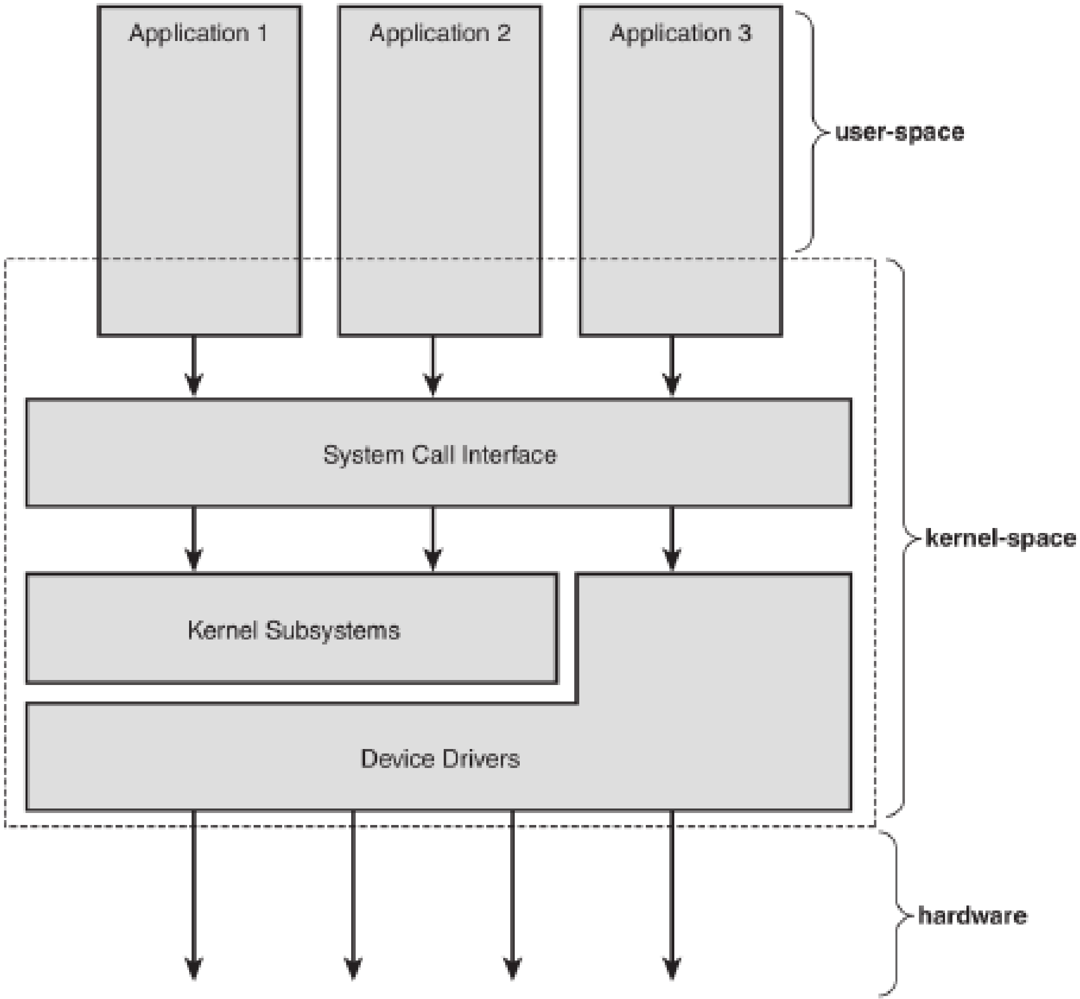
LINUX KERNEL

Display Driver | Camera Driver | Bluetooth Driver | Flash Memory Driver | Binder (IPC) Driver

USB Driver | Keypad Driver | WiFi Driver | Audio Drivers | Power Management

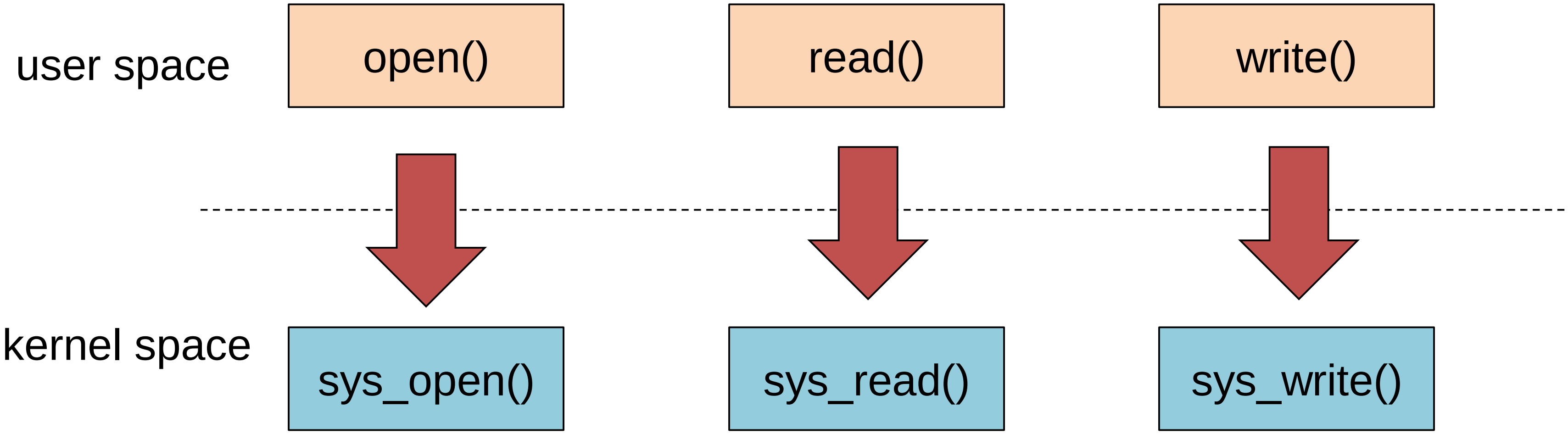
Android is based on Linux

Overview of Operating Systems



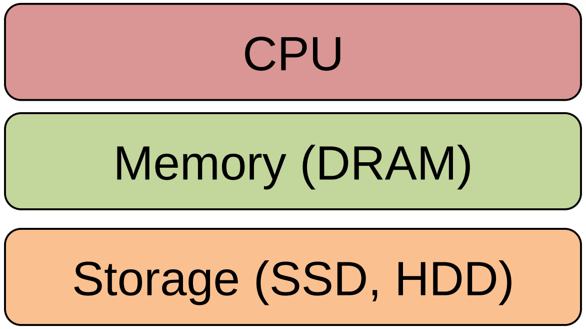
User space and Kernel space

- A CPU is executing in either of user space or in kernel space
- An user-space application talks to the kernel space through system call interface
  - E.g., open(), read(), write(), close()



User space and kernel space

- Memory consists of RAM (random access memory) cells, whose contents can be accessed (i.e., read and written to) at extremely high speeds but are retained only temporarily
  - Its purpose is to hold programs and data that are currently in use and thereby serve as a high speed intermediary between the CPU (central processing unit) and the much slower storage, which most commonly consists of one or more hard disk drives (HDDs)



User space and kernel space

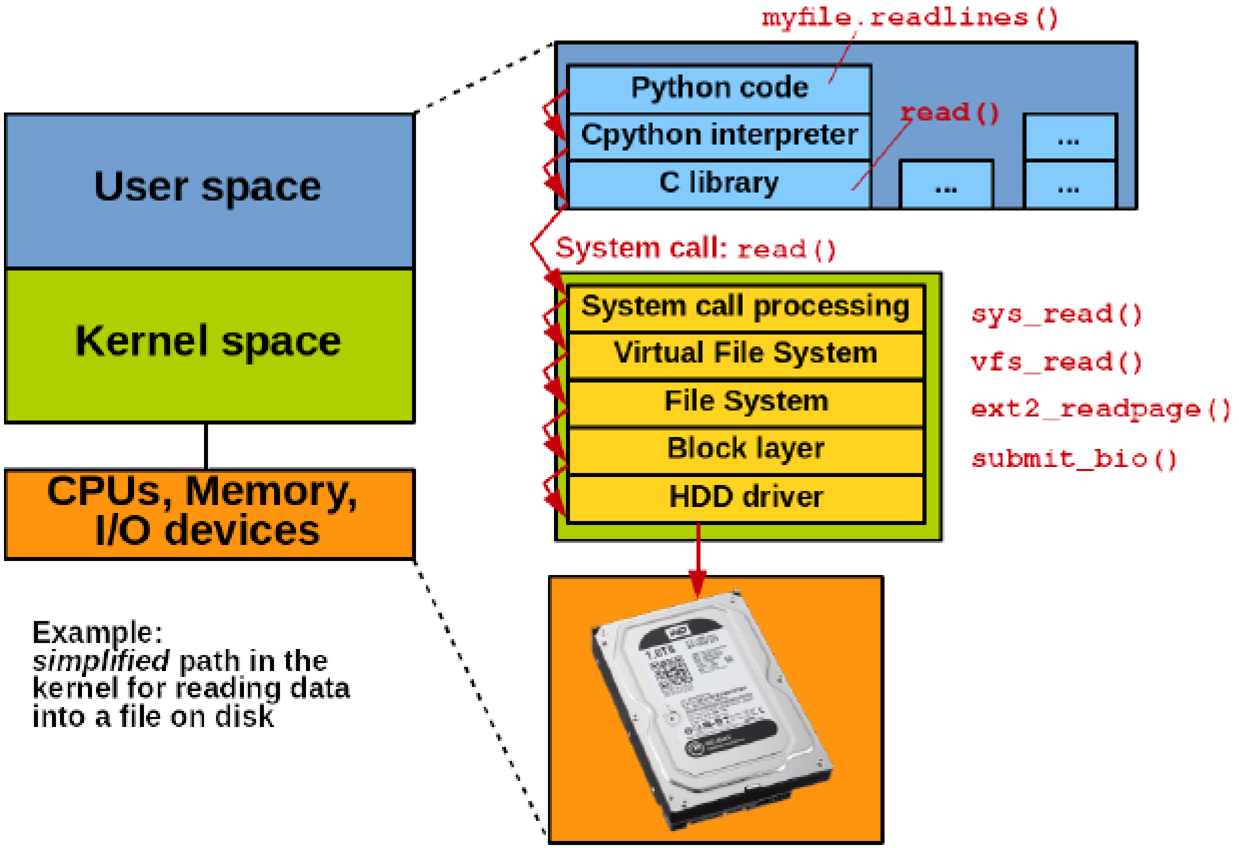
- The memory in Linux can be divided into two distinct regions: kernel space and user space
  - Kernel space is where the kernel executes and provides its services
  - User space is that set of memory locations in which user processes run
    - A process is an executing instance of a program
    - One of the roles of the kernel is to manage individual user processes within this space and to prevent them from interfering with each other

User space and kernel space

- Kernel space can be accessed by user processes only through the use of system calls.
  - System calls are requests in a operating system by an active process for a service performed by the kernel, such as input/output (I/O) or process creation
    - An active process is a process that is currently progressing in the CPU, as contrasted with a process that is waiting for its next turn in the CPU

User space and Kernel space

- Applications requests OS to use OS services via system calls



User space

Kernel space

CPUs, Memory, I/O devices

myfile.readlines()

Python code

Cpython interpreter

C library

read()

...

...

...

System call: read()

System call processing

Virtual File System

File System

Block layer

HDD driver

sys_read()

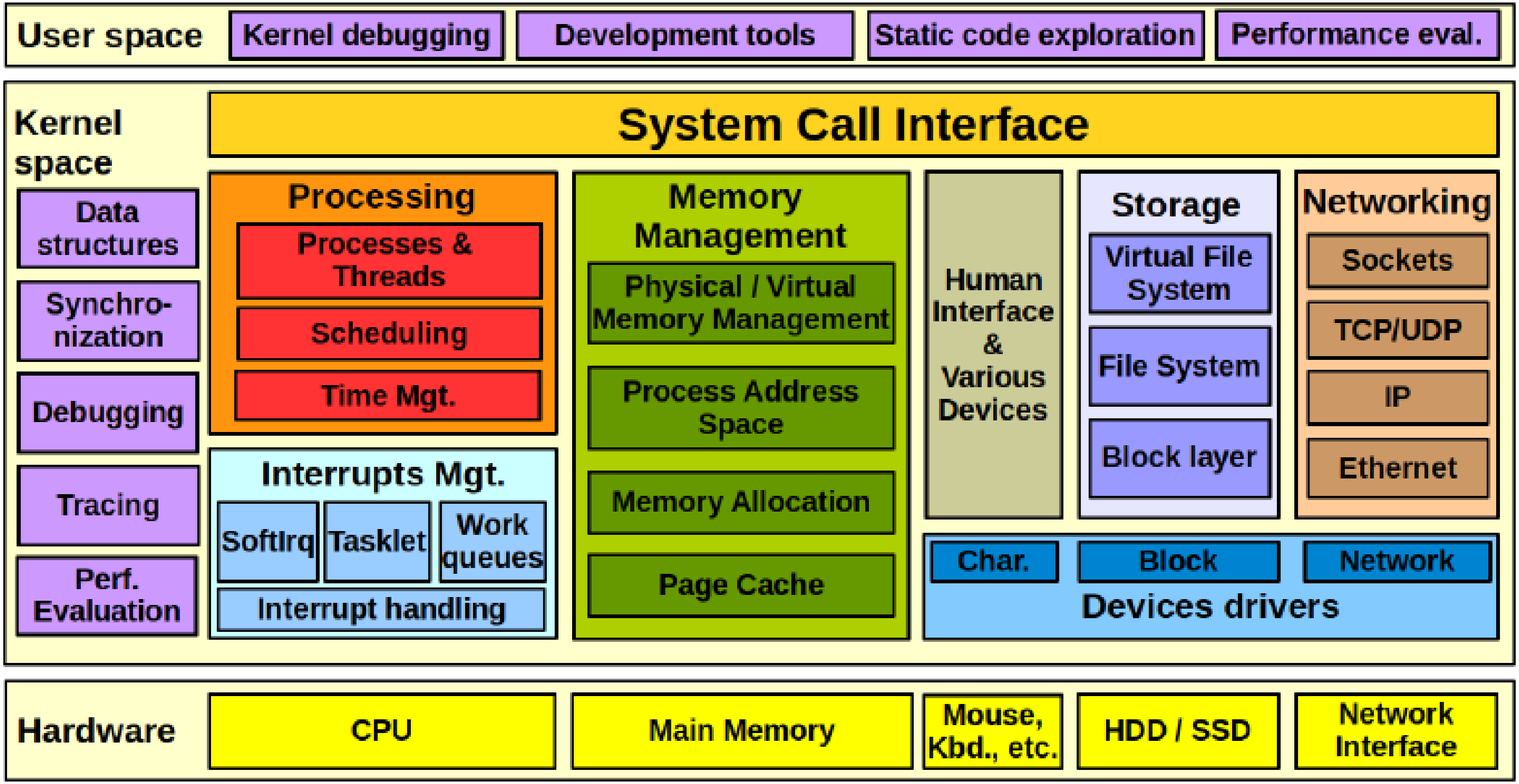
vfs_read()

ext2_readpage()

submit_bio()

Example:
simplified path in the kernel for reading data into a file on disk

Kernel map



User space

Kernel debugging

Development tools

Static code exploration

Performance eval.

Kernel space

System Call Interface

Data structures

Synchro-nization

Debugging

Tracing

Perf. Evaluation

Processing

Processes & Threads

Scheduling

Time Mgt.

Interrupts Mgt.

SoftIrq

Tasklet

Work queues

Interrupt handling

Memory Management

Physical / Virtual Memory Management

Process Address Space

Memory Allocation

Page Cache

Human Interface & Various Devices

Storage

Virtual File System

File System

Block layer

Networking

Sockets

TCP/UDP

IP

Ethernet

Char.

Block

Network

Devices drivers

Hardware

CPU

Main Memory

Mouse, Kbd., etc.

HDD / SSD

Network Interface

Various Linux Distribution

- A Linux distribution is an operating system made from a software collection, which is based upon the Linux kernel and, often, a package management system
  - Linux distributions may be:
    - Commercial or non-commercial
    - Designed for enterprise users, power users, or for home users
    - Supported on multiple types of hardware or platform-specific
    - Designed for servers, desktops, or embedded devices
    - General purpose or highly specialized toward specific machine functionalities (e.g., firewalls, network routers, and computer clusters)

Various Linux Distribution

- Linux distributions are categorized by these package types
  - The three basic types of packages are Debian (deb), RedHat Package Manager (RPM), and other distributions
    - Debian based Linux distributions
      - Ubuntu
        - Ubuntu is the most widely used and most popular Linux distribution today
      - Linux Mint
      - Etc
    - RPM based Linux distributions
      - RedHat Enterprise Linux (RHEL)
      - CentOS
      - Fedora
      - Etc