System Programming under Linux (Draft)

REDA MAHER

Agenda

#	Training Logistics
#	Preparing the environment
#	Linux basic commands
#	Build Process

Logistics

What and Why?

What will we learn?

What is an OS?

- Process management
- Device management
- Filesystem management

Why Unix?

System Programming vs Application Programming

Why do we need to learn this topic?

Create a chance for a job

Deep understanding of the computer systems

Deep understanding of the high-level languages

Linux is used every where

Syllabus

Linux History

Command line usage and Build Process

Process Management

- Process overview
- System calls and command line arguments
- Process creation
- Orphan & Zombie processes
- Bash features
- Intro to Proc fs
- IO redirection in the shell

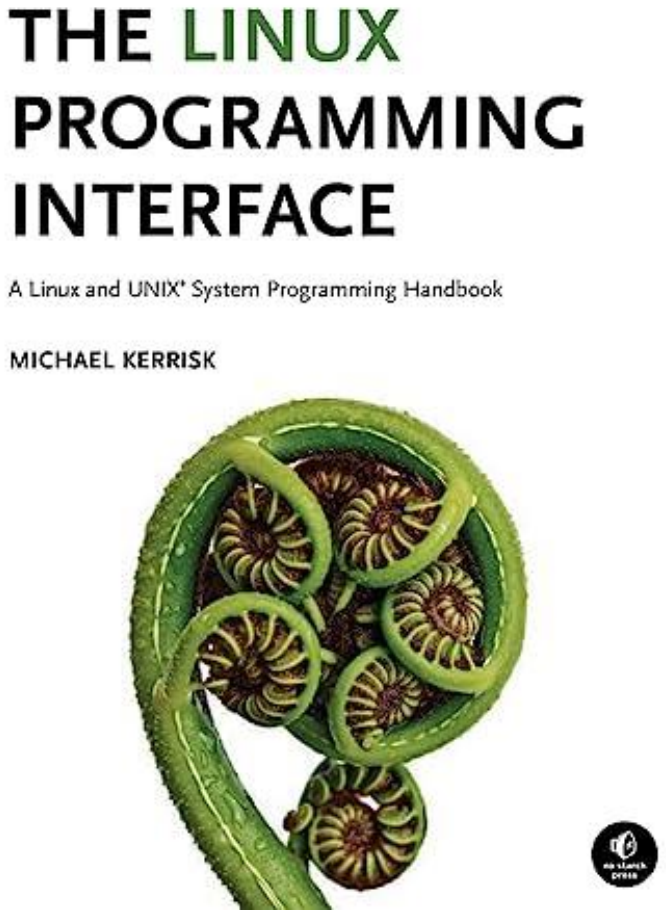
User Management

Filesystem Management

- Intro to HDD
- Parsing MBR Partition Tables
- File system formatting, mounting, and architecture
- Directories, files, links, and permissions in the file system
- Implementing “ls”

Textbook

- “The Linux Programming Interface: A Linux and UNIX System Programming Handbook”, by Michael Kerrisk



Sessions Schedule

Sunday, Tuesday, and Thursday 10:00 AM (~3 - 4hr with one break)

Training duration: 3 consecutive weeks (TBD)

Takeaways

- Interactive Training.
- Get your hands dirty.
- Unified setup (VM or Native).
- The course is an applied course.
- Take notes.
- You need patience in learning.
- This is not a Linux administration course.
- Training certificate.

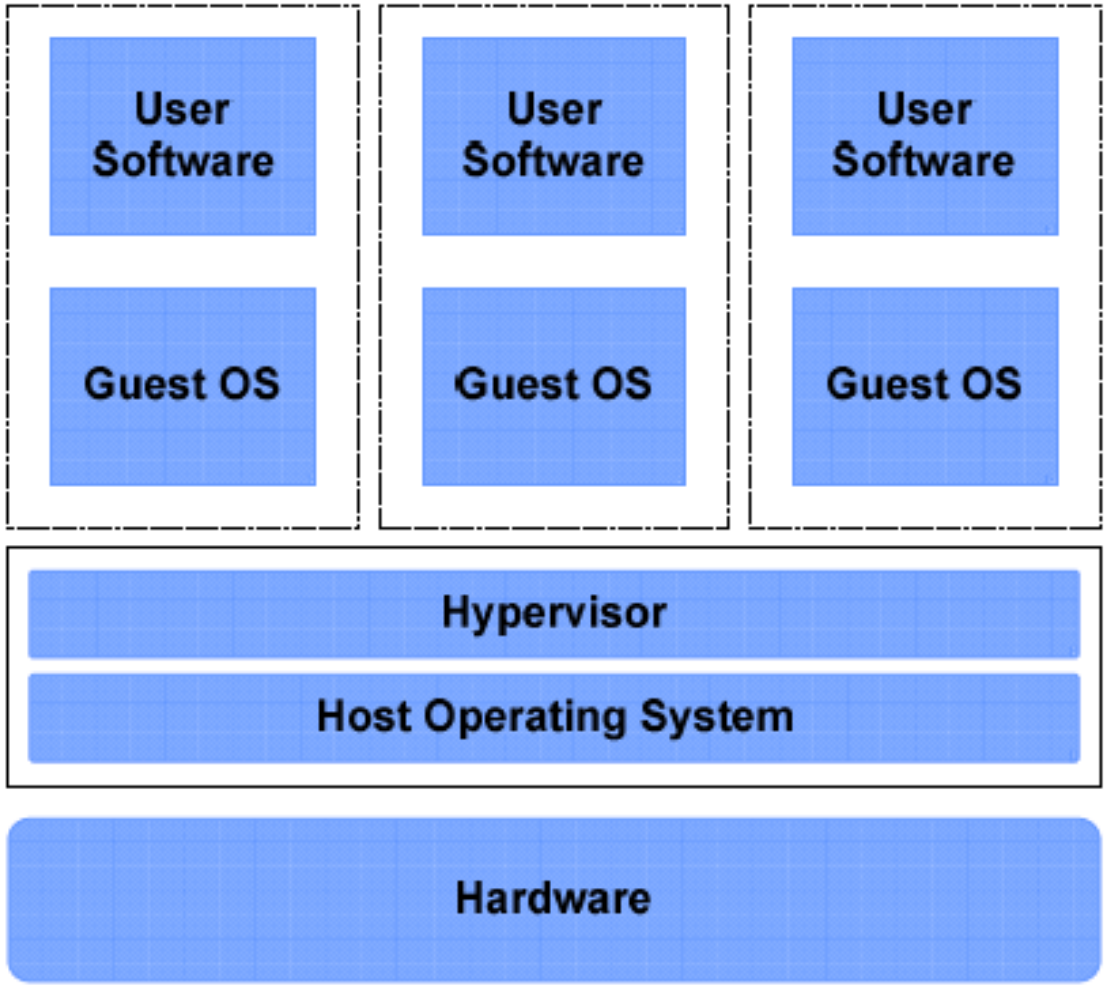
Communication Platform Setup

Environment Preparation

What is Virtualization?

- Virtualization is a framework or methodology of dividing the resources of a computer system into multiple execution environments.

- Platform virtualization is performed on a given hardware platform by host software (a control program), which creates a simulated computer environment, a virtual machine (VM), for its guest software.



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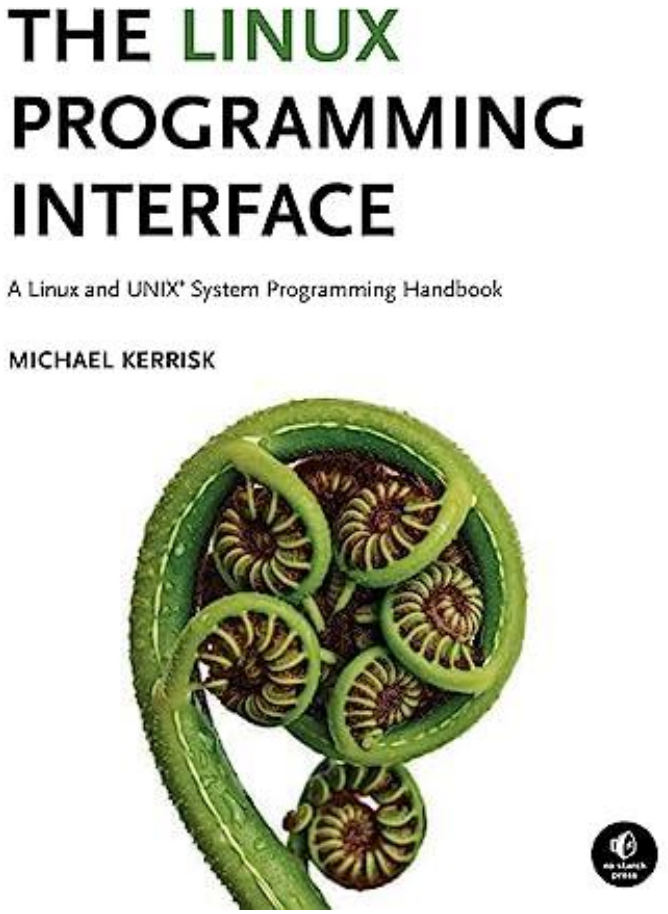

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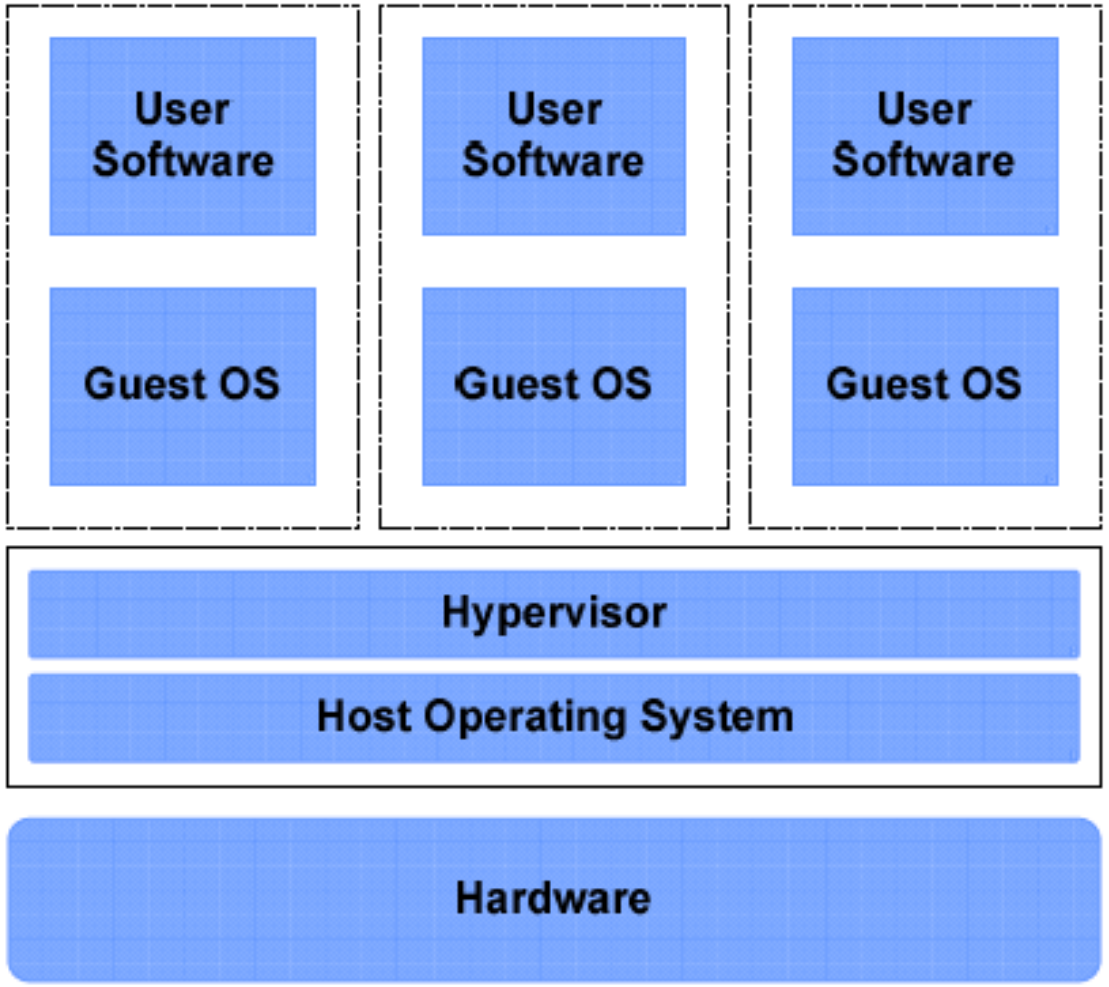
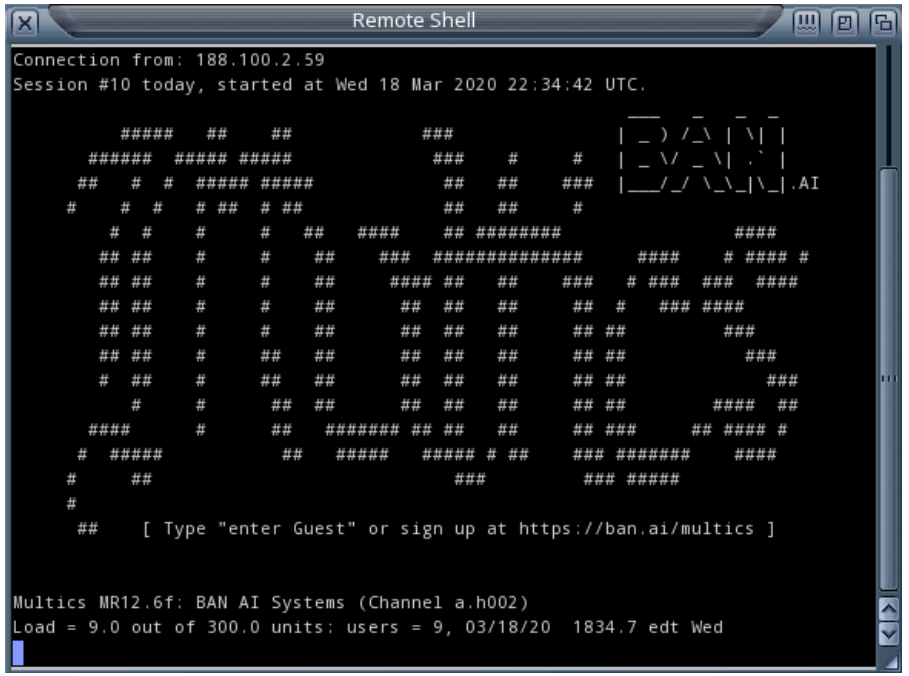


Linux History

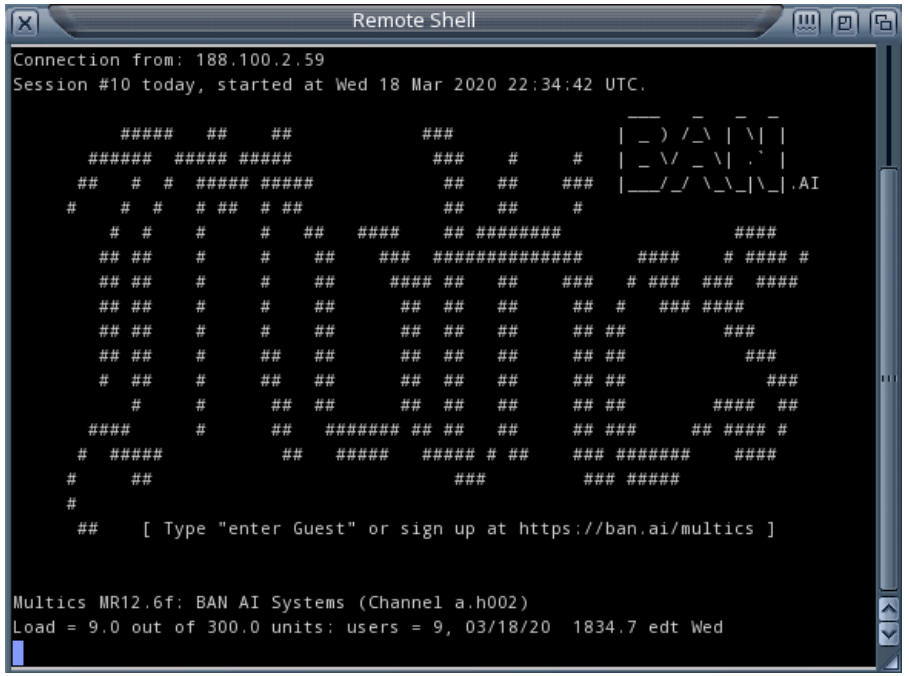
Multics

- Multics ("MULTiplexed Information and Computing Service") is an influential early time-sharing operating system based on the concept of a single-level memory.
- In 1964, Multics was developed as a cooperative project led by MIT along with General Electric and Bell Labs.



Multics Failure

- In 1969, Bell withdrew from the project as it became clear it would not deliver a working system in the short term.
- In 1970, GE decided to exit the computer industry entirely and sold the division to Honeywell.
- Nathan Gregory writes that “*Multics has influenced all modern operating systems since, from microcomputers to mainframes*”.
- Novel Ideas:
  - Dynamic linking.
  - Hierarchical file system.
  - Single-level store for data access.
  - …



Bell Labs

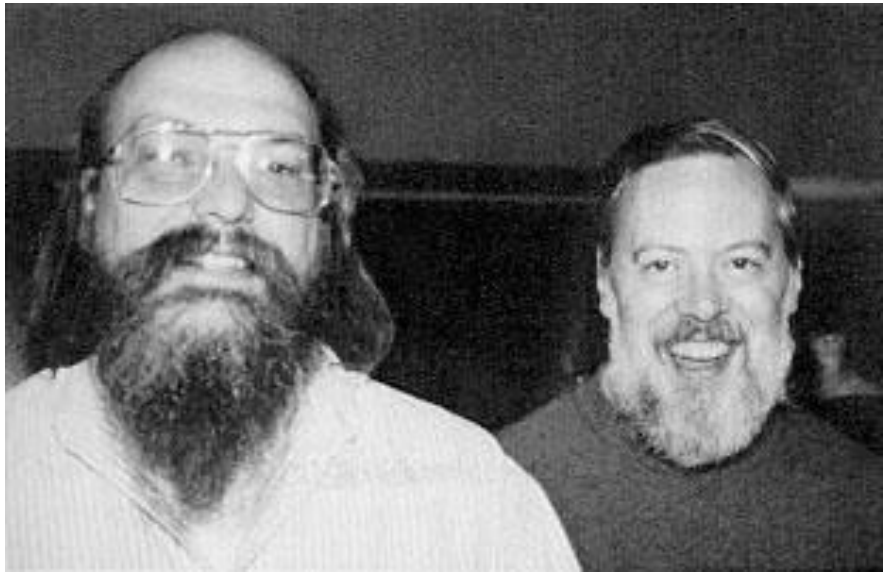
- In 1880, when the French government awarded Alexander Graham Bell the Volta Prize of 50,000 francs for the invention of the telephone. He used the award to fund the Volta Laboratory ("Alexander Graham Bell Laboratory").
- In 1889, *American Telephone & Telegraph Company (AT&T)* and its own subsidiary company took control of American Bell and the Bell System.
- Innovations at Bell labs:
  - Transistor.
  - Laser.
  - Information theory.
  - C, C++, AWK, and others.
  - Unix.
- Nine Nobel Prizes have been awarded for work completed at Bell Laboratories.

Bell Laboratories

AT&T Bell Laboratories

Unix Creation

- Ken Thompson and Dennis Ritchie developed Unix in Bell Labs on DEC PDP-7 machine.

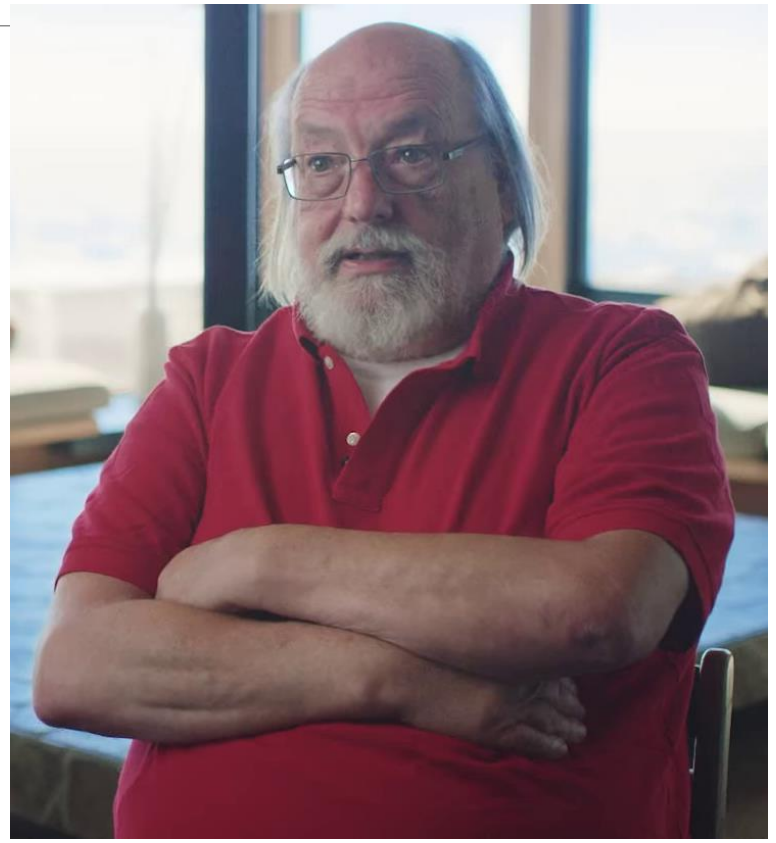


DEC PDP-7

- The PDP-7 was an 18-bit minicomputer produced by Digital Equipment Corporation (DEC) as part of the PDP series (1965).
- Price: US$72,000 (equivalent to $668,604 in 2022).
- Weight: 500 KG.
- Memory: 4K words (9.2 KB).
- Display: Printer.
- Input: Keyboard.

Unix First Version

- Ken Thompson wrote UNIX in 3 weeks in his wife vacation ☺.
- He wrote:
  - Editor.
  - Assembler.
  - Kernel.

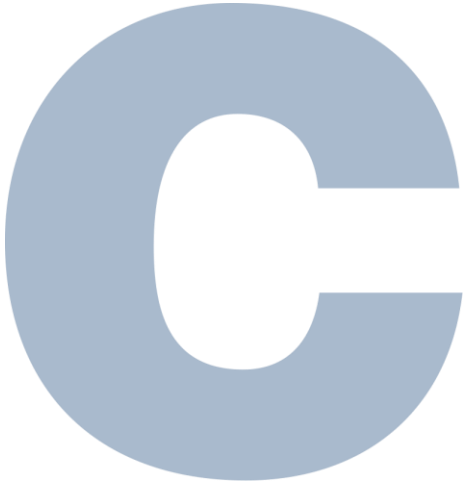


Rewriting Unix on PDP-11

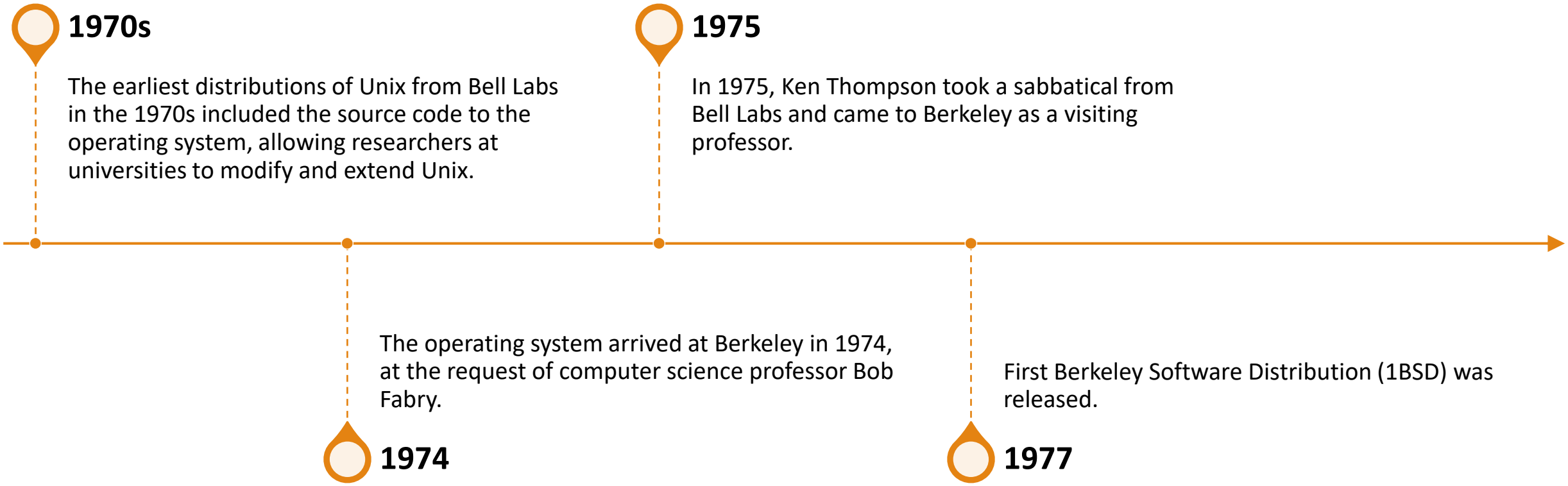
- As UNIX was written in assembly, Ken Thompson needs to rewrite it again on the PDP-11.

Inventing C language

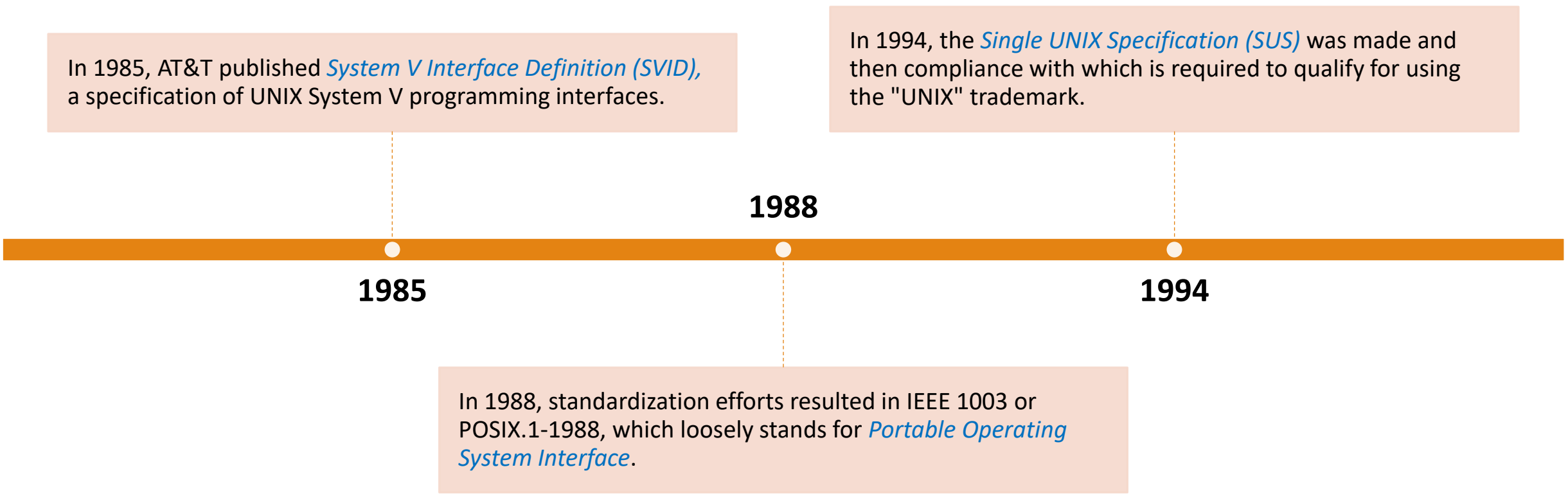
- Dennis Ritchie developed C language as a successor to B language (created by Ken Thompson).
- Then, Unix was ported to the C language.



Unix in UC Berkeley

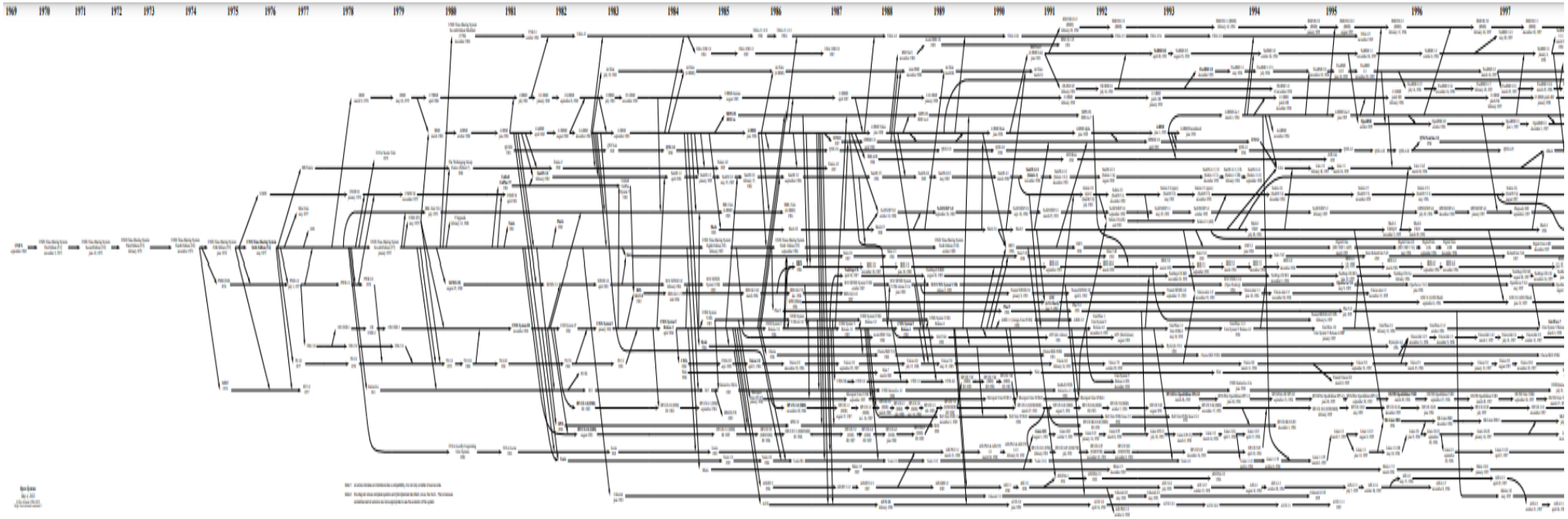


Unix standardization efforts



Unix Evolution

https://www.levenez.com/unix/



GNU

The GNU Project is a free software, mass collaboration project announced by *Richard Stallman* on September 27, 1983.

A recursive acronym meaning ***"GNU's not Unix!“***

The GNU General Public License (GNU GPL or simply GPL) is a series of widely used free software licenses that guarantee end users the four freedoms on the software:

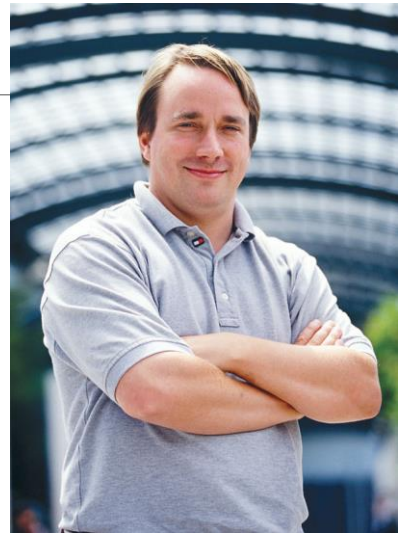
- Run.
- Study.
- Share.
- Modify.

The Creation of Linux

Surrounding conditions:

- Hardware evolved and Intel created X86.
- Internet evolved and mailing lists were popular.
- In 1987, MINIX, a Unix-like system intended for academic use, was released by Andrew S. Tanenbaum.

Linus Torvalds wrote the first kernel version in 1991.



Linux Statistics

47% of professional developers use Linux-based operating systems. (Statista)

Linux powers 39.2% of websites whose operating system is known. (W3Techs)

Linux powers 85% of smartphones. (Hayden James)

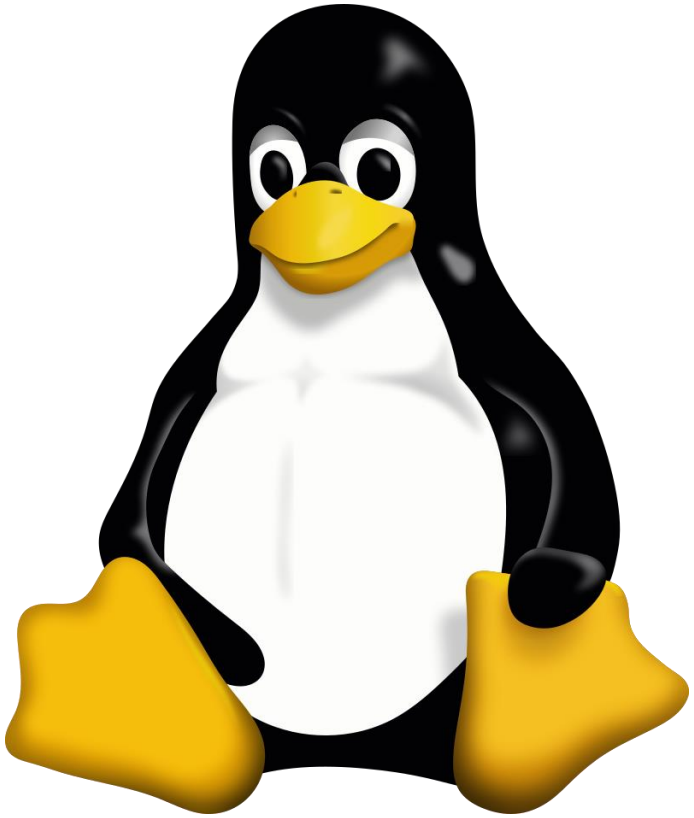
Linux, the third most popular desktop OS, has a market share of 2.09%. (Statista)

The Linux market size worldwide will reach $15.64 billion by 2027. (Fortune Business Insights)

The world's top 500 fastest supercomputers all run on Linux. (Blackdown)

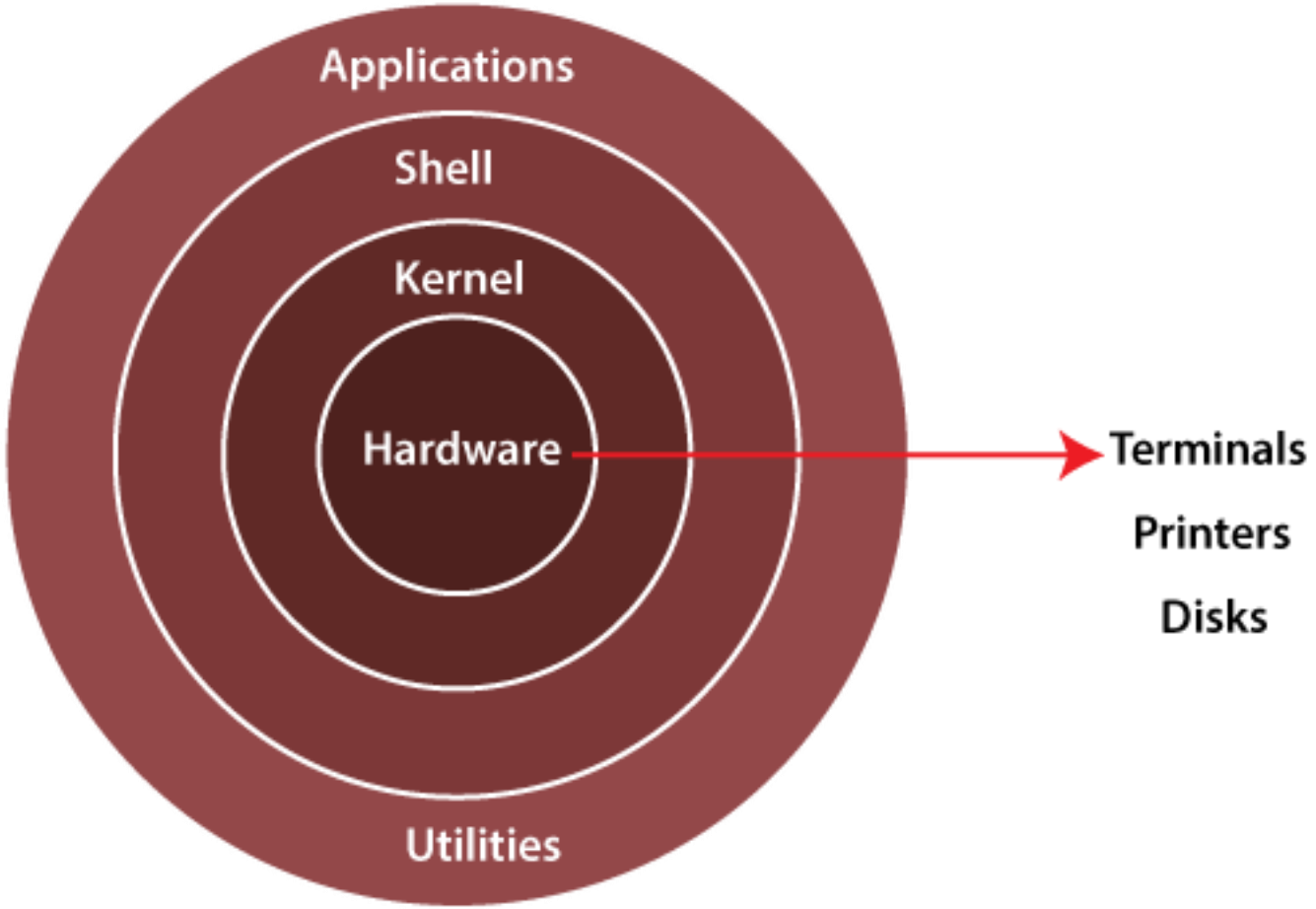
96.3% of the top one million web servers are running Linux. (ZDNet)

Today, there are over 600 active Linux distros. (Tecmint)

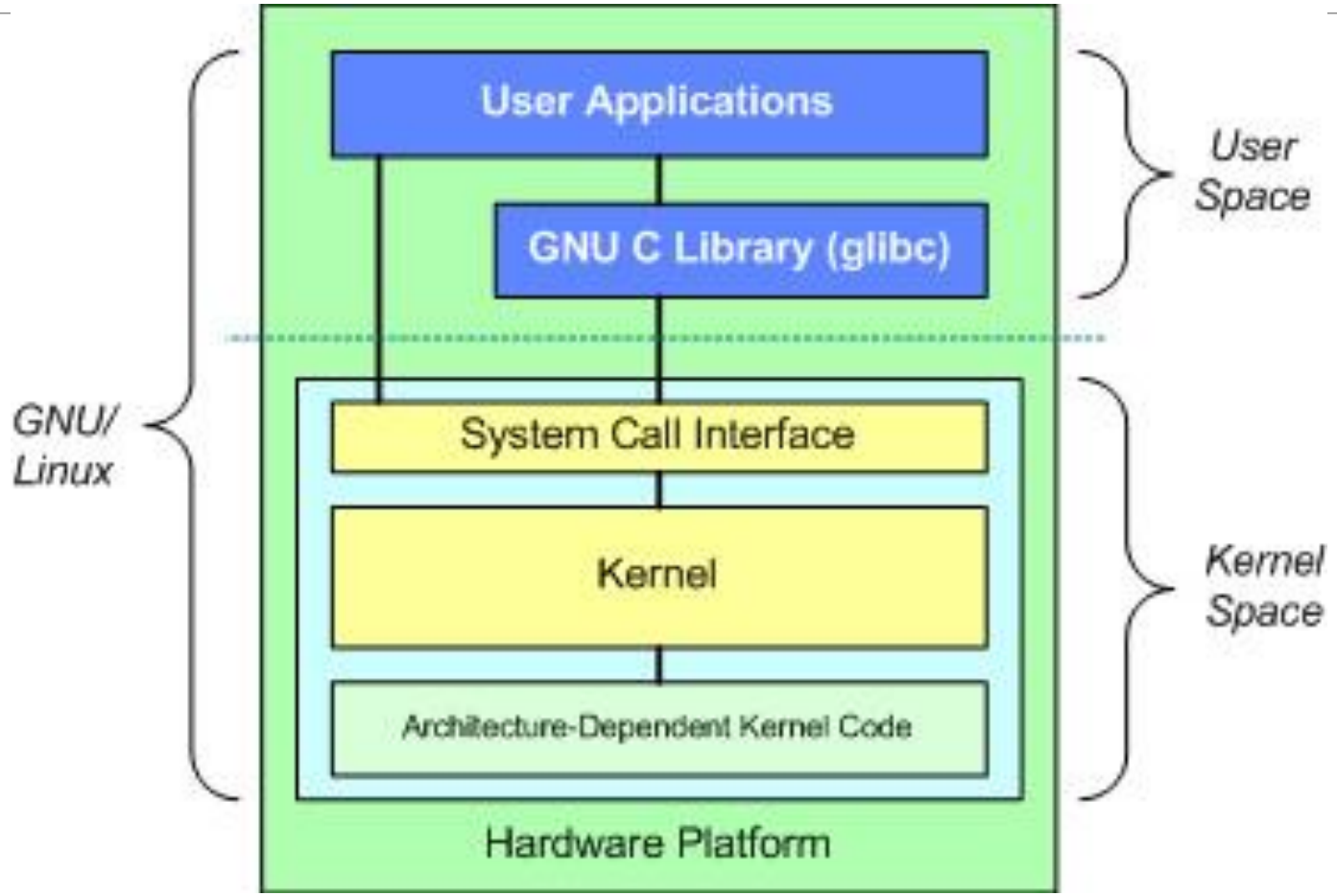


Linux Architecture

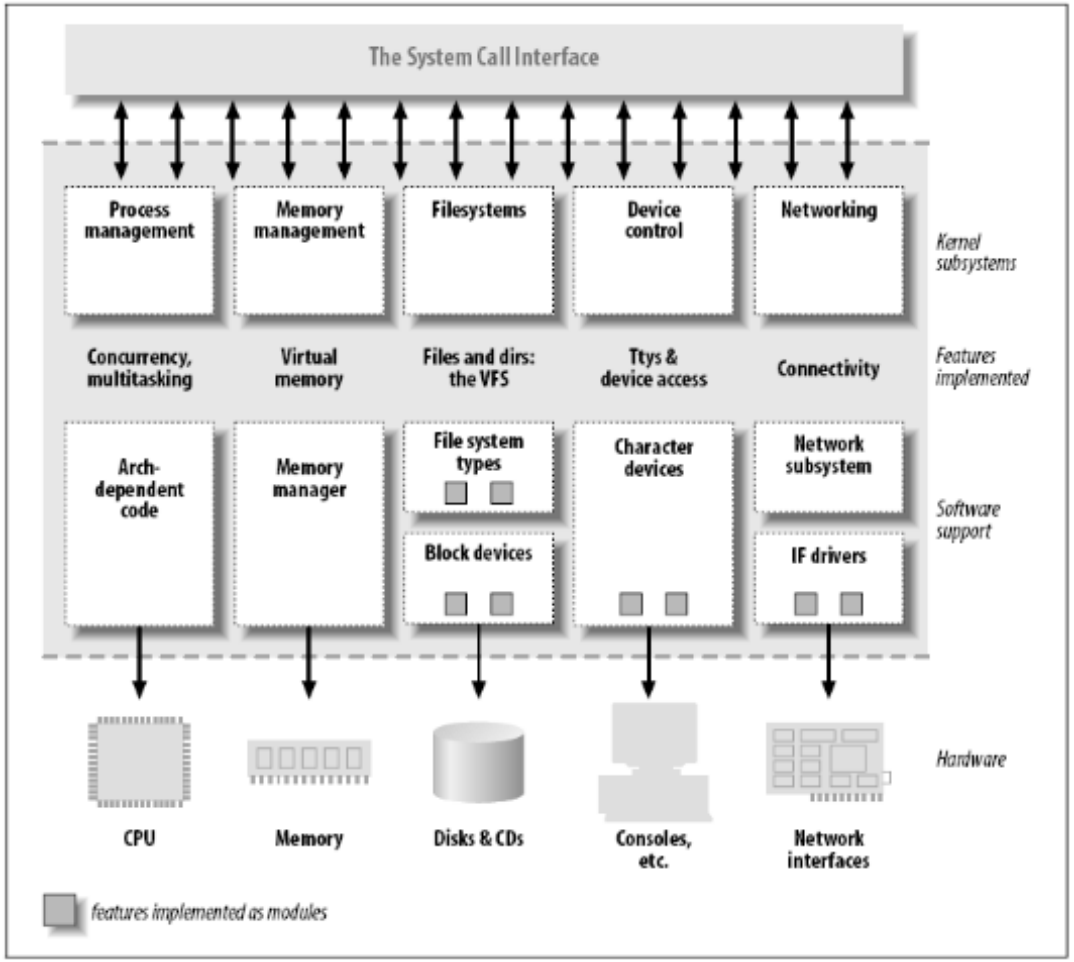
Linux OS


Applications
Shell
Kernel
Hardware
Utilities
Terminals
Printers
Disks

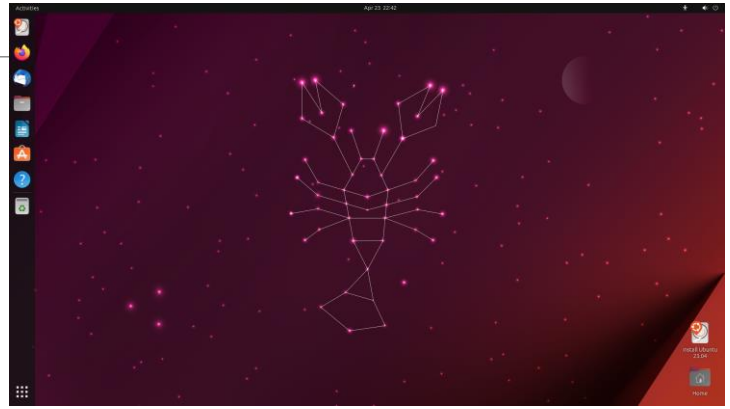
Kernel Space vs User Space



Linux Kernel



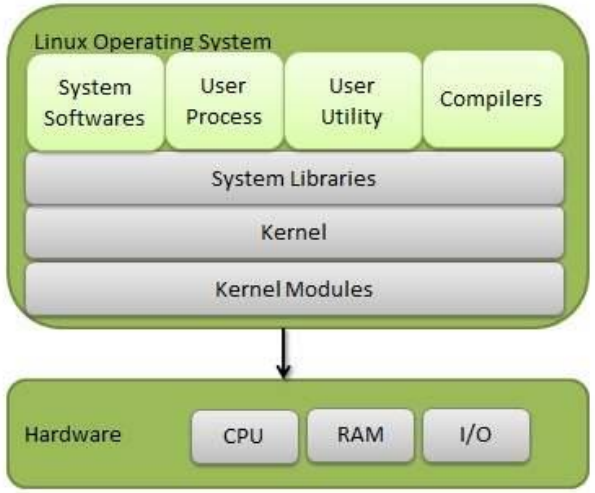
Linux Distributions



- A Linux distribution an OS made through a software collection that contains a Linux kernel, GNU libraries and tools, other software, a window system, documentation, a desktop environment, and a window manager.

Examples:

- Ubuntu
- Linux Mint
- Debian
- Red Hat Enterprise / CentOS
- Fedora
- Arch Linux
- Yocto



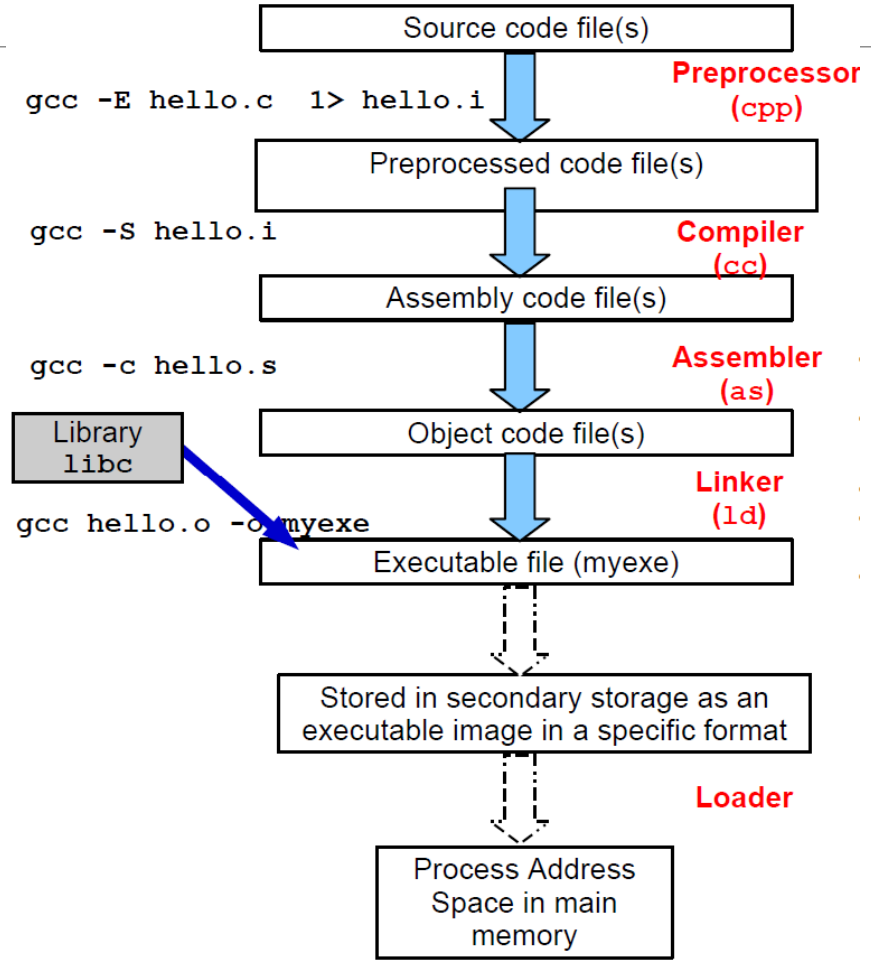
Linux Basic Commands

Basic Commands

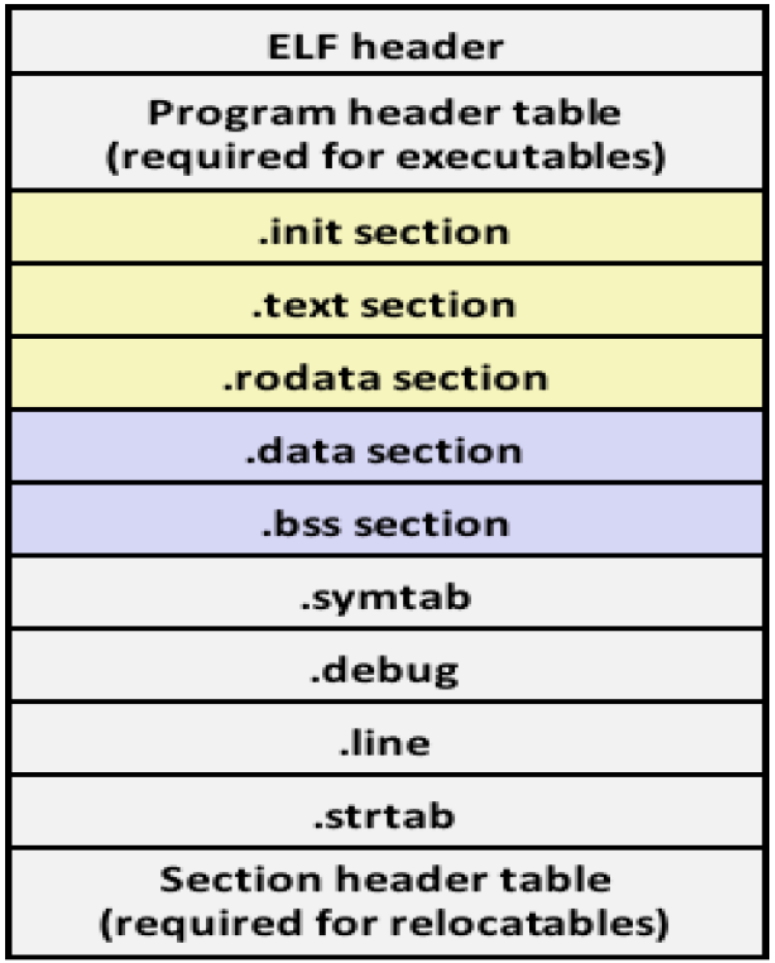
- Navigation (pwd, cd, mkdir, ls, ..).
- Getting help (help, man, ..).
- Copy and rename files.
- Creating directories.
- Viewing files.
- Editing files.
- I/O redirection.
- Pipes.
- History.

Build Process

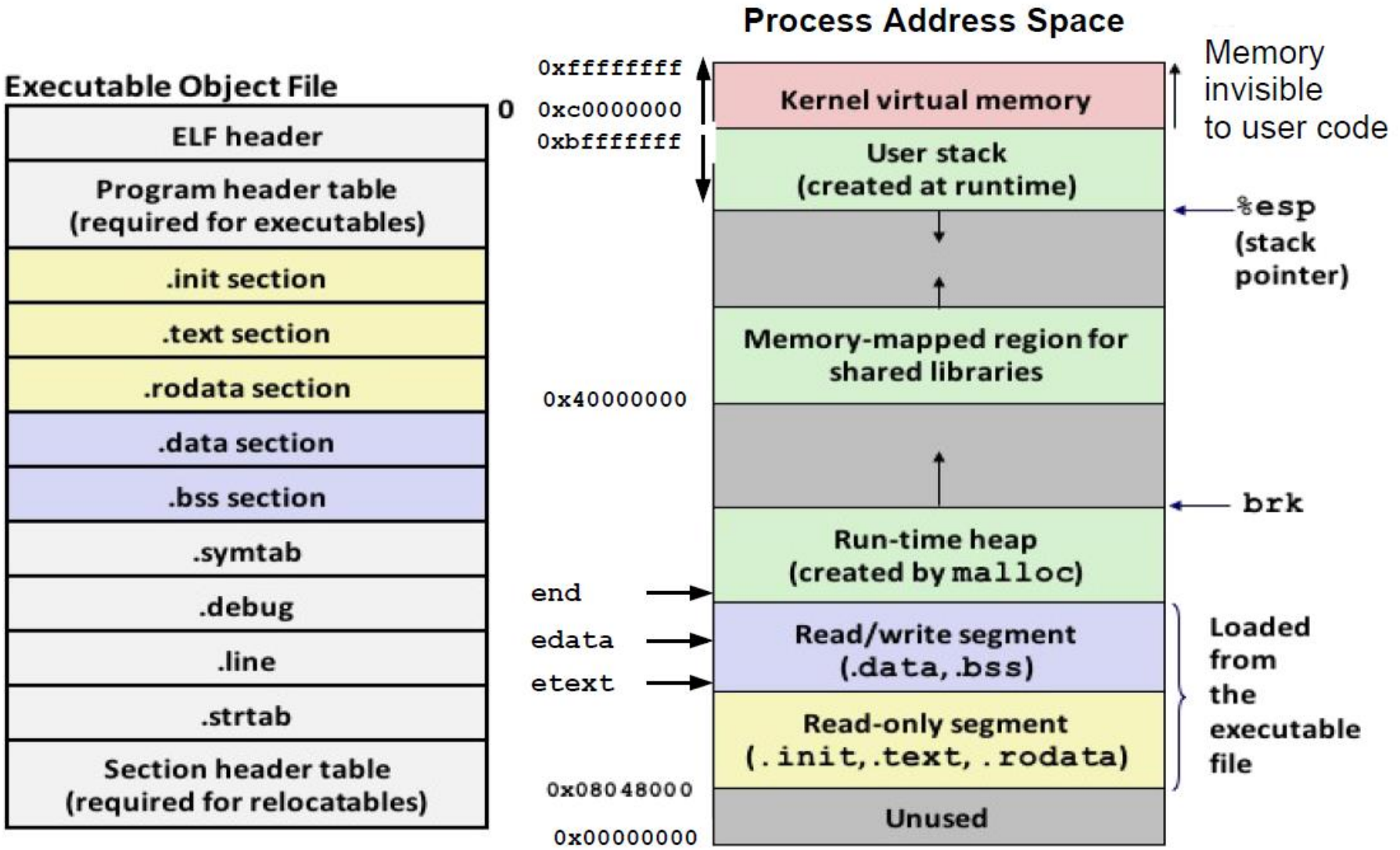
Build Process



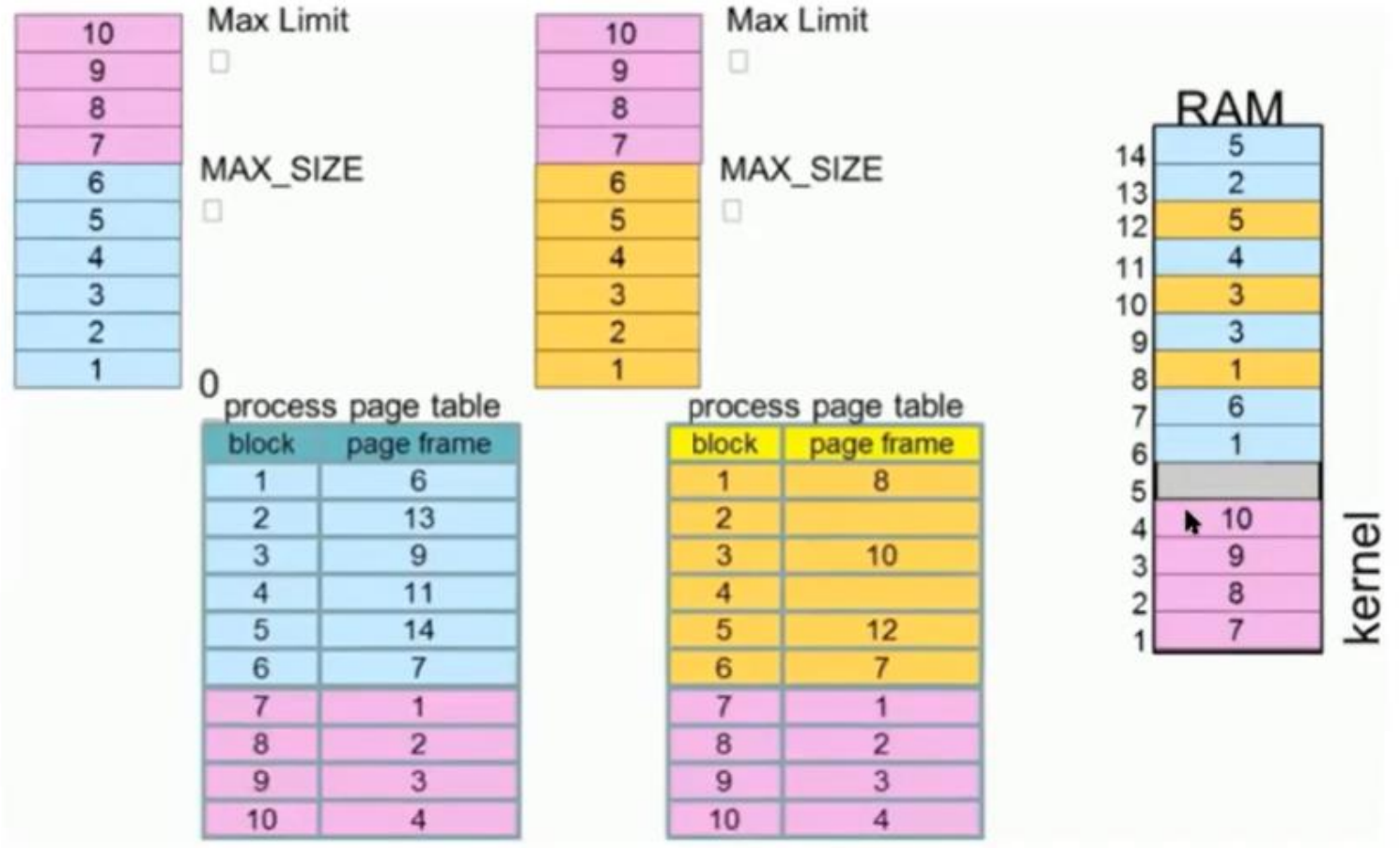
ELF Format


ELF header
Program header table
(required for executables)
.init section
.text section
.rodata section
.data section
.bss section
.symtab
.debug
.line
.strtab
Section header table
(required for relocatables)

Execution View

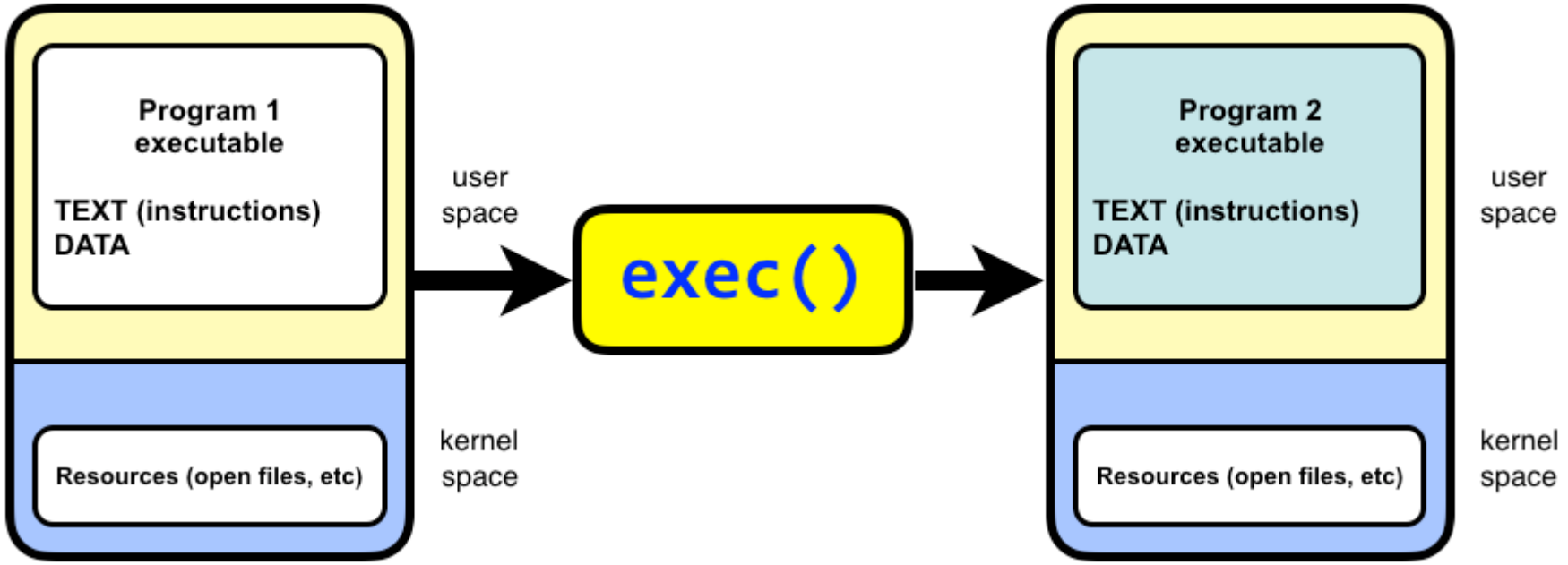


Virtual address

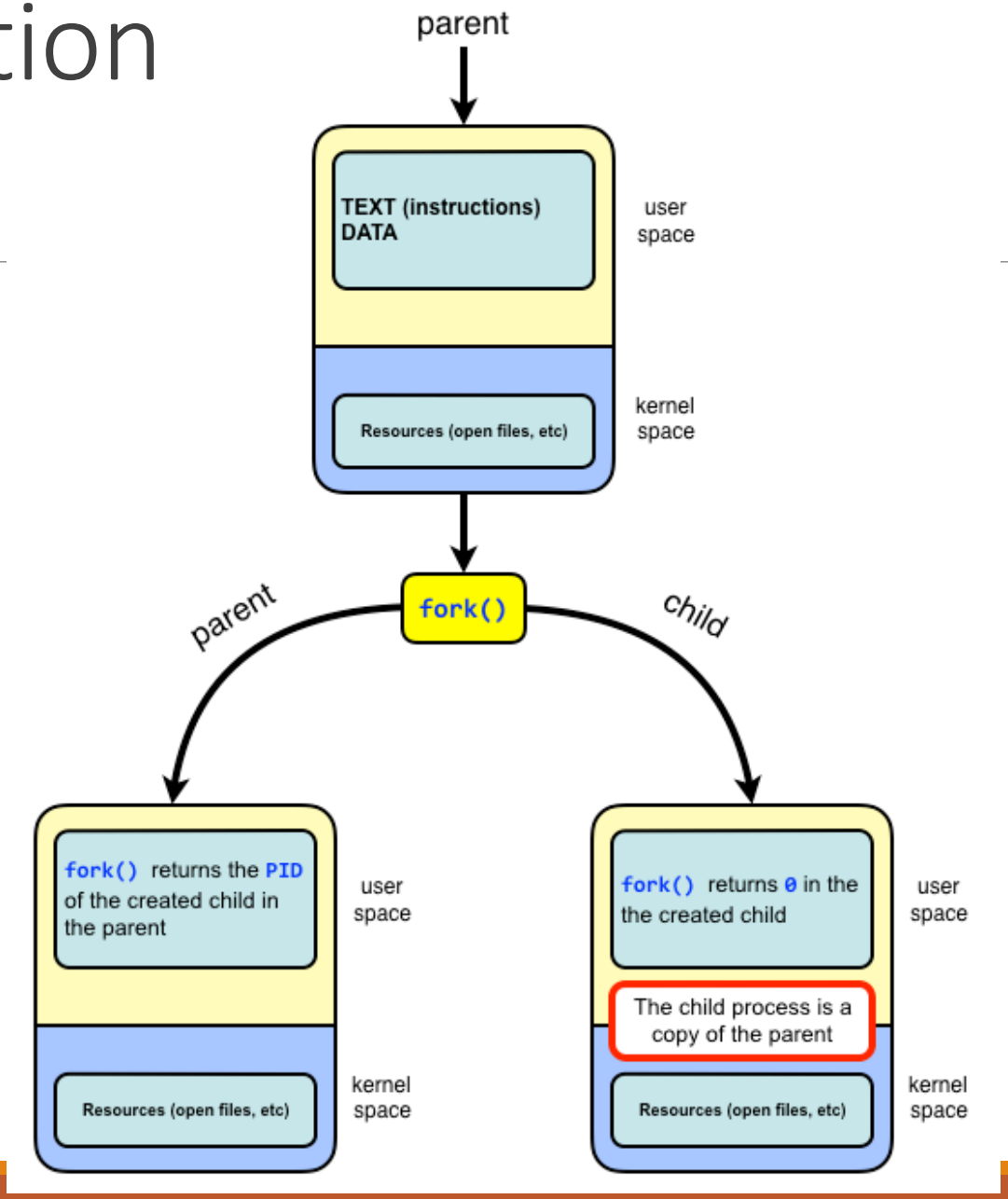


Process Management

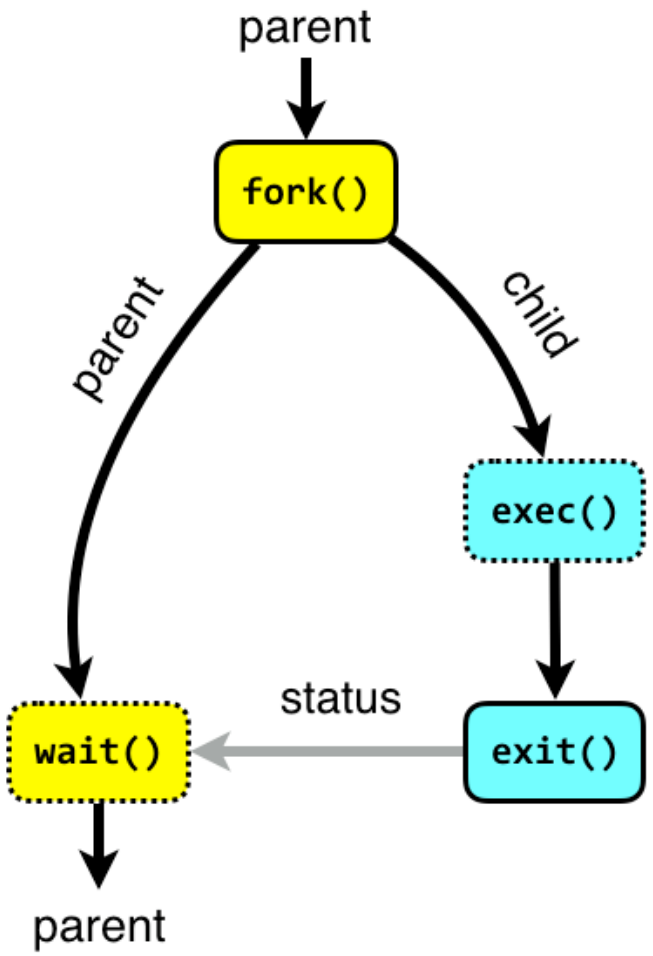
Program Execution



Process Creation



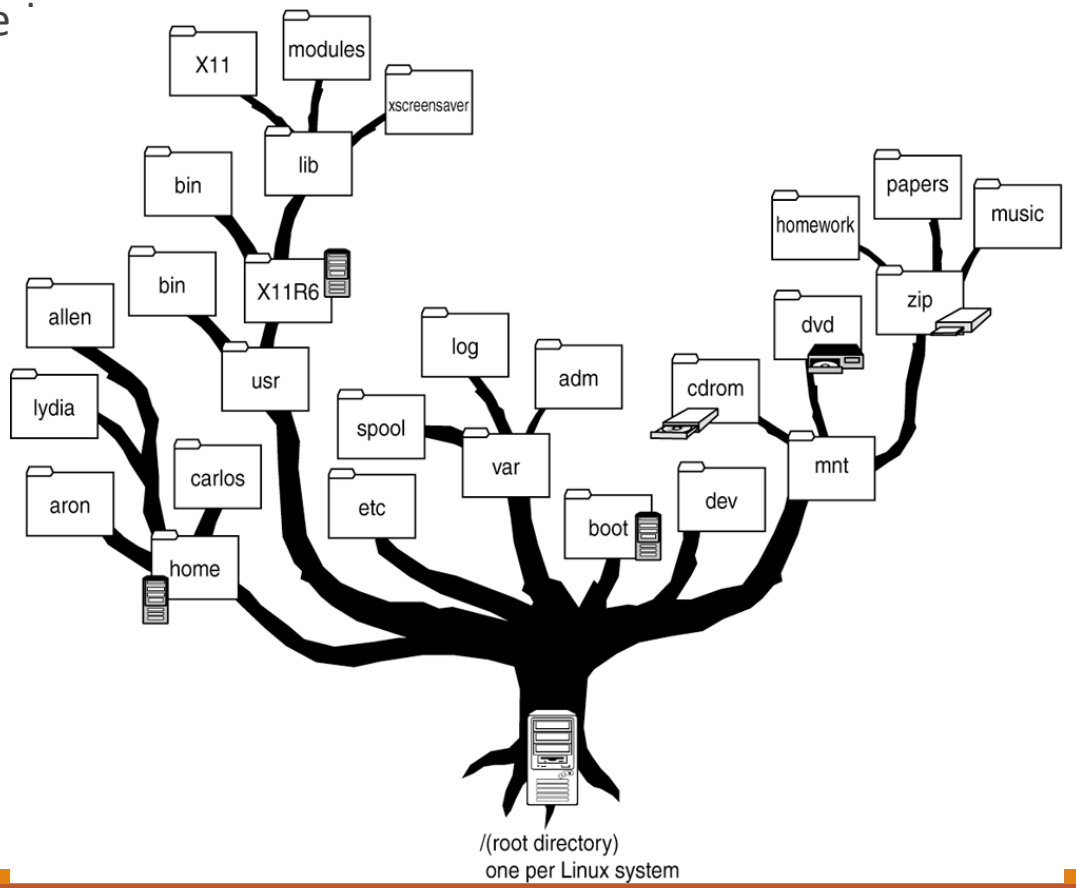
Executing Programs in a New Process



File Systems

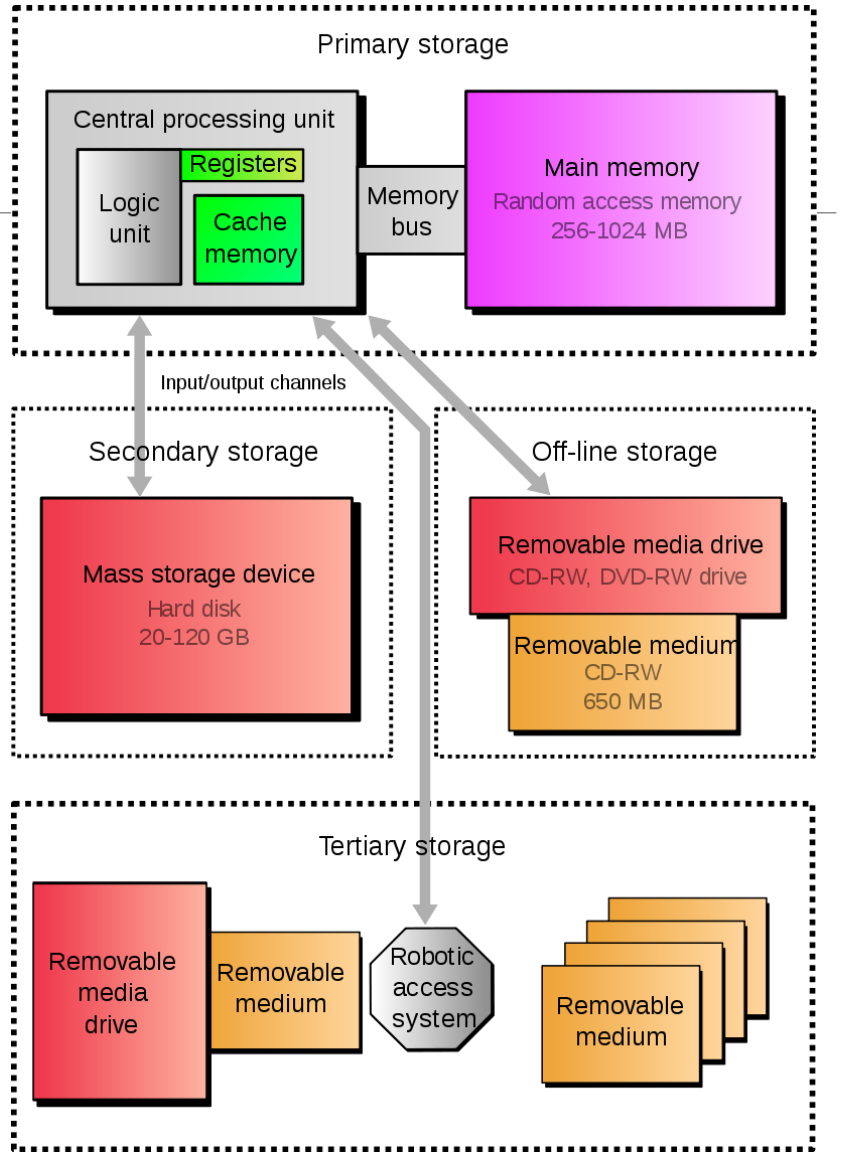
File System

A file system or filesystem (often abbreviated to fs) is a method and data structure that the operating system uses to control how data is stored and retrieve .



Data Storage forms

- **Primary storage** (also known as main memory, internal memory, or prime memory), often referred to simply as memory, is the only one directly accessible to the CPU.
- **Secondary storage** (also known as external memory or auxiliary storage) differs from primary storage in that it is not directly accessible by the CPU.
- **Tertiary storage** or tertiary memory is a level below secondary storage. Typically, it involves a robotic mechanism which will mount (insert) and dismount removable mass storage media into a storage device according to the system's demands; such data are often copied to secondary storage before use.

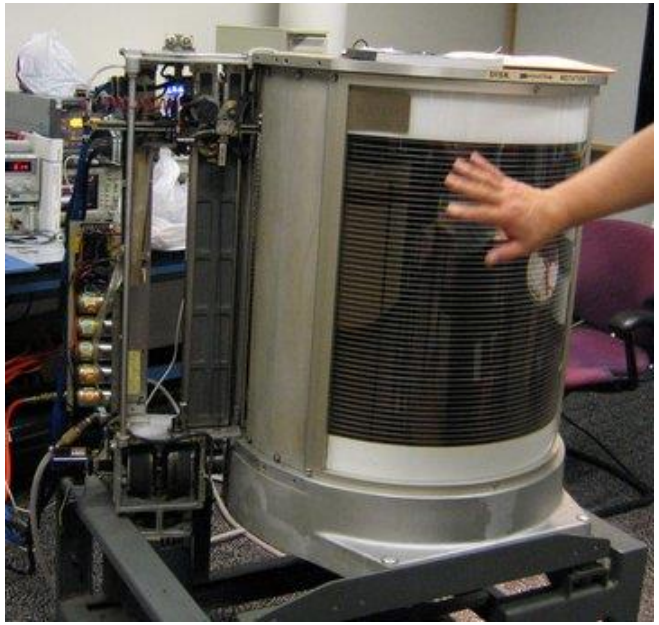


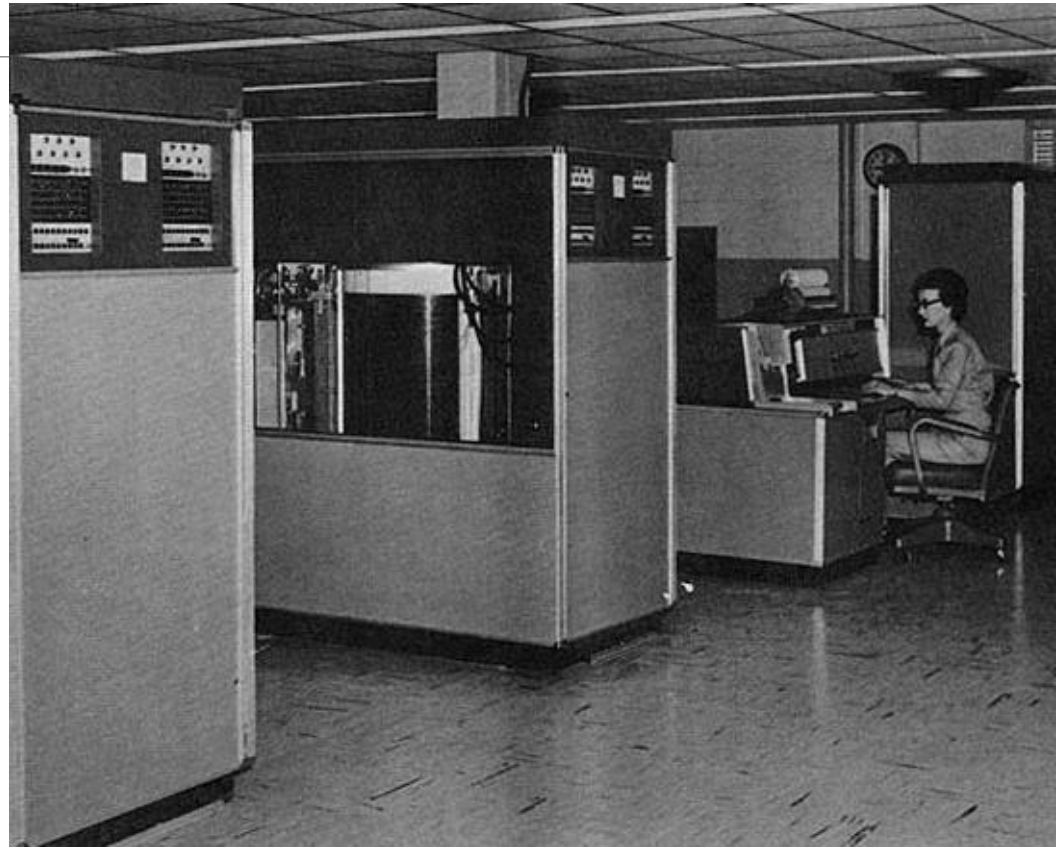
Hard disk drive

- A hard disk drive (HDD) is an electro-mechanical data storage device that stores and retrieves digital data using magnetic storage with one or more rigid rapidly rotating platters coated with magnetic material.
- Introduced by IBM in 1956.

HDD History Examples

- IBM 350 (First Hard disk)
  - Introduced in 1956.
  - Size: two large refrigerators.
  - Capacity: 3.75 Mbyte.





HDD History Examples

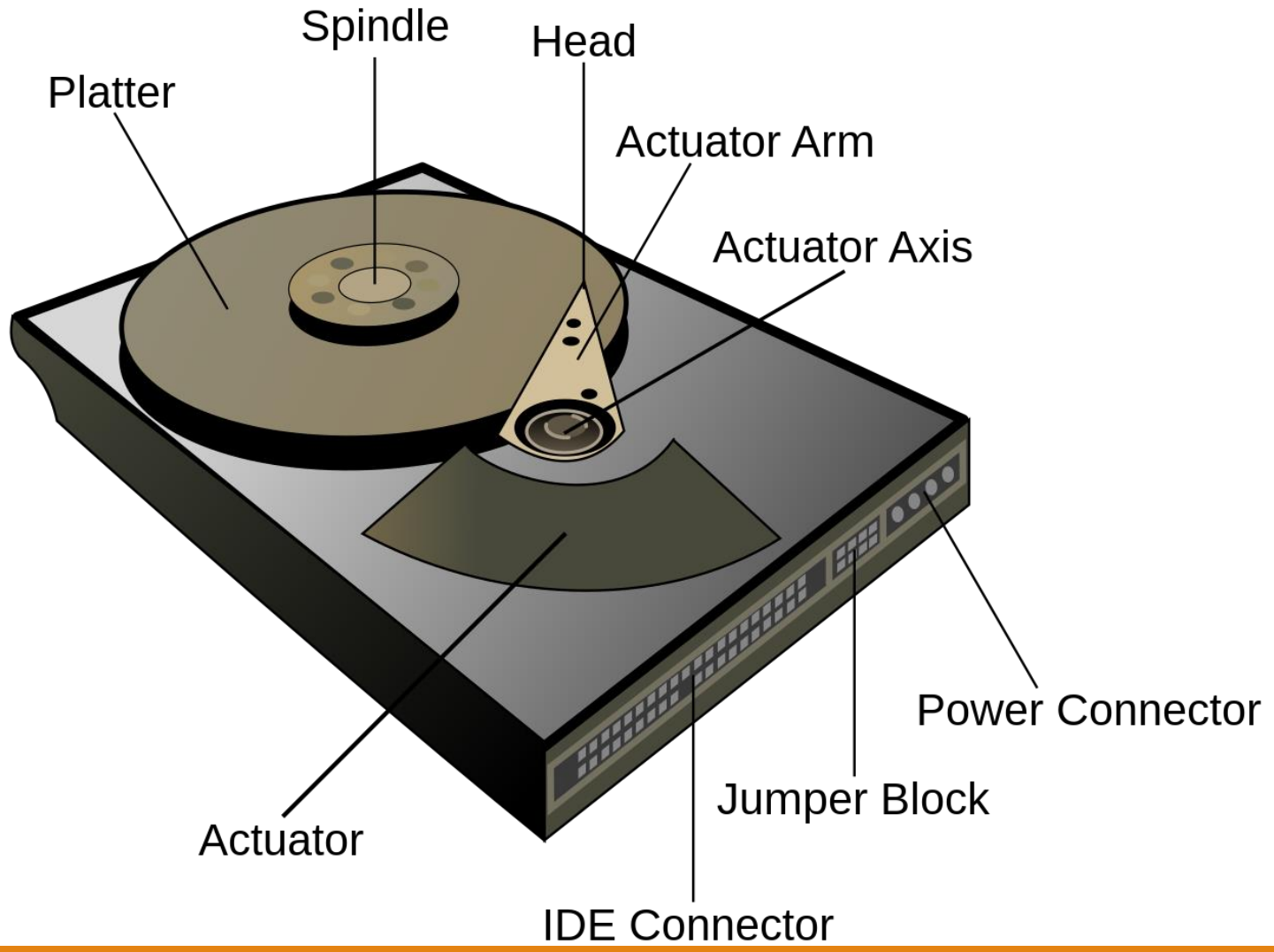
- IBM 1311
  - Introduced in 1962.
  - Size: washing machine.
  - Capacity: 1.43 Mbyte.

HDD Improvements over years

Improvement of HDD characteristics over time

Parameter	Started with (1957)	Improved to	Improvement
Capacity (formatted)	3.75 megabytes[18]	22 terabytes (as of 2023)[19]	5.86-million-to-one[c]
Physical volume	68 cubic feet (1.9 m^3)[d][6]	2.1 cubic inches (34 cm^3)[20][e]	56,000-to-one[f]
Weight	2,000 pounds (910 kg)[6]	2.2 ounces (62 g)[20]	15,000-to-one[g]
Average access time	approx. 600 milliseconds[6]	2.5 ms to 10 ms; RW RAM dependent	about 200-to-one[h]
Price	US$9,200 per megabyte (1961; US$83,107 in 2021)[21]	US$0.024 per gigabyte by 2020[22][i][23]	3.46-billion-to-one[j]
Data density	2,000 bits per square inch[24]	1.3 terabits per square inch in 2015[25]	650-million-to-one[k]
Average lifespan	c. 2000 hrs MTBF[*citation needed*]	c. 2,500,000 hrs (~285 years) MTBF[26]	1250-to-one[l]

Components of HDD



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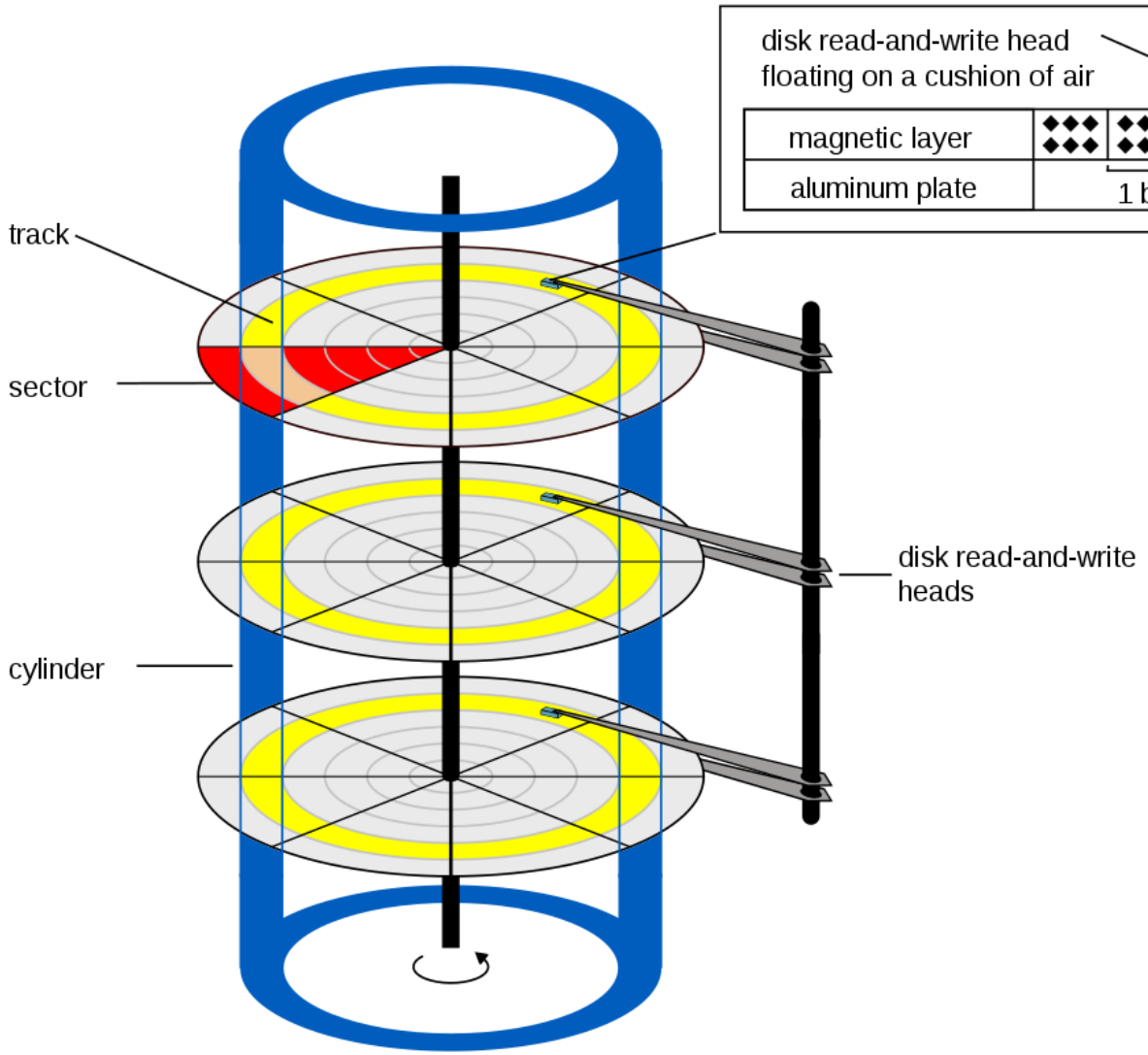
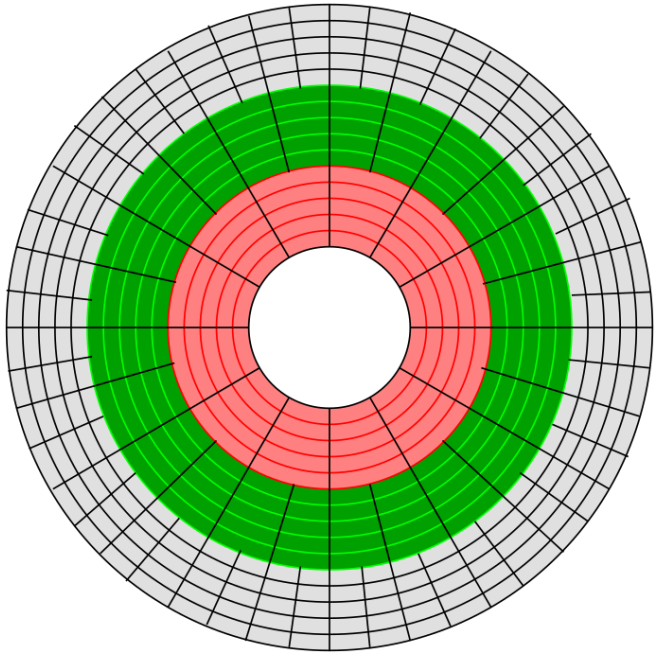


Components of HDD

- Zone bit recording (ZBR) is a method used by disk drives to optimize the tracks for increased data capacity.
- Zone recording was pioneered and patented by *Chuck Peddle* in 1961 while working for General Electric.

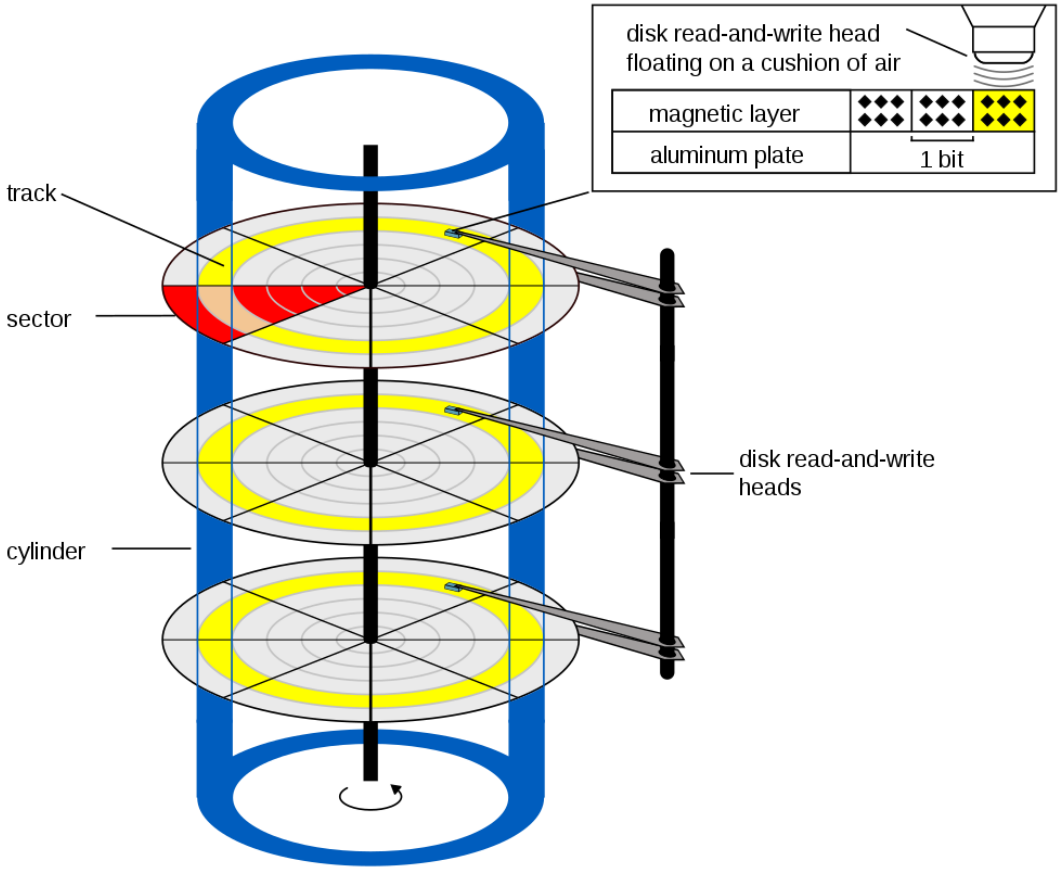


HDD Addressing Schemes

CHS (Cylinder – Head - Sector)

- Limited by:
  - 512 bytes / sector.
  - 63 sectors / track.
  - 255 heads (tracks/Cylinder).
  - 1024 Cylinders.
- Maximum disk size: 8064 MB.

LBA (Logical Block Addressing)



SSD

A solid-state drive (SSD)

- is a solid-state storage device that uses integrated circuit assemblies to store data persistently, typically using flash memory, and functioning as secondary storage in the hierarchy of computer storage.

Outperforms the HDD in:

- Speed.
- Noise.
- Capacity.
- Durability.
- Size.
- Fragmentation.
- Price.

Disk Partitioning

Disk partitioning is the creation of one or more regions on secondary storage, so that each region can be managed separately. These regions are called partitions.

Disk Partitioning reasons:

- Organize data.
- Security.
- Avoid crossing size limits.
- Implement quotes.
- Supporting multiple filesystems.

Partition Types:

- Data Partitions.
- Swap Partitions.

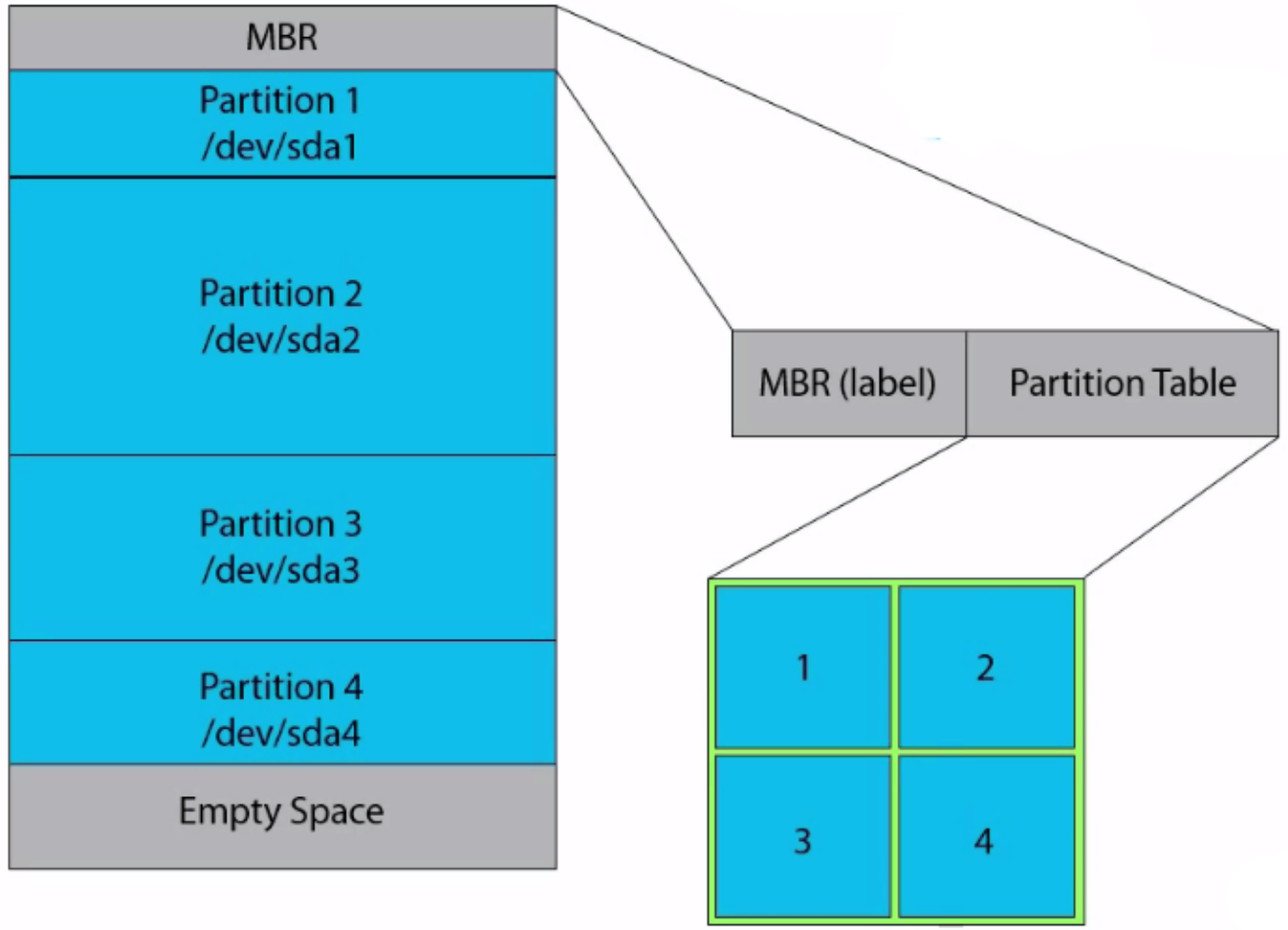
Disk Partitioning

Partition Table: is a table maintained on a disk by the operating system that outlines and describes the partitions on that disk.

Partition Table Types:

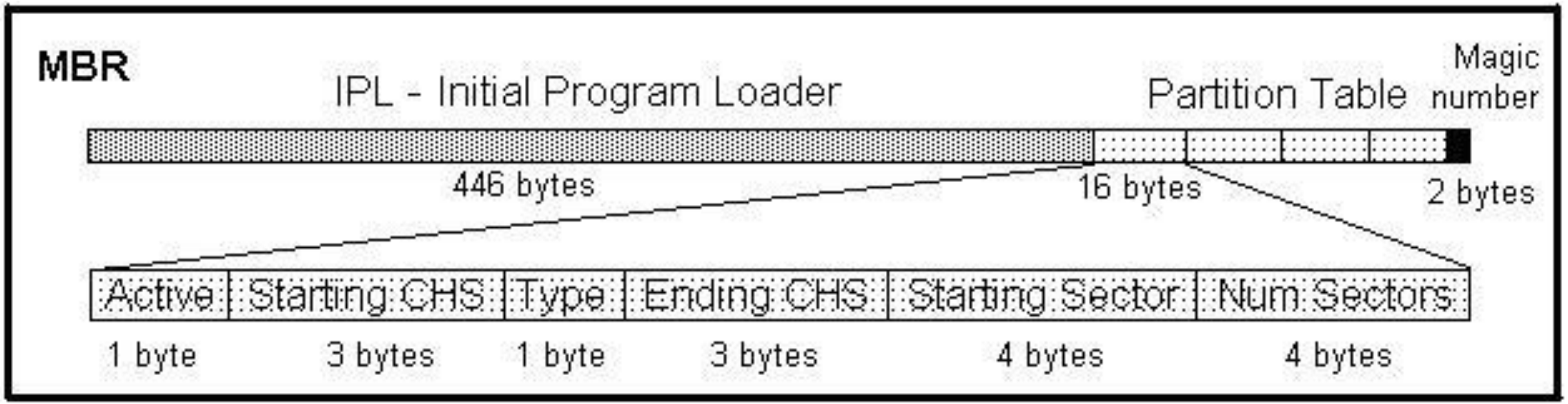
- MBR (Master Boot Record).
- GPT (GUID (Globally Unique IDentifier) Partition Table).

Master Boot Record

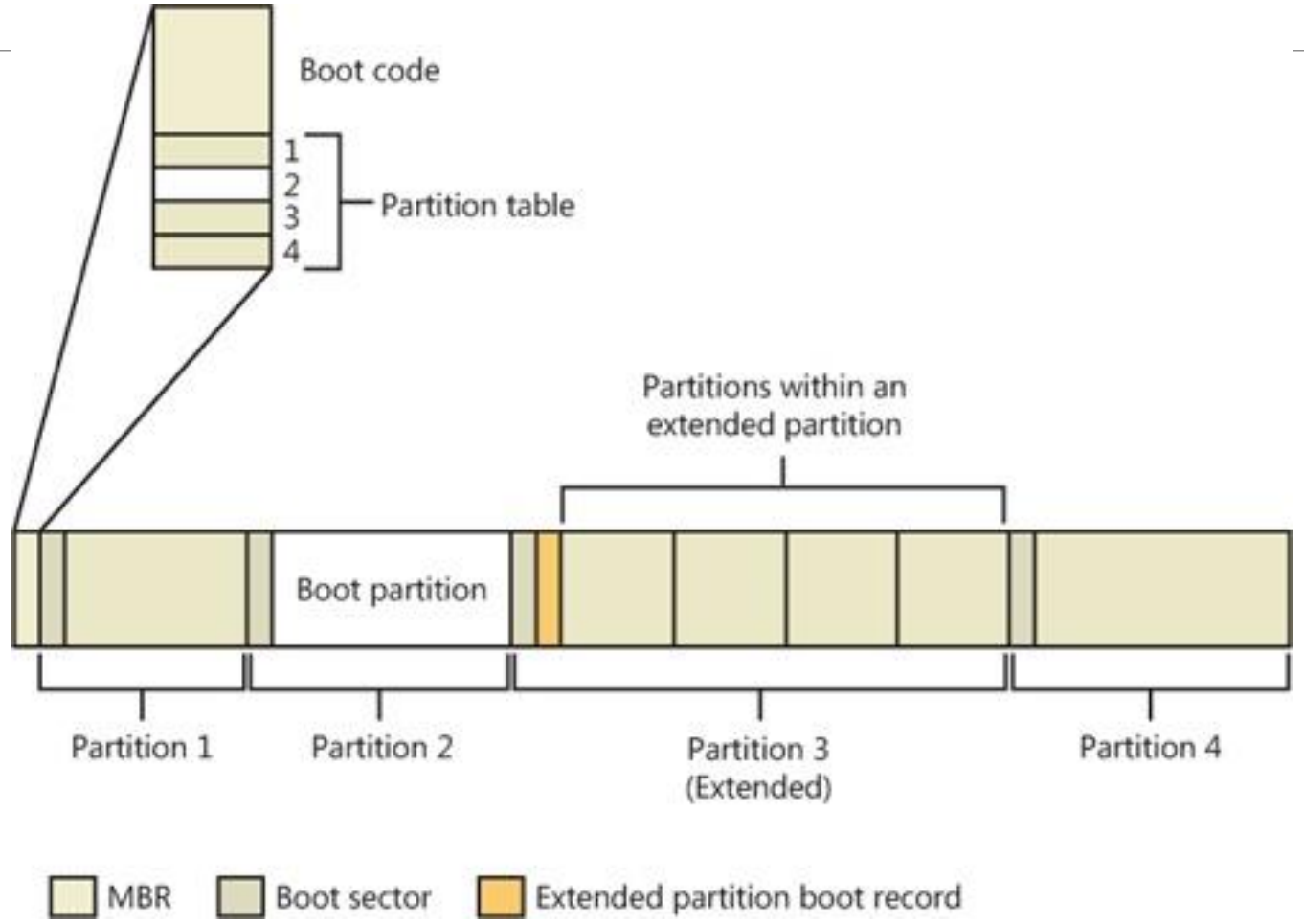


Master Boot Record

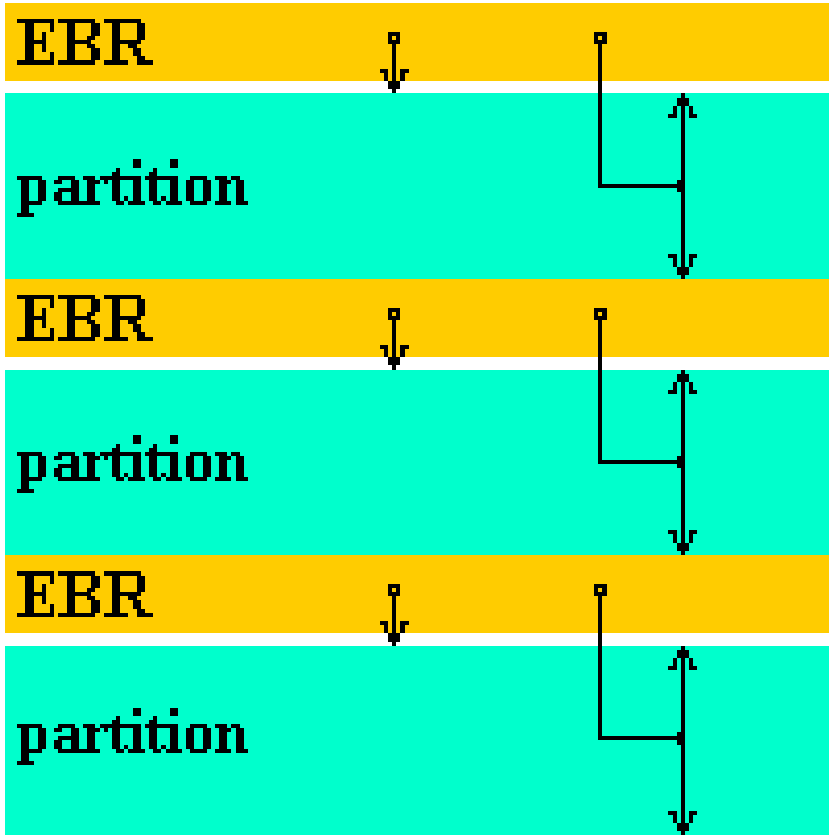
Master Boot Record



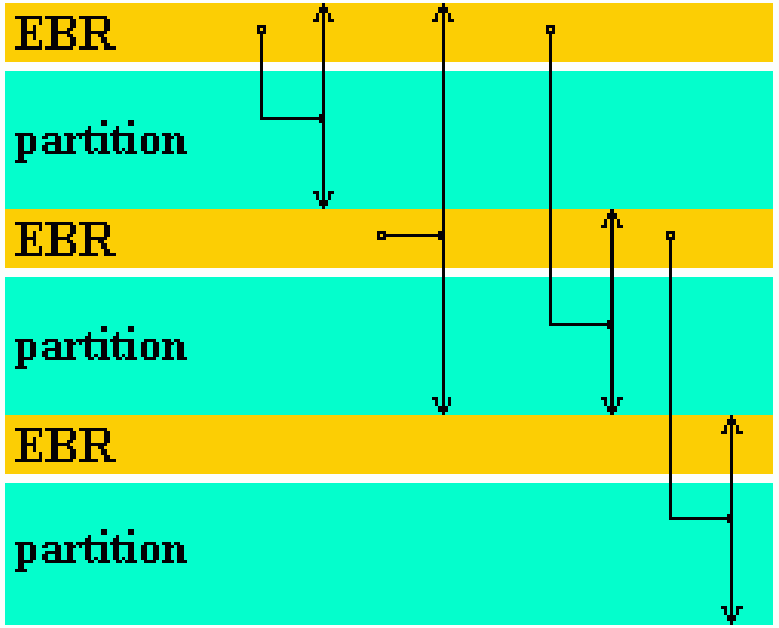
MBR with an Extended Partition



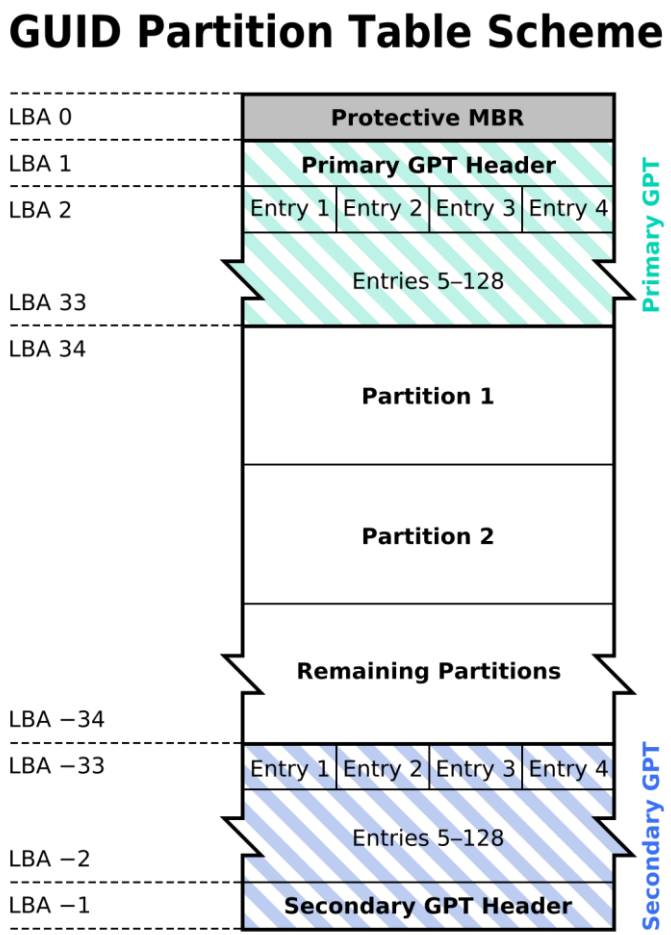
Extended Boot Record (First entry)



Extended Boot Record (Second entry)



GUID Partition Table (GPT)



Up to 128 partition.

Partition size: up to 9.44 ZiB (10^9 TiB).

GPT table is repeated at the end of the hard disk.

GPT Header

GPT header format

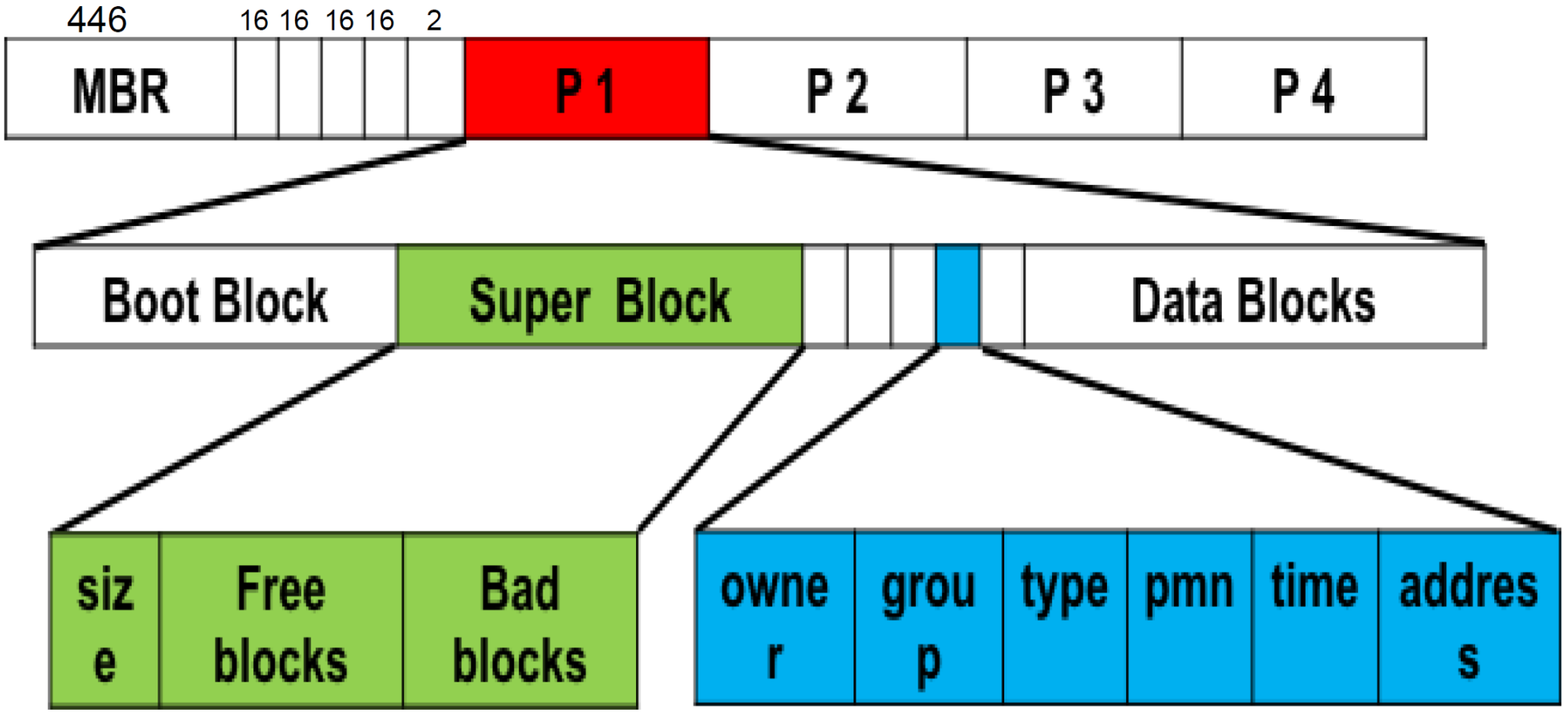
Offset	Length	Contents
0 (0x00)	8 bytes	Signature ("EFI PART", `45h 46h 49h 20h 50h 41h 52h 54h` or `0x5452415020494645ULL`[a] on little-endian machines)
8 (0x08)	4 bytes	Revision number of header - 1.0 (`00h 00h 01h 00h`) for UEFI 2.10
12 (0x0C)	4 bytes	Header size in little endian (in bytes, usually `5Ch 00h 00h 00h` or 92 bytes)
16 (0x10)	4 bytes	CRC32 of header (offset +0 to +0x5b) in little endian, with this field zeroed during calculation
20 (0x14)	4 bytes	Reserved; must be zero
24 (0x18)	8 bytes	Current LBA (location of this header copy)
32 (0x20)	8 bytes	Backup LBA (location of the other header copy)
40 (0x28)	8 bytes	First usable LBA for partitions (primary partition table last LBA + 1)
48 (0x30)	8 bytes	Last usable LBA (secondary partition table first LBA − 1)
56 (0x38)	16 bytes	Disk GUID in mixed endian[12]
72 (0x48)	8 bytes	Starting LBA of array of partition entries (usually 2 for compatibility)
80 (0x50)	4 bytes	Number of partition entries in array
84 (0x54)	4 bytes	Size of a single partition entry (usually `80h` or 128)
88 (0x58)	4 bytes	CRC32 of partition entries array in little endian
92 (0x5C)	*	Reserved; must be zeroes for the rest of the block (420 bytes for a sector size of 512 bytes; but can be more with larger sector sizes)

GPT Partition Entry

GUID partition entry format

Offset	Length	Contents
0 (0x00)	16 bytes	Partition type GUID (mixed endian[12])
16 (0x10)	16 bytes	Unique partition GUID (mixed endian)
32 (0x20)	8 bytes	First LBA (little endian)
40 (0x28)	8 bytes	Last LBA (inclusive, usually odd)
48 (0x30)	8 bytes	Attribute flags (e.g. bit 60 denotes read-only)
56 (0x38)	72 bytes	Partition name (36 UTF-16LE code units)

Unix Filesystem



Inode structure