Lecture 2: Disks and Filesystems

High Performance Computers

Outline

- Disk Hardware
  - Spinning Disks, Solid State Drives
- Partitioning
  - Viewing, Modifying, Creating, Geometry, SSDs
- Filesystems
  - Filesystem Types, Creating, Mounting, UUIDs, Caching, fstab, repairing
- Swap Space
- LVMs
- Internals
  - Inodes, blocks

HDD

3.5”

Shock resistant up to 350g/2ms

SSD

2.5”

Shock resistant up to 1500g/0.5ms

Hard Disk Drive

CHS Addressing (Cylinder, Head, Sector)

Maps to Logical Block Addresses (LBA)

5400, 7200, 10K, 15K RPM

Head is 2-3 nm above the spinning disk (1/30k the width of a human skin cell)

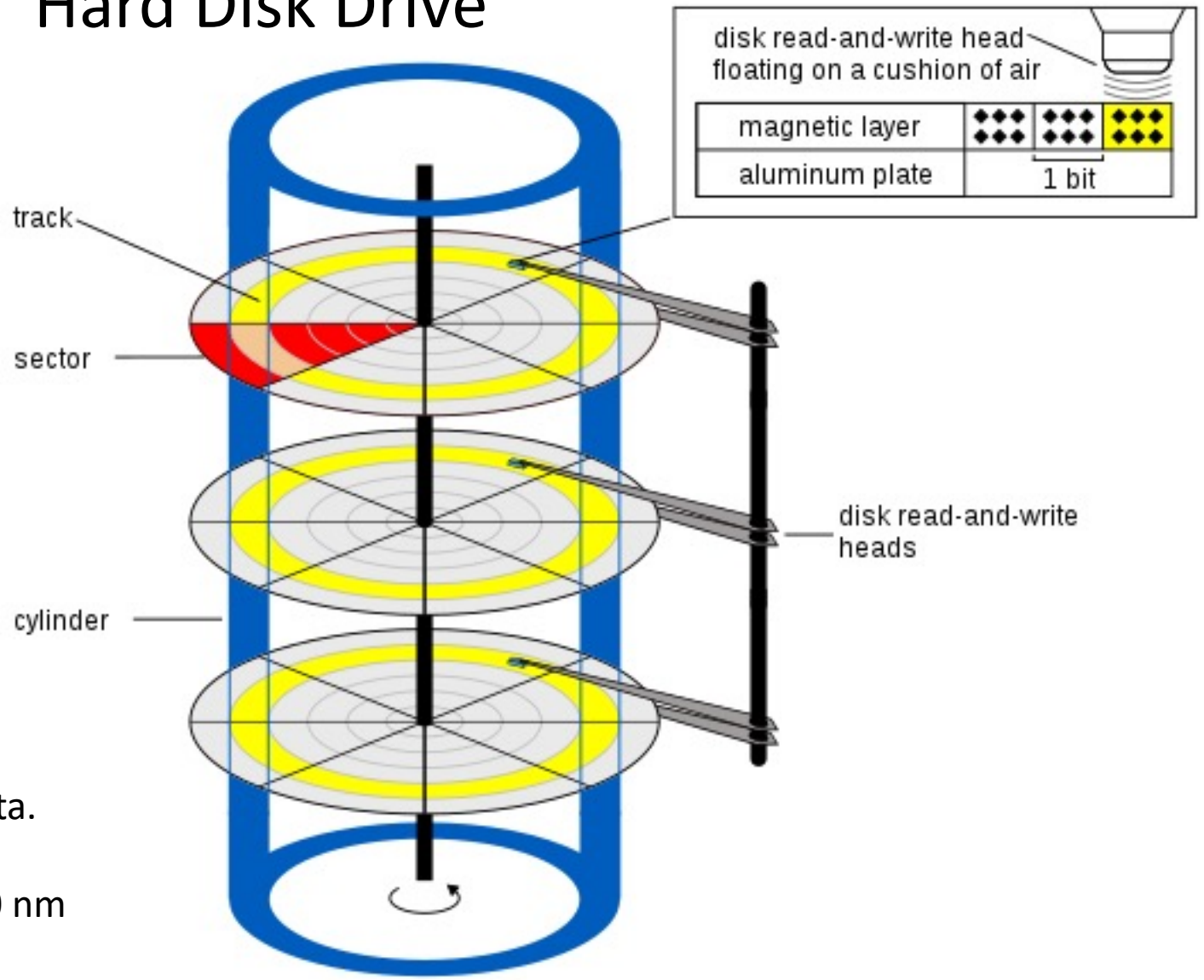
The relative motion of the head over Platter is 115 km/h at the outside and 30 km/h towards the center.

The HDD head can polarize the iron atoms covering the HDD platter to store 0s and 1s.

It can also detect the polarization to read data.

The area that stores the bit value is about 50 nm wide.

A disk crash can literally mean that the head crashed into the platter causing damage.



These regions can be rewritten an unlimited number of times.

Solid State Drive

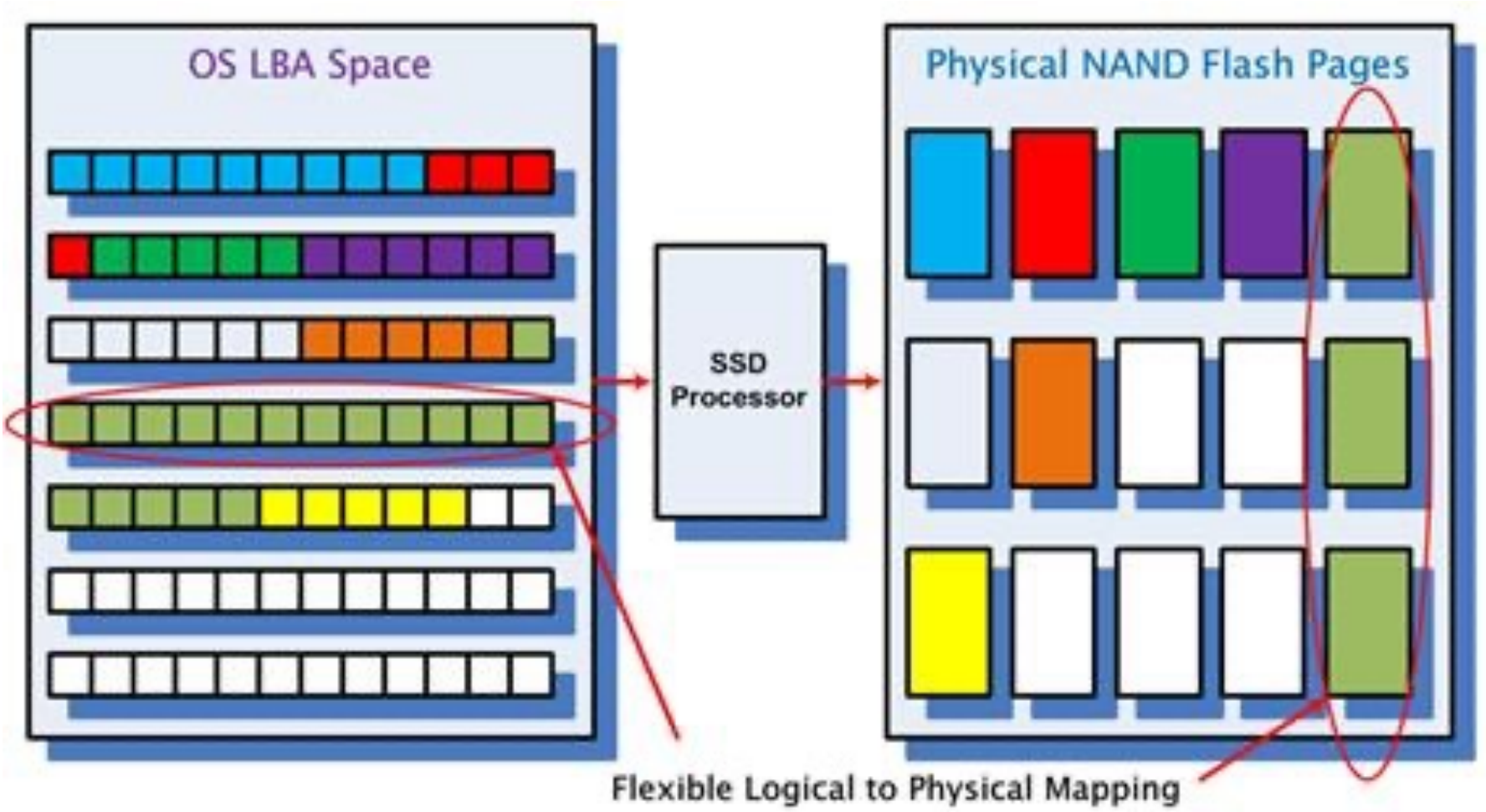
Faster
(Recall NVME (25GB/s) vs SCSI (6GB/s))

Data sectors can only be rewritten a limited number of times (a few 10Ks).

Write Amplification Factor (WAF) makes the rewrite limit worse**. The problem is that data is written at a more granular level (pages) than erasure happens (blocks).**

Basically, an SSD has to erase more storage than it writes.

As the drive fills up data gets more fragmented (is spread across more areas of the drive) and erasing data in all those different areas gets more and more expensive relative to the data written and the rewrite limits are reached fast.

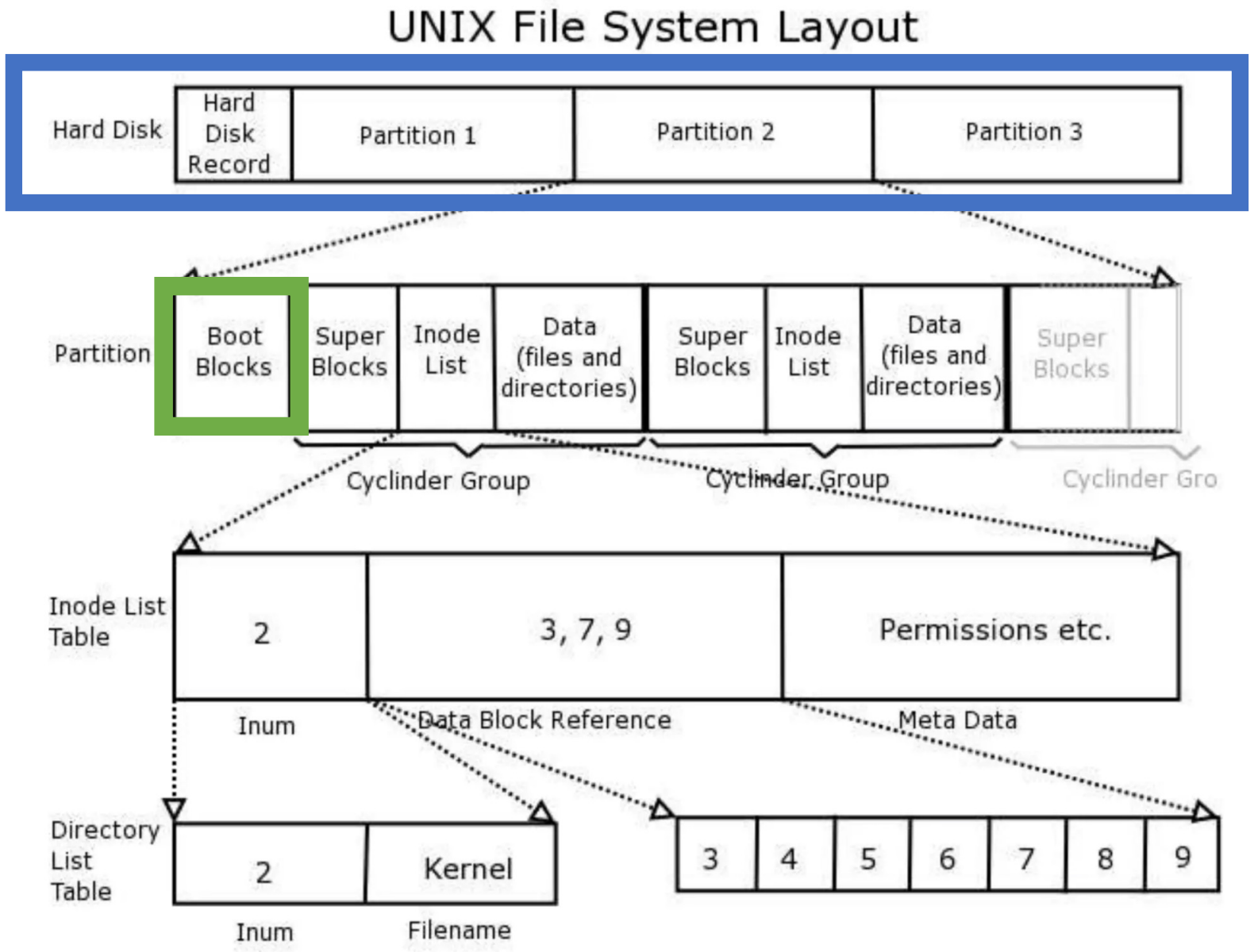


Current Samsung drives are good for about 300 TB of writing. That's fine for a desktop but not for many HPC applications.

HOST accesses SSD through LBA (Logical Block Address). Each LBA represents a Sector (generally 512B in size) and the operating system generally accesses SSD in 4K

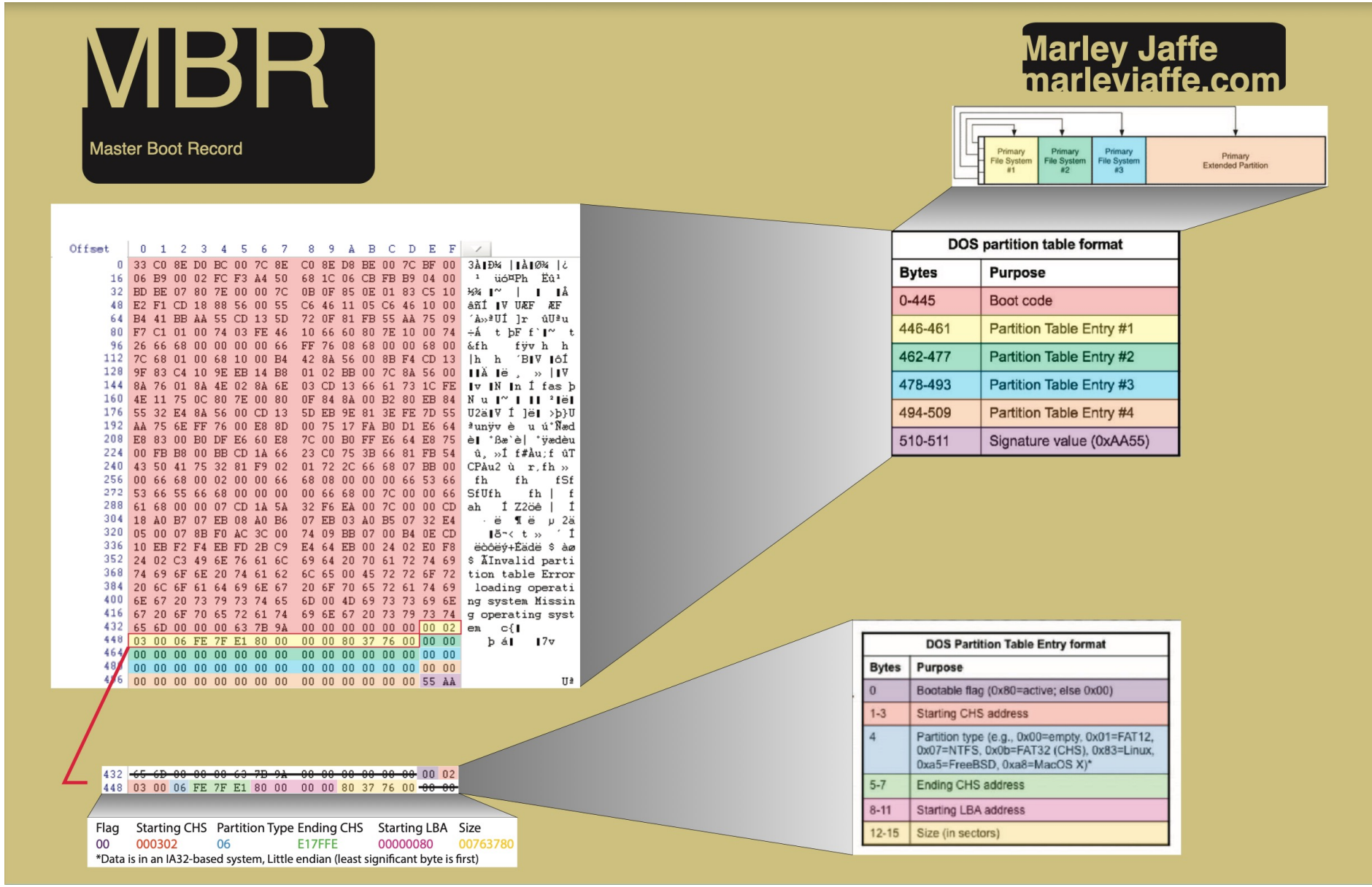
Harddrive Filesystem Layout

- We can do raw reads and writes to disks through /dev/
- But are usually much more organized so we can manage the data



Partitions: Master Boot Record

- An older standard for organizing disk storage (sometimes called the MSDOS partition scheme).
- The MBR tells boot loaders where to find things like the operating system.
- You can have multiple operating systems on different partitions.
- Partitions might also be used to separate data.
- In homework 1 you created separate partitions for /boot and /home
- This is often done to make sure that even if users fill up their partition that doesn't affect vital areas the OS want's to use. Like /boot.



Partitions: Master Boot Record

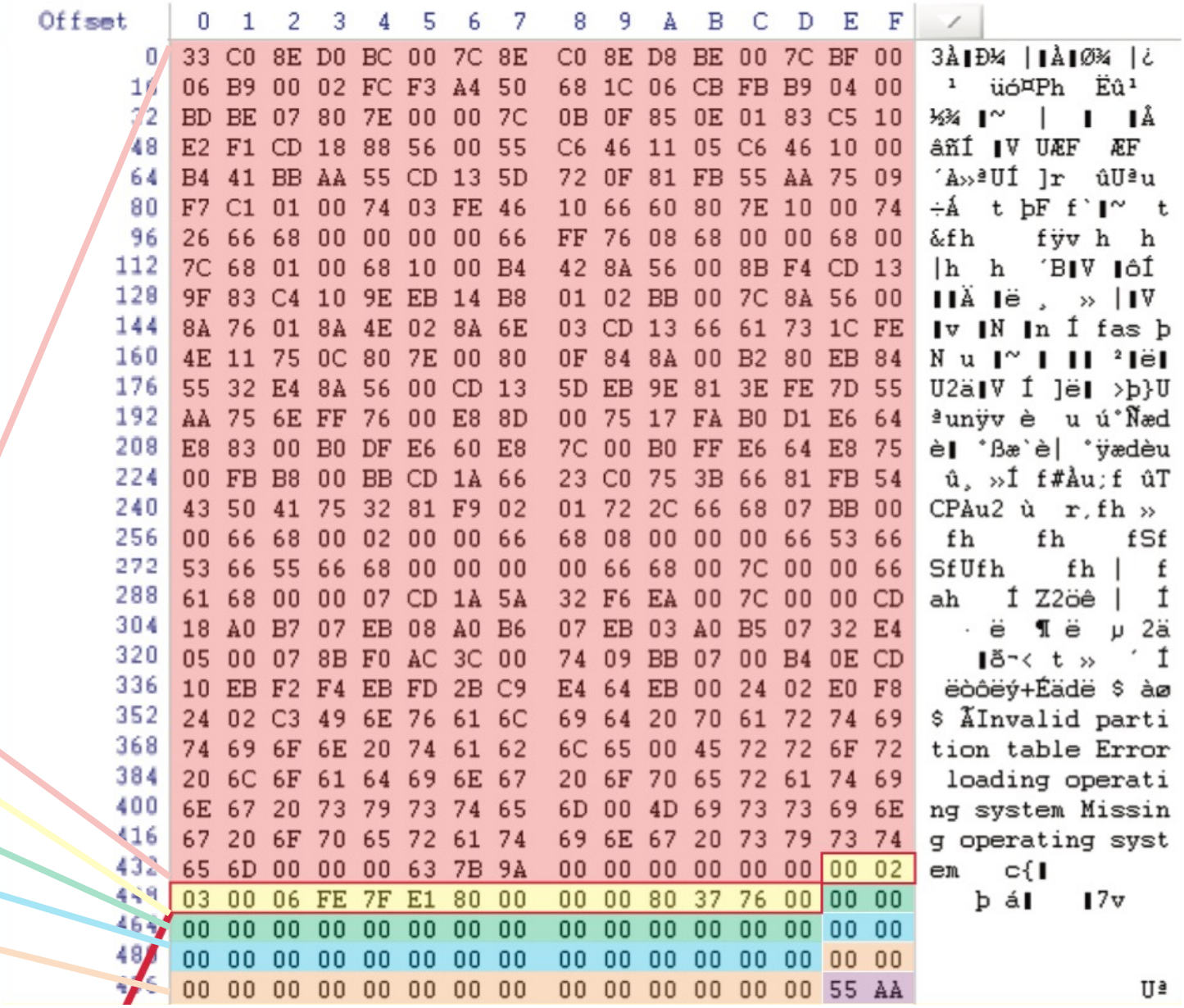
- This is a hexadecimal representation of the binary data at the start of am MBR partitioned disk.
- Useful because characters become readable.
- You can display this data with

```
Log into your Roadrunner cluster
sudo dd if=/dev/sda bs=1 count=1024 | hexdump -C
```

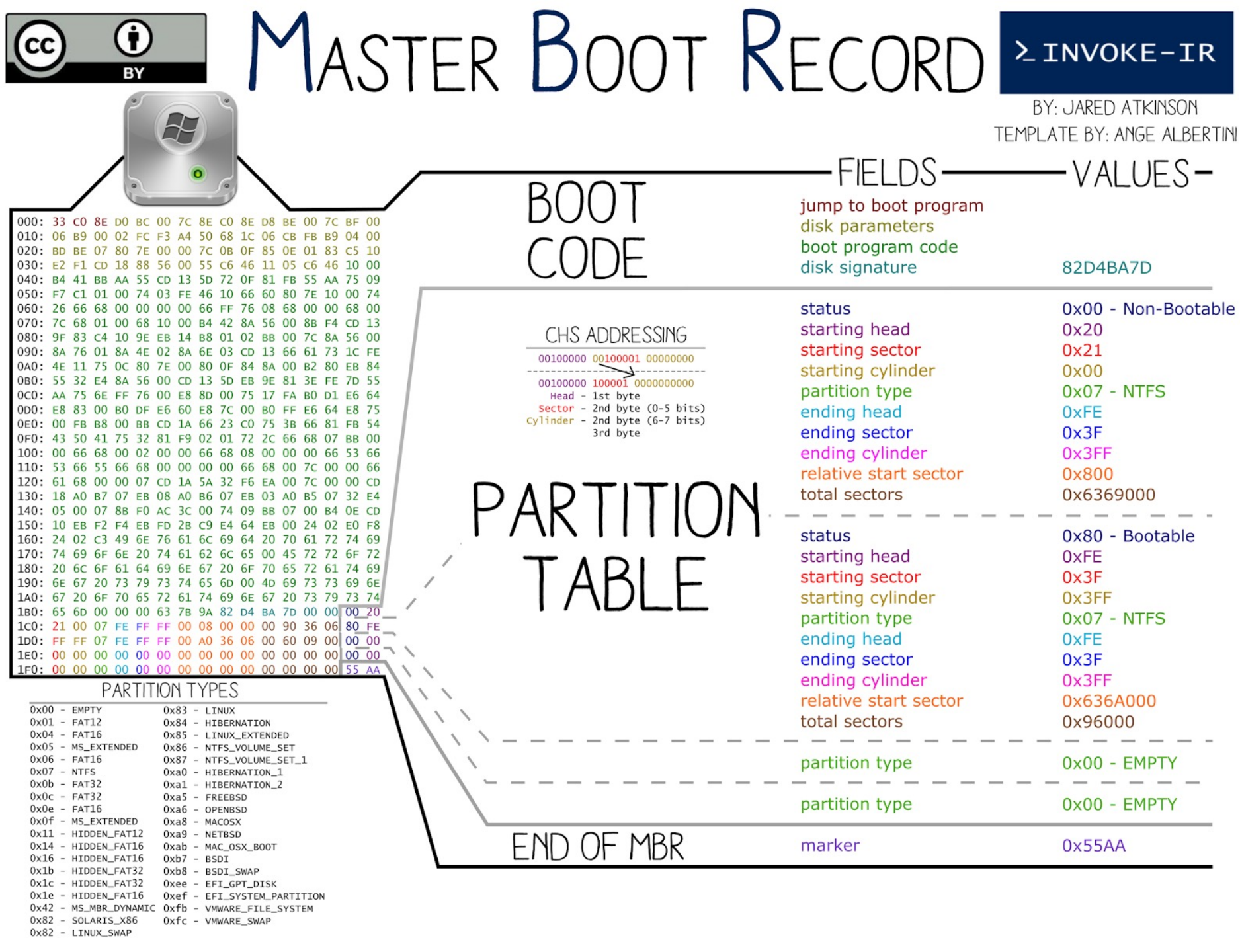
DOS partition table format

Bytes	Purpose
0-445	Boot code
446-461	Partition Table Entry #1
462-477	Partition Table Entry #2
478-493	Partition Table Entry #3
494-509	Partition Table Entry #4
510-511	Signature value (0xAA55)

Also known as the magic number



Only 445 bytes available to contain the boot program (!)



How the Master Boot Code Works

1. System startup self-check - BIOS checks the system hardware and CMOS Settings.
2. Read the master boot record - detect bootable devices, BIOS reads the MBR sector into memory.
3. Check whether the end flag of the MBR is 0000:7C00H equals 55AAH. When the boot device meets the requirements, the BIOS transfers control to the MBR to start the operating system.

The master boot code uses what's called CHS fields (Starting and Ending Cylinder, Head, and Sector fields) from the partition table to locate the boot sector portion of the partition.

The MBR can refer to partitions on other drives.

You can create a single partition on a drive and use it without an MBR.

FreeBSD: Bootstrap Source Code:
https://svnweb.freebsd.org/base/stable/8/sys/boot/i386/boot0/boot0.S?revision=196045&view=markup

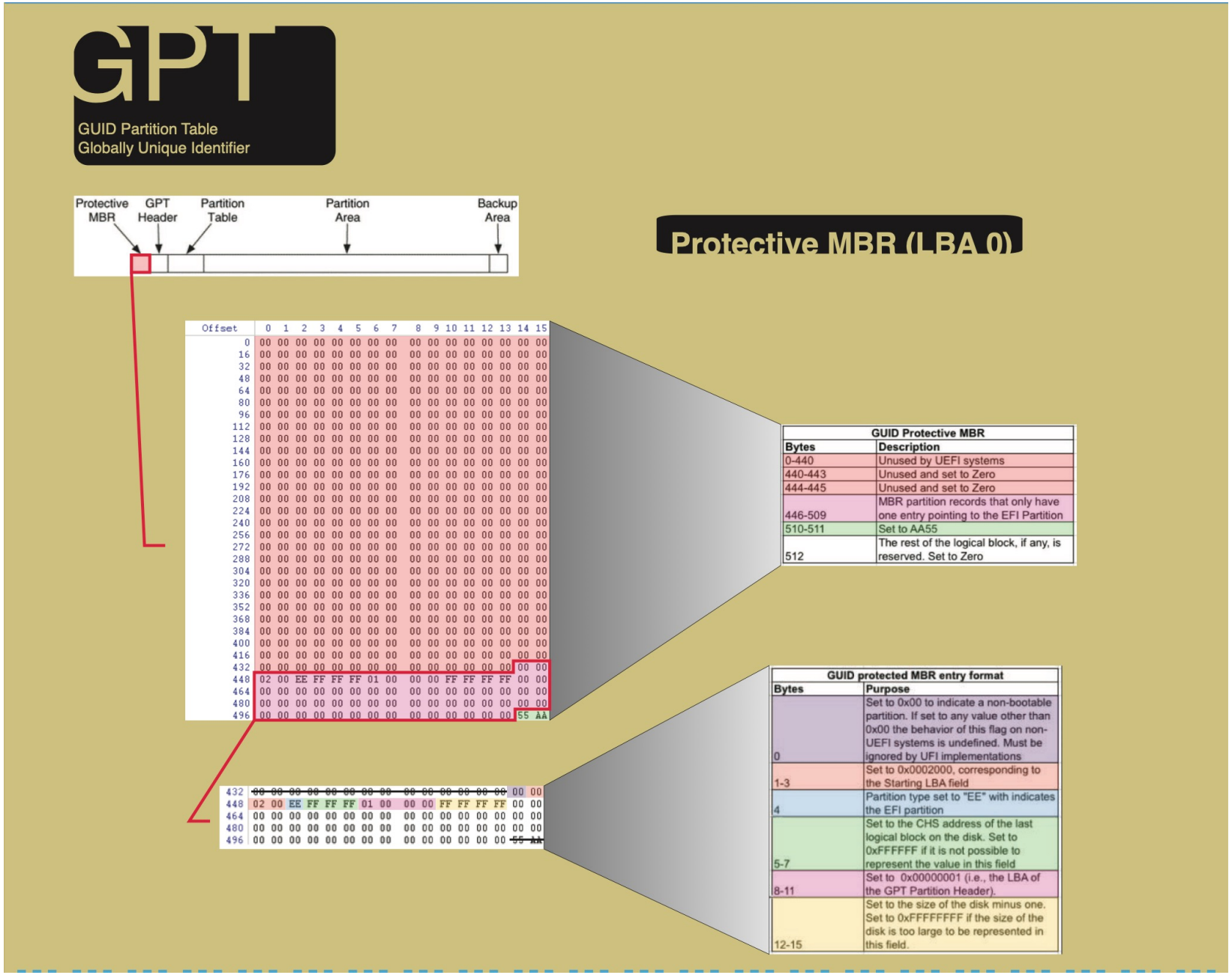
```
/*
 * BOOT BLOCK STRUCTURE
 *
 * This code implements a Master Boot Record (MBR) for an Intel/PC disk.
 * It is 512 bytes long and it is normally loaded by the BIOS (or another
 * bootloader) at 0:0x7c00. This code depends on %cs:%ip being 0:0x7c00
 *
 * The initial chunk of instructions is used as a signature by external
 * tools (e.g. boot0cfg) which can manipulate the block itself.
 *
 * The area at offset 0x1b2 contains a magic string ('Drive '), also
 * used as a signature to detect the block, and some variables that can
 * be updated by boot0cfg (and optionally written back to the disk).
 * These variables control the operation of the bootloader itself,
 * e.g. which partitions to enable, the timeout, the use of LBA
 * (called 'packet') or CHS mode, whether to force a drive number,
 * and whether to write back the user's selection back to disk.
 *
 * As in every Master Boot Record, the partition table is at 0x1be,
 * made of four 16-byte entries each containing:
 *
 *   OFF SIZE DESCRIPTION
 *    0   1 status (0x80: bootable, 0: non bootable)
 *    1   3 start sector CHS
 *   8:head, 6:sector, 2:cyl bit 9..8, 8:cyl bit 7..0
 *    4   1 partition type
 *    5   3 end sector CHS
 *    8   4 LBA of first sector
 *   12   4 partition size in sectors
 *
 * and followed by the two bytes 0x55, 0xAA (MBR signature).
 */
```

Bootstrap Loader Snippet

```
*
 * CONSTANTS
 *
 * NHRDRV is the address in segment 0 where the BIOS writes the
 * total number of hard disks in the system.
 * LOAD is the original load address and cannot be changed.
 * ORIGIN is the relocation address. If you change it, you also nee
 * to change the value passed to the linker in the Makefile
 * PRT_OFF is the location of the partition table (from the MBR
standard).
 * B0_OFF is the location of the data area, known to boot0cfg so
 * it cannot be changed. Computed as a negative offset from 0x200
 * MAGIC is the signature of a boot block.
 */


.set NHRDRV,0x475 # Number of hard drives
.set ORIGIN,0x600 # Execution address
.set LOAD,0x7c00 # Load address


.set PRT_OFF,0x1be # Partition table
.set B0_OFF,(B0_BASE-0x200) # Offset of boot0 data


.set MAGIC,0xaa55 # Magic: bootable


.set KEY_ENTER,0x1c # Enter key scan code
.set KEY_F1,0x3b # F1 key scan code
.set KEY_1,0x02 # #1 key scan code


.set ASCII_BEL,'#' # ASCII code for <BEL>
.set ASCII_CR,0x0D # ASCII code for <CR>/
```

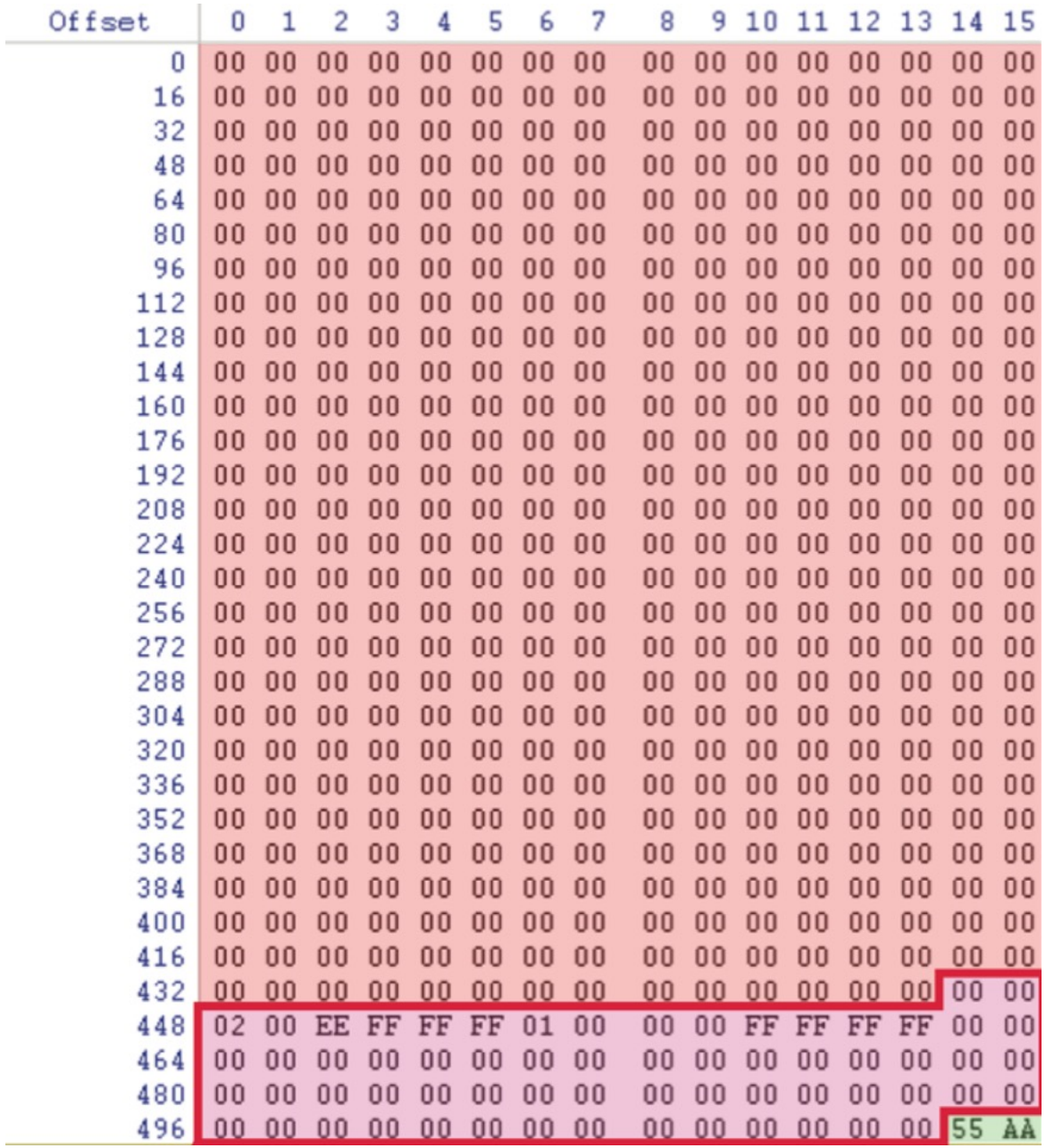
GUID Partition Table (GPT)
Global Unique ID (GUID)

- Newer
- MBR Supports 4 primary partitions (+ extended partition area)
- GPT supports 128 partitions.
- Requires Unified Extensible Firmware Interface (UEFI).



GUID Protective MBR

Bytes	Description
0-440	Unused by UEFI systems
440-443	Unused and set to Zero
444-445	Unused and set to Zero
446-509	MBR partition records that only have one entry pointing to the EFI Partition
510-511	Set to AA55
512	The rest of the logical block, if any, is reserved. Set to Zero



Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
16	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
32	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
48	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
64	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
80	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
96	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
112	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
128	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
144	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
160	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
176	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
192	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
208	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
224	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
240	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
256	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
272	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
288	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
304	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
320	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
336	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
352	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
368	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
384	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
400	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
416	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
432	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
448	02	00	EE	FF	FF	FF	01	00	00	00	FF	FF	FF	FF	00	00
464	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
480	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
496	00	00	00	00	00	00	00	00	00	00	00	00	00	00	55	AA

GUID Protective MBR	
Bytes	**Description**
0-440	Unused by UEFI systems
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510-511	Set to AA55
512	The rest of the logical block, if any, is reserved. Set to Zero

GUID protected MBR entry format	
Bytes	**Purpose**
0	Set to 0x00 to indicate a non-bootable partition. If set to any value other than 0x00 the behavior of this flag on non-UEFI systems is undefined. Must be ignored by UFI implementations
1-3	Set to 0x0002000, corresponding to the Starting LBA field
4	Partition type set to "EE" with indicates the EFI partition
5-7	Set to the CHS address of the last logical block on the disk. Set to 0xFFFFFF if it is not possible to represent the value in this field
8-11	Set to 0x00000001 (i.e., the LBA of the GPT Partition Header).
12-15	Set to the size of the disk minus one. Set to 0xFFFFFFFF if the size of the disk is too large to be represented in this field.

Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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32	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
48	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
64	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
80	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
96	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
112	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
128	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
144	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
160	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
176	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
192	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
208	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
224	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
240	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
256	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
272	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
288	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
304	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
320	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
336	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
352	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
368	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
384	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
400	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
416	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
432	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
448	02	00	EE	FF	FF	FF	01	00	00	00	FF	FF	FF	FF	00	00
464	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
480	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
496	00	00	00	00	00	00	00	00	00	00	00	00	00	00	55	AA

GUID Protective MBR

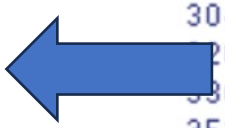
Bytes	Description
0-440	Unused by UEFI systems
440-443	Unused and set to Zero
444-445	Unused and set to Zero
446-509	MBR partition records that only have one entry pointing to the EFI Partition
510-511	Set to AA55
512	The rest of the logical block, if any, is reserved. Set to Zero

GUID protected MBR entry format

Bytes	Purpose
0	Set to 0x00 to indicate a non-bootable partition. If set to any value other than 0x00 the behavior of this flag on non-UEFI systems is undefined. Must be ignored by UFI implementations
1-3	Set to 0x0002000, corresponding to the Starting LBA field
4	Partition type set to "EE" with indicates the EFI partition
5-7	Set to the CHS address of the last logical block on the disk. Set to 0xFFFFFF if it is not possible to represent the value in this field
8-11	Set to 0x00000001 (i.e., the LBA of the GPT Partition Header).
12-15	Set to the size of the disk minus one. Set to 0xFFFFFFFF if the size of the disk is too large to be represented in this field.

Here the bootstrap loader gets a whole partition (no more 512 bytes)

EFI partition is typically 100-500 MB



Offset	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
16	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
32	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
48	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
64	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
80	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
96	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
112	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
128	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
144	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
160	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
176	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
192	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
208	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
224	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
240	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
256	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
272	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
288	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
304	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
[illegible]	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
[illegible]	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
352	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
368	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
384	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
400	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
416	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
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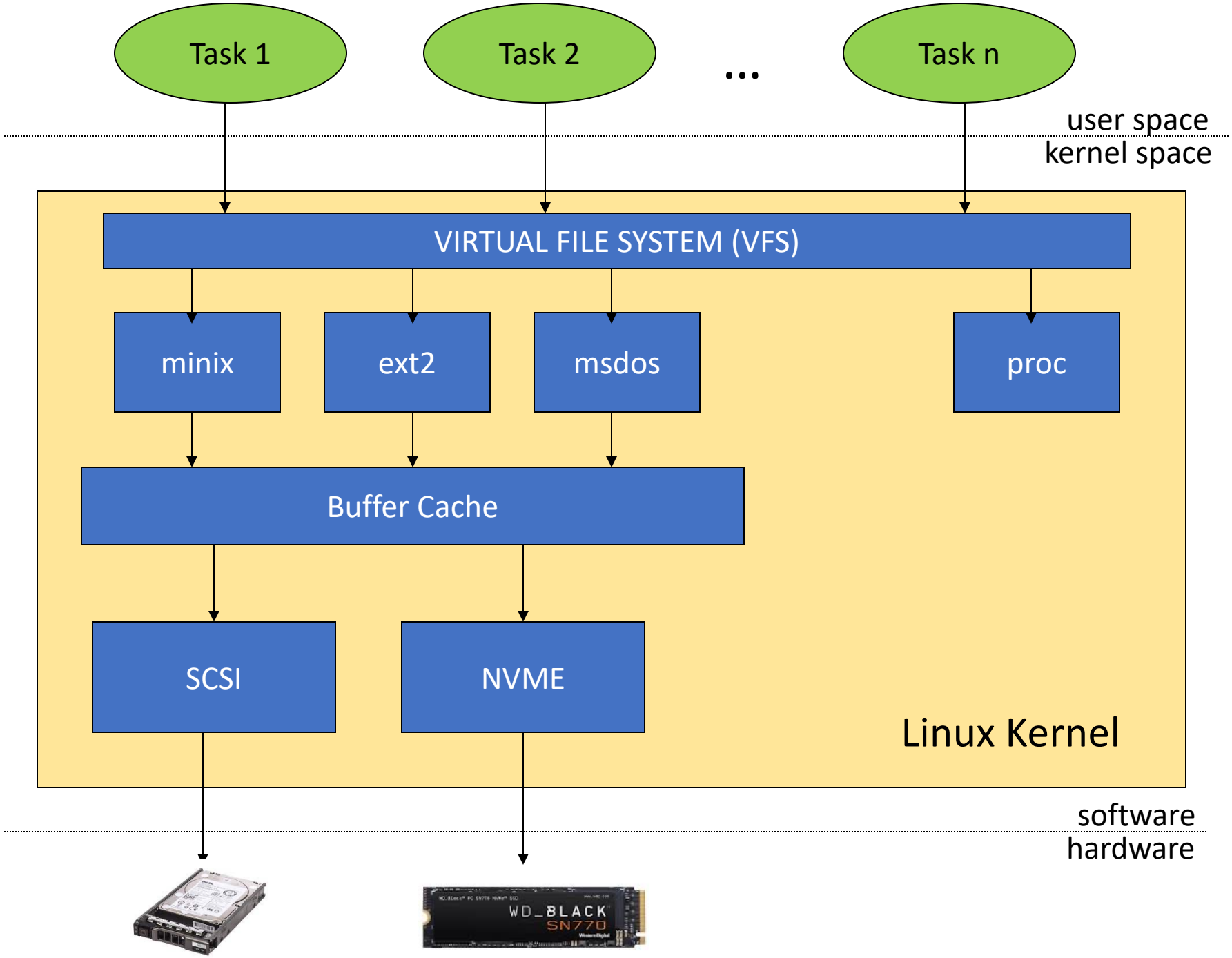
448	02	00	EE	FF	FF	FF	01	00	00	00	FF	FF	FF	FF	00	00
464	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
480	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
496	00	00	00	00	00	00	00	00	00	00	00	00	00	00	55	AA

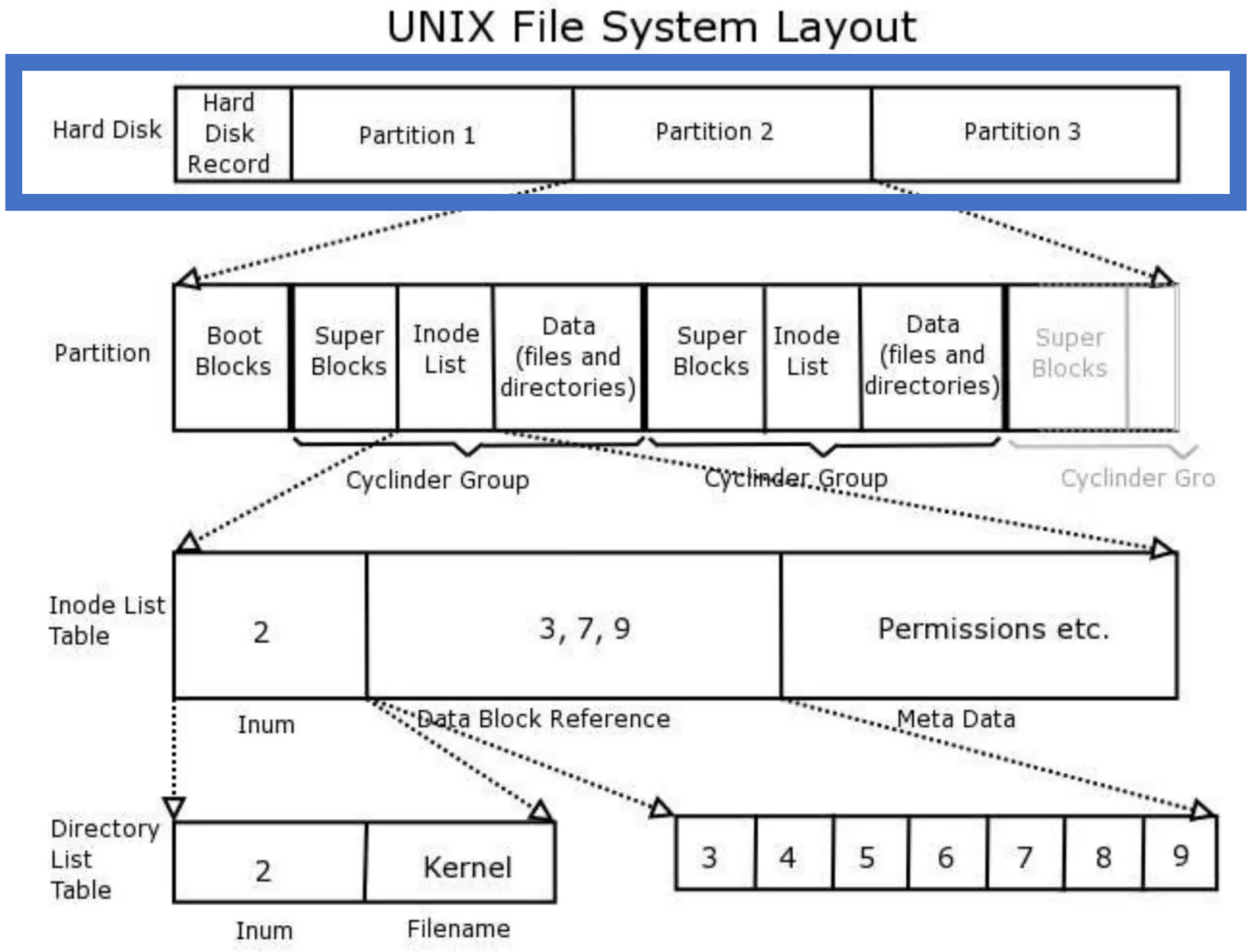
```
sudo dd if=/dev/sda bs=1 count=1024 | hexdump -C

00000000  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
*
000001c0  02 00 ee ff ff ff 01 00  00 00 ff 87 df e8 00 00  |................|
000001d0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
*
000001f0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 55 aa  |..............U.|
00000200  45 46 49 20 50 41 52 54  00 00 01 00 5c 00 00 00  |EFI PART....\...|
00000210  3b 51 e7 56 00 00 00 00  01 00 00 00 00 00 00 00  |;Q.V............|
00000220  ff 87 df e8 00 00 00 00  22 00 00 00 00 00 00 00  |........".......|
00000230  de 87 df e8 00 00 00 00  d0 cc 71 f7 27 f4 7c 44  |..........q.'.|D|
00000240  91 6c 14 53 7c 7c 43 2b  02 00 00 00 00 00 00 00  |.l.S||C+........|
00000250  80 00 00 00 80 00 00 00  a2 63 be d1 00 00 00 00  |.........c......|
00000260  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
*
1024+0 records in
1024+0 records out
1024 bytes (1.0 kB, 1.0 KiB) copied, 0.00254417 s, 402 kB/s
00000400
```

Is this a GPT or MBR partition layout?


Task 1
Task 2
...
Task n
user space
kernel space
VIRTUAL FILE SYSTEM (VFS)
minix
ext2
msdos
proc
Buffer Cache
SCSI
NVME
Linux Kernel
software
hardware
WD_BLACK
SN770

Partitions

- We can do raw reads and writes to disks through /dev/
- But are usually much more organized so we can manage the data



Generalised Linux Filesystem

- The superblock contains all of the information about how the file system is configured, such as block size, block address range, and mount status.
- The i-nodes contain the file attributes and a map indicating where the blocks of the file are located on the disk. They are of 128 bytes.
- The data blocks are where file contents are stored.
- i-node in position 2 of the table usually points to the entry for the root directory file in the file system.

File Systems

- In general file systems are simple
  - Abstraction for secondary storage
    - Files
  - Logical organization of files
    - Directories
  - Sharing of data between users/processes
    - Permissions/ACLs

UNIX File System

- Implemented as part of original UNIX system
  - Ritchie and Thompson, Bell Labs, 1969
- Designed for workgroup scenario
  - Multiple users sharing a single system
- Still forms the basis of all UNIX based file systems

5 parts of a UNIX Disk

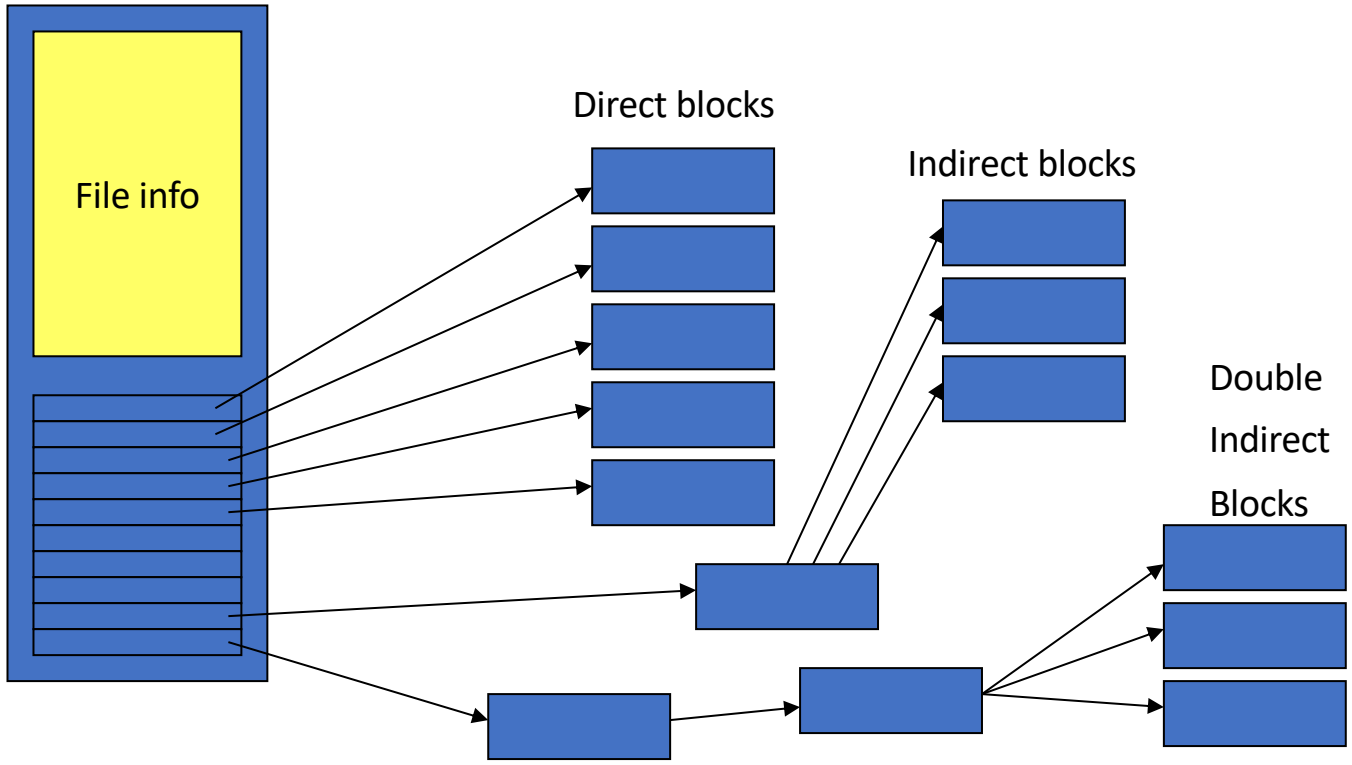
- Boot Block
  - Contains boot loader
- Superblock
  - The file systems “header”
  - Specifies location of file system data structures
- inode area
  - Contains descriptors (inodes) for each file on the disk
  - All inodes are the same size
  - Head of the inode free list is stored in superblock
- File contents area
  - Fixed size blocks containing data
  - Head of freelist stored in superblock
- Swap area
  - Part of disk given to virtual memory system

Unix directory files

- A directory is a flat file of fixed size entries
- Each entry consists of an inode # and a file name

i-node number	File name
152	.
18	..
216	my_file
4	another_file
93	oh_my_god
144	a_directory

inode



Contiguous Allocation

- Allocate each file to contiguous blocks on disk
  - Meta-data includes first block and size of file
  - OS allocates single chunk of free space

- Advantages
  - Low overhead for meta-data
  - Excellent sequential performance
  - Simple to calculate random addresses
- Disadvantages
  - Horrible external fragmentation (requires compaction)
  - Usually must move entire file to resize it

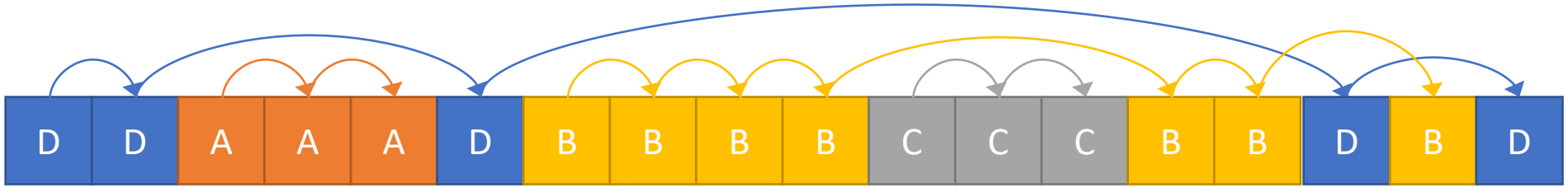
Extent Based Allocation

- Allocate multiple contiguous regions (extents)
  - Meta-data: Small array of extents (first block + size)

- Improves contiguous allocation
  - File can grow over time
  - External fragmentation reduced
- Advantages
  - Limited overhead for meta-data
  - Good performance with sequential accesses
  - Simple to calculate random addresses
- Disadvantages
  - External fragmentation can still be a problem
  - Extents can be exhausted (fixed size array in meta-data)

Linked Allocation

- Allocate linked-list of fixed size blocks
  - Meta-data: location of file's first block
  - Each block stores pointer to next block



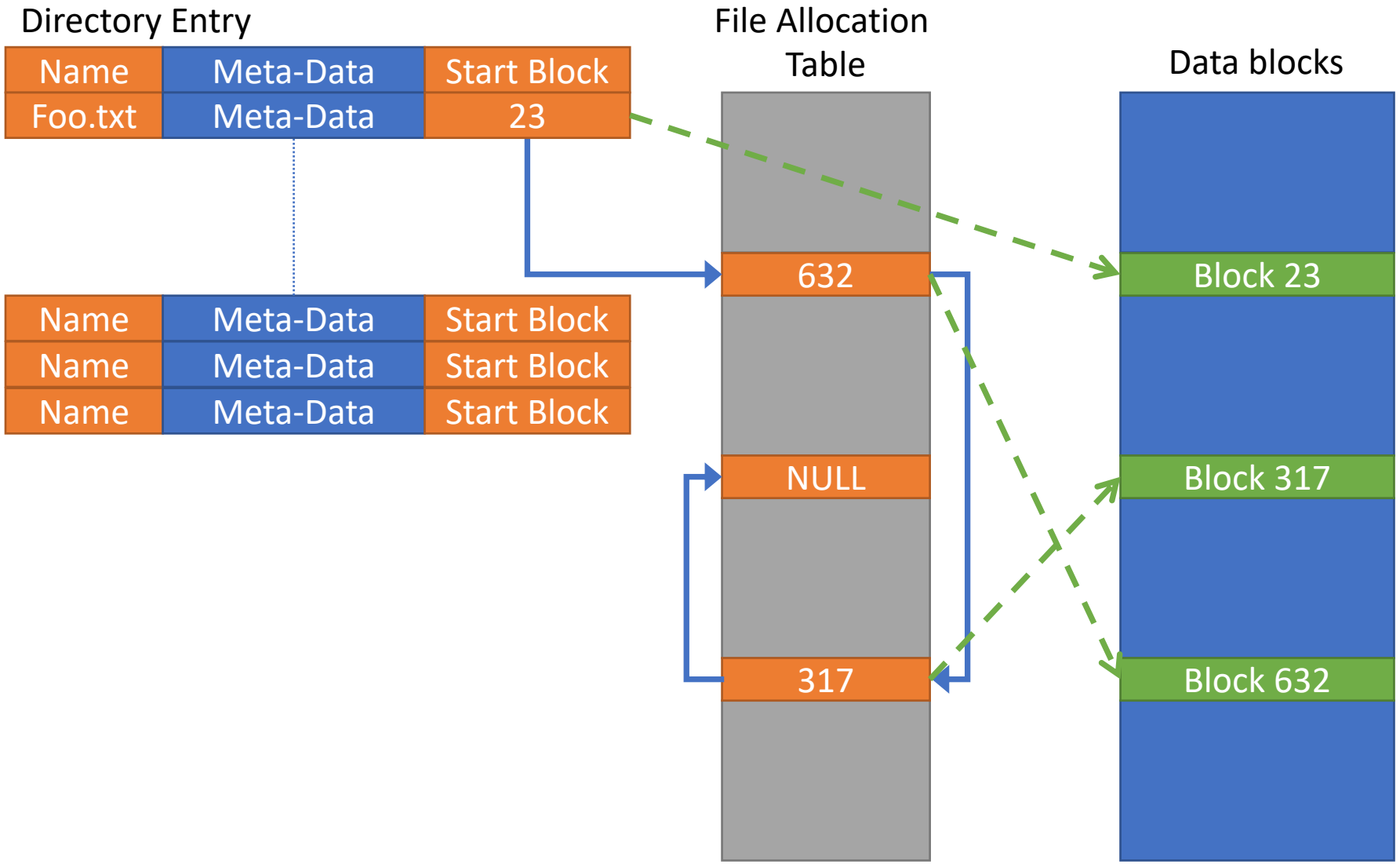
- Advantages
  - No External fragmentation
  - File size can be very dynamic
- Disadvantages
  - Random access takes a long time
  - Sequential accesses can be slow
    - Can try to allocate contiguously to avoid this
  - Very sensitive to corruption

File Allocation Table (FAT)

- Variation of Linked Allocation
  - Linked list information stored in FAT table (on disk)
  - Meta-data: Location of first block of file

- Comparison to Linked Allocation
  - Same basic advantages and disadvantages
  - Additional disadvantage:
    - Two disk reads for 1 data block
  - Optimization: Cache FAT table in memory

File-Allocation Table



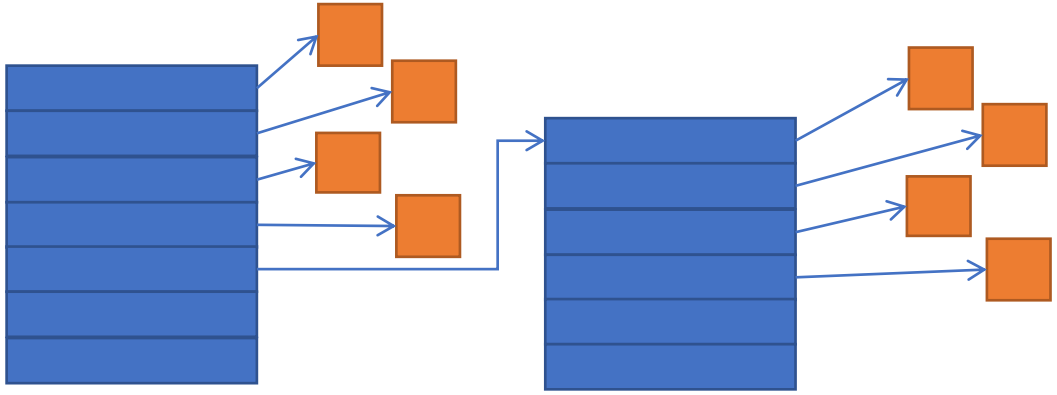
Indexed Allocation

- Allocate fixed-size blocks for each file
  - Meta-data: Fixed size array of block pointers
    - Array allocated at file creation time

- Advantages
  - No external fragmentation
  - Files can be easily grown, with no limit
  - Supports random access
- Disadvantages
  - Large overhead for meta-data
    - Unneeded pointers are still allocated

Multi-level Index Files

- Variation of Indexed Allocation
  - Dynamically allocate hierarchy of pointers to blocks as needed
  - Meta-data: Small number of pointers allocated statically
    - Allocate blocks of pointers as needed



- Comparison to Indexed Allocation
  - Advantage: Less wasted space
  - Disadvantage: Random reads require multiple disk reads

Free Space Management

- How do you remember which blocks are free
  - Operations: Free block, allocate block
- Free List: Linked list of free blocks
  - Advantages: Simple, constant time operations
  - Disadvantage: Quickly loses locality
- Bitmap: Bitmap of all blocks indicating which are free
  - Advantages: Can find sequence of consecutive blocks
  - Disadvantage: Space overhead

So…

- With a boot block you can boot a machine
  - Stores code for boot loader
- With a superblock you can access a file system
  - Superblock always kept at a fixed location
  - Specifies where you can find FS state information
    - By convention root directory (‘/’) is stored in second inode
  - Most current boot loaders read superblock to find kernel image

Inode format

- User and group IDs
- Protection bits
- Access times
- File Type
  - Directory, normal file, symbolic link, etc
- Size
  - Length in bytes
- Block list
  - Location of data blocks in file contents area
- Link Count
  - Number of directories (hard links) referencing this inode

Unix Inodes and Path Search

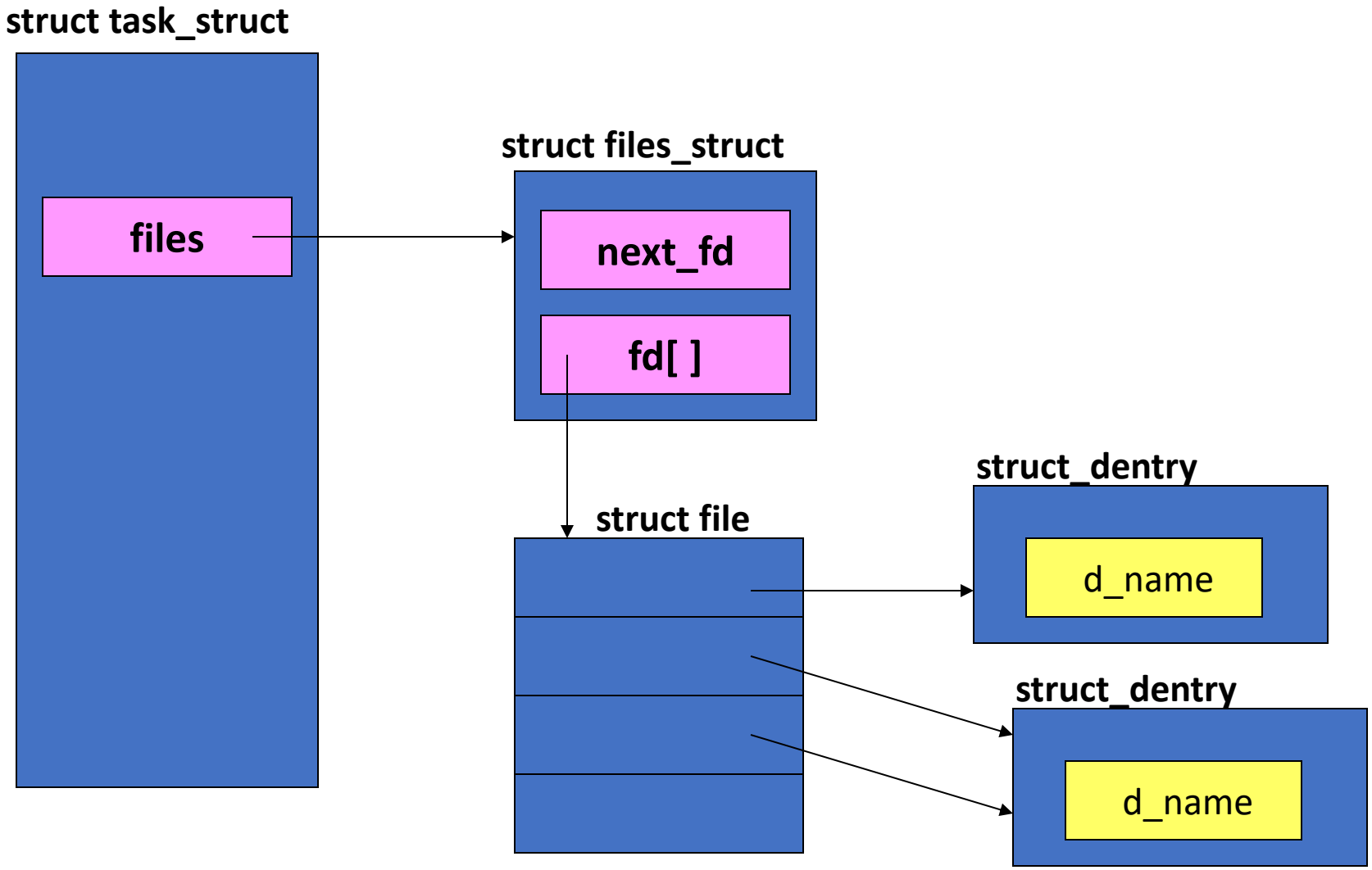
- Unix Inodes are not directories
  - Inodes describe where on disk a file's blocks are stored
  - Directories are files
    - Inodes describe where a directory's blocks are stored
- Directory entries map file names to inodes
  - To open "/foo", use Master Block to find inode for "/"
    - Open "/", search for entry "foo"
    - This entry specifies block number for inode of "foo"
  - Read "foo"'s inode into memory
    - Get first data block location from inode
    - Read block into memory

```
[matthew@moonshine ~]$ df -i
 matthew@moonshine dev]$ df -i
Filesystem                      Inodes  IUsed      IFree IUse% Mounted on
devtmpfs                       8157993    909    8157084    1% /dev
tmpfs                          8163114      1    8163113    1% /dev/shm
tmpfs                           819200   1138     818062    1% /run
/dev/mapper/rl_dhcp52-root    36700160 153255   36546905    1% /
/dev/mapper/rl_dhcp52-home   434087936    774  434087162    1% /home
/dev/sda2                       524288     30     524258    1% /boot
/dev/sda1                            0      0          0     - /boot/efi
tmpfs                          1632622     21    1632601    1% /run/user/1000
```

Inodes are a limited resource. End users usually know that the amount of storage space is limited, but the number of inodes available is just as important.

Inodes in the table above gives the total number of available inodes. Iused is how many have been used so far. If we run out no more files or directories can be created.

Each task opens its own files



Naming files

- Important to be able to *find* files after they're created
- Every file has at least one name
- Name can be
  - Human-accessible: "foo.c", "my photo", "Go Panthers!", "Go Banana Slugs!"
  - Machine-usable: 4502, 33481
- Case may or may not matter
  - Depends on the file system
- Name may include information about the file's contents
  - Certainly does for the user (the name should make it easy to figure out what's in it!)
  - Computer may use part of the name to determine the file type

```
Last login: Fri Feb  2 10:31:15 on ttys000
matthew@dhcp178 ~ % ssh matthew@129.24.245.16
matthew@129.24.245.16's password:
Last login: Mon Jan 29 10:11:40 2024 from
129.24.246.178
[matthew@moonshine ~]$
```

```
[matthew@moonshine ~]$ sudo parted -l
Model: DELL PERC H310 (scsi)
Disk /dev/sda: 1000GB
Sector size (logical/physical): 512B/512B
Partition Table: gpt
Disk Flags:


Number  Start   End     Size    File system  Name                  Flags
 1      1049kB  630MB   629MB   fat32        EFI System Partition  boot, esp
 2      630MB   1704MB  1074MB  xfs
 3      1704MB  1000GB  998GB                                      lvm


Model:  USB DISK 3.0 (scsi)
Disk /dev/sdb: 15.5GB
Sector size (logical/physical): 512B/512B
Partition Table: msdos
Disk Flags:

Number  Start  End     Size    Type     File system  Flags
 2      340kB  7604kB  7264kB  primary               esp
```

```
Last login: Fri Feb  2 10:31:21 on ttys001
matthew@dhcp178 ~ % ssh matthew@129.24.245.16
matthew@129.24.245.16's password:
Last login: Fri Feb  2 11:31:49 2024 from 129.24.246.178
[matthew@moonshine ~]$
```

Open another terminal to your server

```
[matthew@moonshine ~]$ sudo udevadm monitor --kernel
[sudo] password for matthew:
monitor will print the received events for:
KERNEL - the kernel uevent
```

```
[matthew@moonshine ~]$ lsblk
[matthew@moonshine ~]$ sudo umount /dev/sdb
```

```
[matthew@moonshine ~]$ cat /etc/fstab

/dev/mapper/rl_dhcp52-root /                       xfs     defaults        0 0
UUID=a447244c-dab4-41a2-b908-8a931134c113
/boot                   xfs     defaults        0 0
UUID=A57E-CA77          /boot/efi           vfat    umask=0077,shortname=winnt 0 2
/dev/mapper/rl_dhcp52-home /home                       xfs     defaults        0 0
/dev/mapper/rl_dhcp52-swap none                       swap    defaults        0 0
```

If your system runs out of memory (RAM) then the least recently used data is moved to the swap space on the HDD.

This keeps you from crashing – but reading and writing data from disk is about 1/100th the speed of RAM.

So, if lots of data gets moved to disk the system becomes so slow it is unusable. This is called disk thrashing.

Amount of RAM in the system	Recommended swap space	Recommended swap space if allowing for hibernation
⩽ 2 GB	2 times the amount of RAM	3 times the amount of RAM
> 2 GB – 8 GB	Equal to the amount of RAM	2 times the amount of RAM
> 8 GB – 64 GB	At least 4 GB	1.5 times the amount of RAM
> 64 GB	At least 4 GB	Hibernation not recommended

```
[matthew@moonshine ~]$ sudo fdisk /dev/sdb
[sudo] password for matthew:


Welcome to fdisk (util-linux 2.37.4).
Changes will remain in memory only, until you decide to write
them.
Be careful before using the write command.


The device contains 'iso9660' signature and it will be
removed by a write command. See fdisk(8) man page and --wipe
option for more details.
```

```
Command (m for help): p


Disk /dev/sdb: 14.46 GiB, 15525216256 bytes, 30322688 sectors
Disk model: USB DISK 3.0
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x73b44ec8


Device     Boot Start     End Sectors  Size Id Type
/dev/sdb1  *        0 3293407 3293408  1.6G  0 Empty
/dev/sdb2         664   14851   14188  6.9M ef EFI (FAT-
12/16/32)
```

Why do you think is says DOS and EFI?

```
Command (m for help): q
```

Why do you think is says DOS and EFI?

```
[matthew@moonshine ~]$ sudo dd if=/dev/sdb
of=Rocky9.1_minimal.iso bs=4M status=progress

15509602816 bytes (16 GB, 14 GiB) copied, 415 s, 37.4 MB/s
30322688+0 records in
30322688+0 records out
15525216256 bytes (16 GB, 14 GiB) copied, 416.363 s, 37.3 MB/s
```

```
[matthew@moonshine ~]$ lsblk
NAME                  MAJ:MIN RM   SIZE RO TYPE
MOUNTPOINTS
sda                     8:0    0   931G  0 disk
├─sda1                  8:1    0   600M  0 part /boot/efi
├─sda2                  8:2    0     1G  0 part /boot
└─sda3                  8:3    0 929.4G  0 part
  ├─rl_dhcp52-root    253:0    0    70G  0 lvm  /
  ├─rl_dhcp52-swap    253:1    0  31.5G  0 lvm  [SWAP]
  └─rl_dhcp52-home    253:2    0   828G  0 lvm  /home
sdb                     8:16   1  14.5G  0 disk
├─sdb1                  8:17   1   1.6G  0 part
└─sdb2                  8:18   1   6.9M  0 part
sr0                    11:0    1  1024M  0 rom
```

```
[matthew@moonshine ~]$ sudo fdisk /dev/sdb
[sudo] password for matthew:


Welcome to fdisk (util-linux 2.37.4).
Changes will remain in memory only, until you decide to write
them.
Be careful before using the write command.


The device contains 'iso9660' signature and it will be removed
by a write command. See fdisk(8) man page and --wipe option for
more details.


Command (m for help):
```

```
[matthew@moonshine ~]$ sudo fdisk /dev/sdb
[sudo] password for matthew:


Welcome to fdisk (util-linux 2.37.4).
Changes will remain in memory only, until you decide to write
them.
Be careful before using the write comma


The device contains 'iso9660' sig                e removed
by a write command. See fdisk(8)                 option for
more details.


Command (m for help):
```

```
Command (m for help): p
Disk /dev/sdb: 14.46 GiB, 15525216256 bytes, 30322688 sectors
Disk model: USB DISK 3.0
Geometry: 255 heads, 63 sectors/track, 14806 cylinders
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x73b44ec8


Device     Boot Start     End Sectors  Size Id Type
/dev/sdb1  *        0 3293407 3293408  1.6G  0 Empty
/dev/sdb2         664   14851   14188  6.9M ef EFI (FAT-
12/16/32)

Command (m for help):
```

```
The device contains 'iso9660' signature and it will be removed
by a write command. See fdisk(8) man page and --wipe option for
more details.


Command (m for help): d
Partition number (1,2, default 2): 1


Partition 1 has been deleted.
```

```
Command (m for help): p

Disk /dev/sdb: 14.46 GiB, 15525216256 bytes, 30322688 sectors
Disk model: USB DISK 3.0
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x73b44ec8
```

The partition table is gone so no partitions are displayed.

But Fdisk doesn’t actually ask the kernel to make changes until after you hit w to write the changes.

```
Command (m for help): w

The partition table has been altered.
Calling ioctl() to re-read partition table.
Syncing disks.
```

The partition table is gone so no partitions are displayed.

But Fdisk doesn’t actually ask the kernel to make changes until after you hit w to write the changes.

When you use the “w” command fdisk makes function calls to the kernel and the kernel makes the changes to the USB drive

```
KERNEL[1122527.084021] remove   /devices/pci0000:00/0000:00:1d.0/usb2/2-1/2-
1.2/2-1.2:1.0/host0/target0:0:0/0:0:0:0/block/sdb/sdb1 (block)

KERNEL[1122527.084060] remove   /devices/pci0000:00/0000:00:1d.0/usb2/2-1/2-
1.2/2-1.2:1.0/host0/target0:0:0/0:0:0:0/block/sdb/sdb2 (block)

KERNEL[1122527.086394] change   /devices/pci0000:00/0000:00:1d.0/usb2/2-1/2-
1.2/2-1.2:1.0/host0/target0:0:0/0:0:0:0/block/sdb (block)

KERNEL[1122527.093141] change   /devices/pci0000:00/0000:00:1d.0/usb2/2-1/2-
1.2/2-1.2:1.0/host0/target0:0:0/0:0:0:0/block/sdb (block)

KERNEL[1122527.094259] change   /devices/pci0000:00/0000:00:1d.0/usb2/2-1/2-
1.2/2-1.2:1.0/host0/target0:0:0/0:0:0:0/block/sdb (block)
```

```
Command (m for help): w

The partition table has been altered.
Calling ioctl() to re-read partition table.
Syncing disks.
```

The partition table is gone so no partitions are displayed.

But Fdisk doesn’t actually ask the kernel to make changes until after you hit w to write the changes.

```
[matthew@moonshine ~]$ sudo fdisk /dev/sdb

Command (m for help): p
Disk /dev/sdb: 14.46 GiB, 15525216256 bytes, 30322688 sectors
Disk model: USB DISK 3.0
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x73b44ec8

Device     Boot Start   End Sectors  Size Id Type
/dev/sdb2          664 14851   14188  6.9M ef EFI (FAT-12/16/32)

Command (m for help): d
Selected partition 2
Partition 2 has been deleted.
Command (m for help): w
```

```
[matthew@moonshine ~]$ lsblk
NAME                  MAJ:MIN RM   SIZE RO TYPE MOUNTPOINTS
sda                     8:0    0   931G  0 disk
├─sda1                  8:1    0   600M  0 part /boot/efi
├─sda2                  8:2    0     1G  0 part /boot
└─sda3                  8:3    0 929.4G  0 part
  ├─rl_dhcp52-root    253:0    0    70G  0 lvm  /
  ├─rl_dhcp52-swap    253:1    0  31.5G  0 lvm  [SWAP]
  └─rl_dhcp52-home    253:2    0   828G  0 lvm  /home
sdb                     8:16   1  14.5G  0 disk
sr0                    11:0    1  1024M  0 rom
```

```
[matthew@localhost ~]$ sudo fdisk /dev/sdb
Welcome to fdisk (util-linux 2.37.4).
Changes will remain in memory only, until you decide to write
them.
Be careful before using the write command.
Command (m for help): n
Partition type
   p   primary (0 primary, 0 extended, 4 free)
   e   extended (container for logical partitions)
Select (default p): p
Partition number (1-4, default 1): 1
First sector (2048-30322687, default 2048):
Last sector, +/-sectors or +/-size{K,M,G,T,P} (2048-30322687,
default 30322687):
Created a new partition 1 of type 'Linux' and of size 14.5 GiB.
```

```
Command (m for help): w
The partition table has been altered.
Calling ioctl() to re-read partition table.
Syncing disks.
```

```
[matthew@localhost ~]$ lsblk
NAME                  MAJ:MIN RM   SIZE RO TYPE MOUNTPOINTS
sda                     8:0    0   931G  0 disk
├─sda1                  8:1    0   600M  0 part /boot/efi
├─sda2                  8:2    0     1G  0 part /boot
└─sda3                  8:3    0 929.4G  0 part
  ├─rl_dhcp52-root    253:0    0    70G  0 lvm  /
  ├─rl_dhcp52-swap    253:1    0  31.5G  0 lvm  [SWAP]
  └─rl_dhcp52-home    253:2    0   828G  0 lvm  /home
sdb                     8:16   1  14.5G  0 disk
└─sdb1                  8:17   1  14.5G  0 part
sr0                    11:0    1  1024M  0 rom
```

```
[matthew@moonshine ~]$ sudo mkfs.ext4 /dev/sdb1
mke2fs 1.46.5 (30-Dec-2021)
Creating filesystem with 3790080 4k blocks and 948416 inodes
Filesystem UUID: 6e7aaea1-7e15-41dd-8fd3-b9b5248e6636
Superblock backups stored on blocks:
32768, 98304, 163840, 229376, 294912, 819200, 884736, 1605632,
2654208


Allocating group tables: done
Writing inode tables: done
Creating journal (16384 blocks):
done
Writing superblocks and filesystem accounting information: done
```

```
[matthew@moonshine ~]$ sudo mkfs.xfs /dev/sdb1
[matthew@moonshine ~]$ sudo mkfs.xfs -f /dev/sdb1
meta-data=/dev/sdb1              isize=512    agcount=4, agsize=947520 blks
         =                       sectsz=512   attr=2, projid32bit=1
         =                       crc=1        finobt=1, sparse=1, rmapbt=0
         =                       reflink=1    bigtime=1 inobtcount=1
nrext64=0
data     =                       bsize=4096   blocks=3790080, imaxpct=25
         =                       sunit=0      swidth=0 blks
naming   =version 2              bsize=4096   ascii-ci=0, ftype=1
log      =internal log           bsize=4096   blocks=16384, version=2
         =                       sectsz=512   sunit=0 blks, lazy-count=1
realtime =none                   extsz=4096   blocks=0, rtextents=0
```

```
[matthew@moonshine ~]$ sudo mount /dev/sdb1 /mnt
[matthew@moonshine ~]$
```

Now we can mount the filesystem.

The mount command takes a block device (such as a partition) and an existing directory file.

/mnt exists for this purpose but you can put any directory as the argument.

```
matthew@moonshine mnt]$ sudo chown matthew: /mnt
[matthew@moonshine mnt]$ cd /mnt
[matthew@moonshine mnt]$ touch test.txt
[matthew@moonshine mnt]$ ls
test.txt
[matthew@moonshine mnt]$
```

By default only the root user can write to this external usb mount.

We use chmod to make matthew the owner and touch to create a new file.

Input/Output Monitoring is important for HPC

```
[matthew@moonshine ~]$ sudo yum install iotop
[sudo] password for matthew:
Last metadata expiration check: 0:25:53 ago on Mon 05 Feb 2024 10:37:13 AM CST.
Dependencies resolved.
================================================================================
 Package          Architecture          Version          Repository          Size
================================================================================
Installing:
 iotop             noarch               0.63-0.el9       baseos               62 k

Transaction Summary
================================================================================
Install  1 Package
```

Now let’s restore our ISO image to the USB drive:

```
[matthew@moonshine ~]$ sudo dd if=Rocky9.1_minimal.iso
of=/dev/sdb bs=4M status=progress
[sudo] password for matthew:
12494831616 bytes (12 GB, 12 GiB) copied, 126 s, 99.1 MB/
```

Input/Output Monitoring is important for HPC

```
[matthew@moonshine ~]$ sudo iotop
Total DISK READ : 0.00 B/s | Total DISK WRITE :       8.82 M/s
Actual DISK READ: 0.00 B/s | Actual DISK WRITE:      12.97 M/s
  TID  PRIO  USER     DISK READ  DISK WR     TID  PRIO  USER     DISK READ  DISK WRITE    COMMAND

 171200 be/4 root        0.00 B/s    8.82 M/s dd if=Rocky9.1_minimal.iso of=/dev/sdb bs=4M status=progress
      1 be/4 root        0.00 B/s    0.00 B/s systemd --switched-root --system --deserialize 31
      2 be/4 root        0.00 B/s    0.00 B/s [kthreadd]
      3 be/0 root        0.00 B/s    0.00 B/s [rcu_gp]
      4 be/0 root        0.00 B/s    0.00 B/s [rcu_par_gp]
      5 be/0 root        0.00 B/s    0.00 B/s [slub_flushwq]
      6 be/0 root        0.00 B/s    0.00 B/s [netns]
      8 be/0 root        0.00 B/s    0.00 B/s [kworker/0:0H-events_highpri]
     11 be/0 root        0.00 B/s    0.00 B/s [mm_percpu_wq]
     12 be/4 root        0.00 B/s    0.00 B/s [kworker/u64:1-mlx4]
     13 be/4 root        0.00 B/s    0.00 B/s [rcu_tasks_kthre]
     14 be/4 root        0.00 B/s    0.00 B/s [rcu_tasks_rude_]
     15 be/4 root        0.00 B/s    0.00 B/s [rcu_tasks_trace]
     16 be/4 root        0.00 B/s    0.00 B/s [ksoftirqd/0]
     17 be/4 root        0.00 B/s    0.00 B/s [pr/tty0]
     18 be/4 root        0.00 B/s    0.00 B/s [rcu_preempt]
     19 rt/4 root        0.00 B/s    0.00 B/s [migration/0]
     20 rt/4 root        0.00 B/s    0.00 B/s [idle_inject/0]
```

Now let’s restore our ISO image to the USB drive:

```
[matthew@moonshine ~]$ sudo dd if=Rocky9.1_minimal.iso
of=/dev/sdb bs=4M status=progress
[sudo] password for matthew:
12494831616 bytes (12 GB, 12 GiB) copied, 126 s, 315 MB/s
```

Notice that the write speed is faster than the read speed! Compare it to the write speed reported by iotop.

Does that make sense?

Now let’s restore our ISO image to the USB drive:

```
[matthew@moonshine ~]$ sudo dd if=Rocky9.1_minimal.iso
of=/dev/sdb bs=4M status=progress
[sudo] password for matthew:
12494831616 bytes (12 GB, 12 GiB) copied, 126 s, 315 MB/s
```

The write is actually going to RAM. The kernel will write to the USB disk when it gets around to it.
Dangerous if you unplug the USB now.

Now let’s restore our ISO image to the USB drive:

```
[matthew@moonshine ~]$ sudo dd if=Rocky9.1_minimal.iso
of=/dev/sdb bs=4M status=progress oflag=direct
[sudo] password for matthew:
12494831616 bytes (12 GB, 12 GiB) copied, 126 s, 11 MB/s
```

Iflag=direct in dd will tell the kernel to bypass the RAM cache.