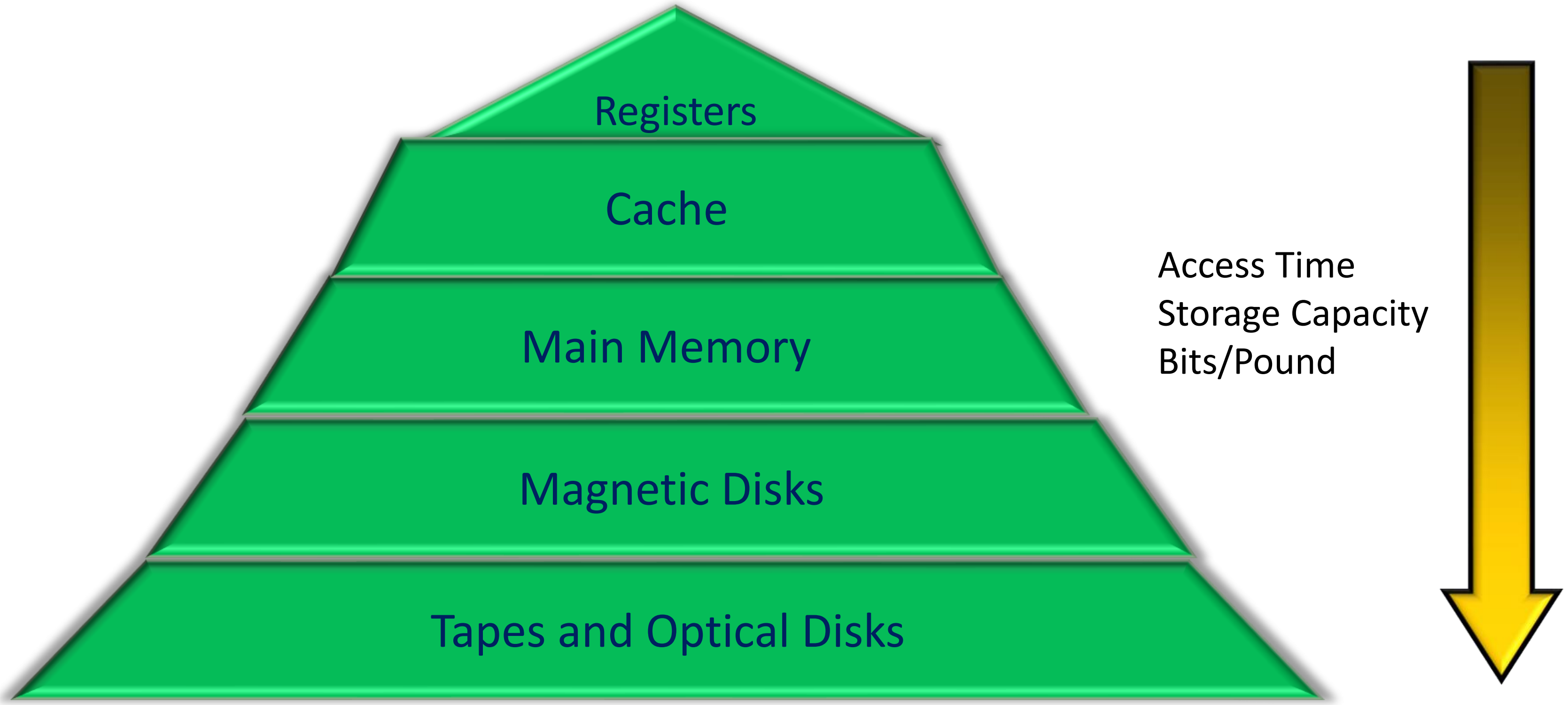
Secondary Memory, I/O And Bus

Hard disk

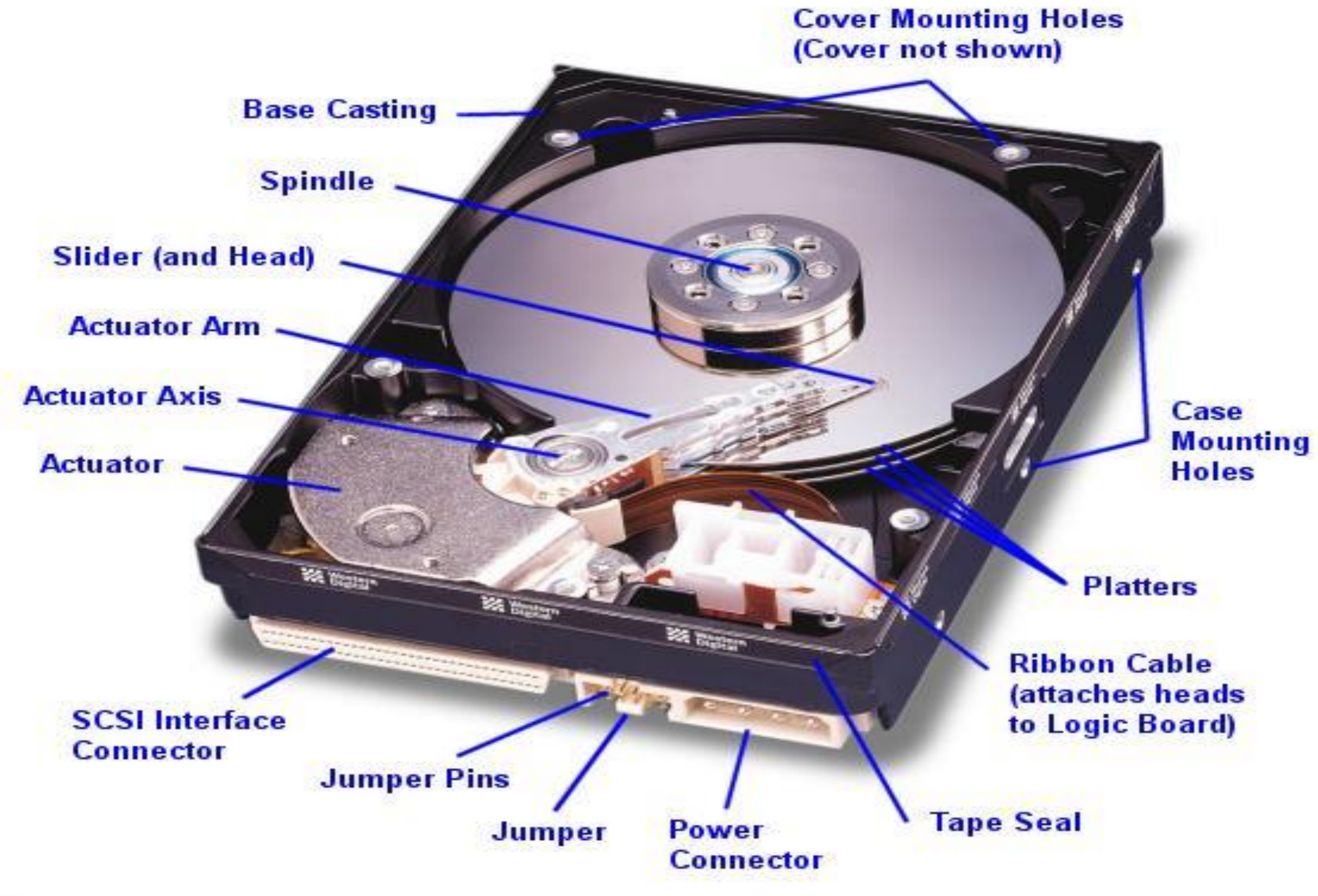
I/O: device, controller, data transfer, polling, interrupt

Bus: bus arbitrator, ISA and PCI bus

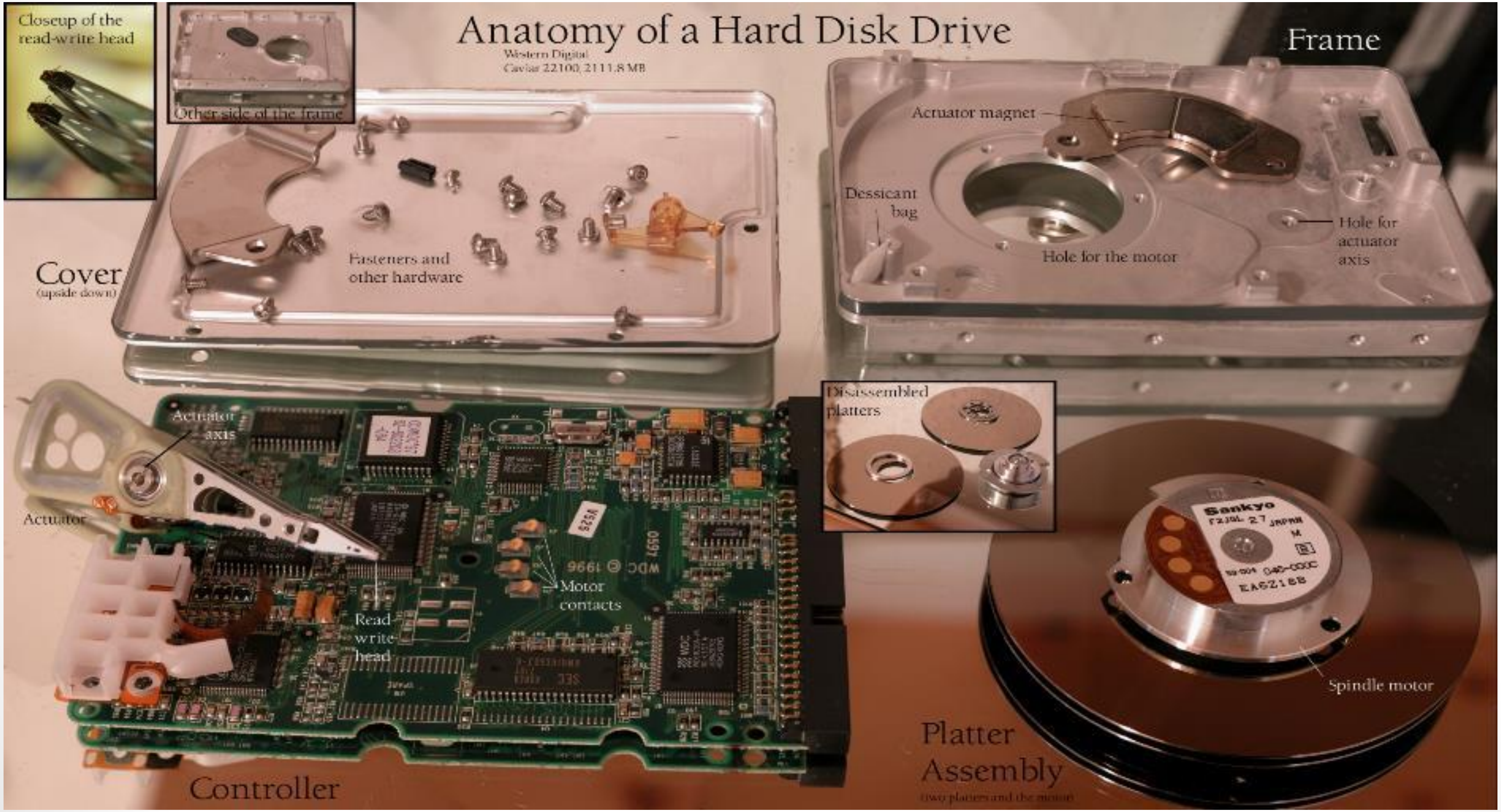


The Memory Hierarchy

HARD DISC STRUCTURE



Anatomy of a Hard Drive



FILE SYSTEM 5-Layers

1. **Physical Layer**

   The drive itself

2. **File System Layer** (Partition Information)

3. **Data Layer** (Where data is stored)

   Blocks and clusters

4. **Metadata Layer**

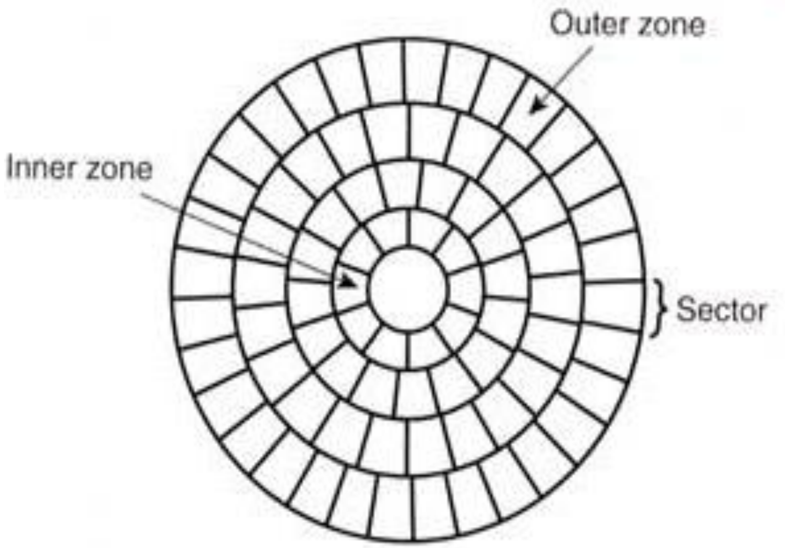
   Structure information (EXT2/3, FAT, NTFS)

5. **File Name layer**

   Name of the file

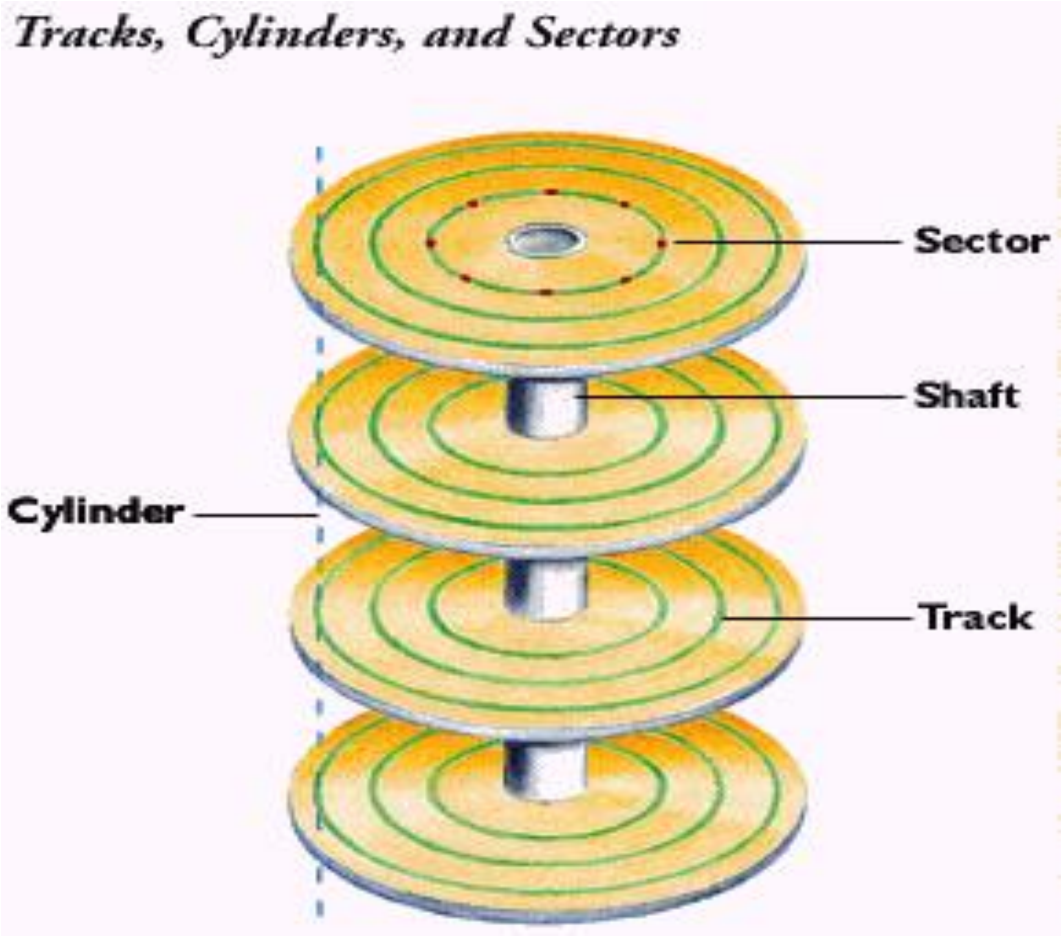
Physical Structure

- A disk is divided into many concentric circles (lines of recorded data) called “tracks”
- Each track is sub-divided segments called “sectors”



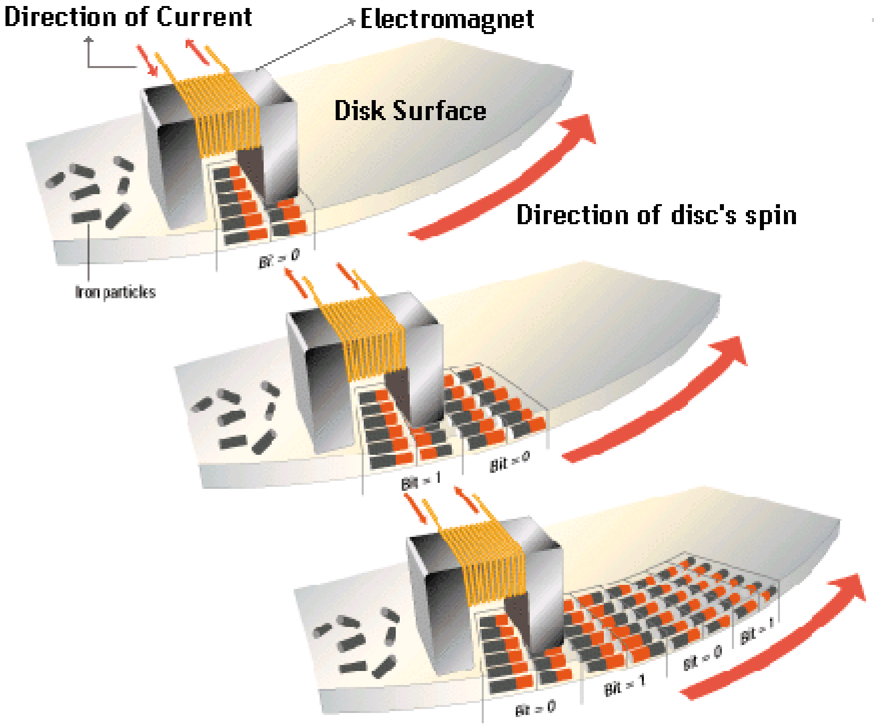
- The number of sectors per track is the same in all tracks
- So the outer sectors are larger than the inners, but have the same capacity

HARD DISC STRUCTURE con't



Data Recording

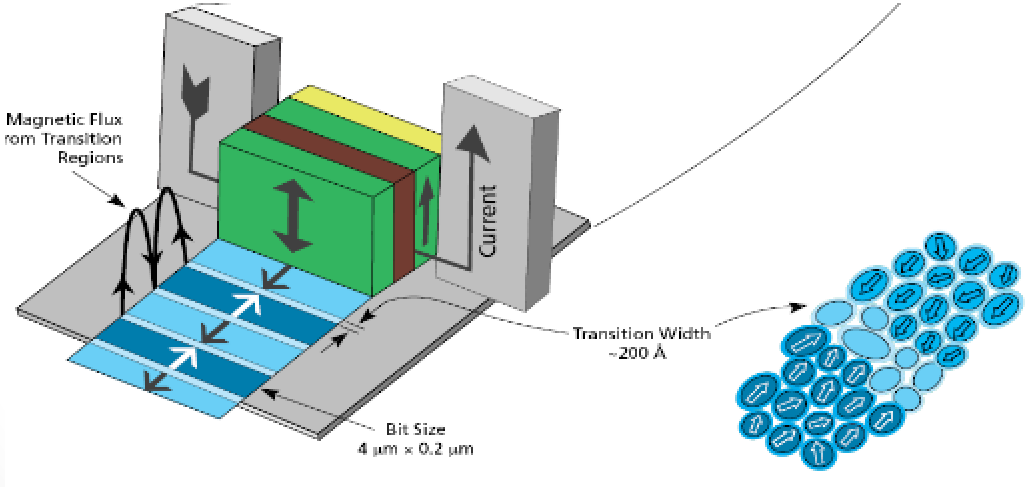
- An electric current flows through a coil of wire
- A magnetic field is produced
- This field is used to magnetize the coating of iron oxide on a floppy disk
- Varying electrical current, the signal is passed through the coil and the variations are "recorded" on the disk

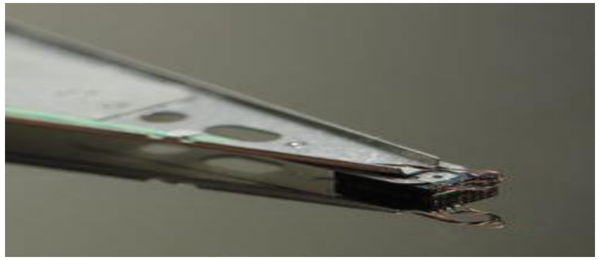


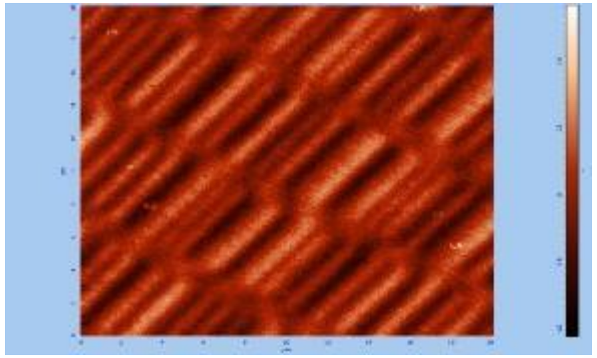
Data being recorded by a read/write head

Hard Disc Structure con’t

Magnetic storage devices, such as hard disks consist of a spinning disk and read/write heads which can add or erase binary data. Underneath a 2 nanometer carbon coating is a disk of cobalt-platinum particles which act like tiny magnets. To store (write) a bit, current is sent through a coil on the write head; creating a magnetic field and magnetizing the area beneath it. The write head aligns about 1000 of the Co/Pt particles, forming a region called a magnetic domain. Neighboring domains are separated by walls about 2 particles wide (20 nm).





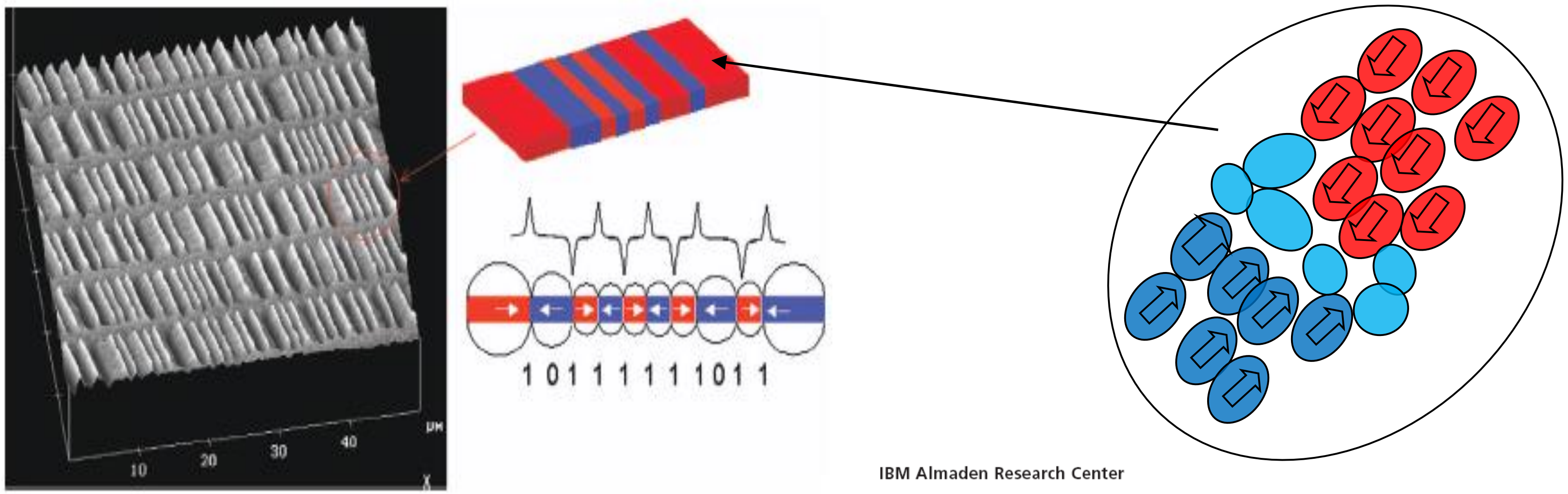


Disc Structure con’t

Data is stored on hard drive disks through magnetization transitions at domain boundaries.

“1” Bit- magnetization reversal between two domains

“0” Bit- no change between adjacent domains



IBM Almaden Research Center

DATA Organisation

- The Data Layer is the reason for having a file system. This is where file data is saved.
- File systems typically use 512-byte sectors
- For efficiency, consecutive sectors are organized and allocated together into a data unit.

- Typically data unit names depend on file system.
  - FAT & NTFS uses clusters.
  - UNIX (FFS and EXT2FS) uses Blocks.

Cluster

- Data units (sectors) of disk must be addressed,
  - Which units belong to which file
  - Which units are free.
  - Which units are damaged (bad sectors)
- On disks having large capacity, allocating one sector as a unit would make the addressing table to large.
- So we combine sectors and create a Cluster.
- Clusters represent the smallest amount of disk space that can be allocated.
- The smaller the cluster size, the more efficient the disk space usage. But the larger the addressing table.
- The number of sectors per cluster a file system uses is stored in the Boot Record

DOS-based Partitions

- In the first sector 0,0,1. we find a partition table that can describe upto 4 partitions.
- The partition table describes the starting sector, the number of sectors, and the type.
- Type usually refers to the OS that is in it. i.e. Windows, Linux.

Extended Partitions

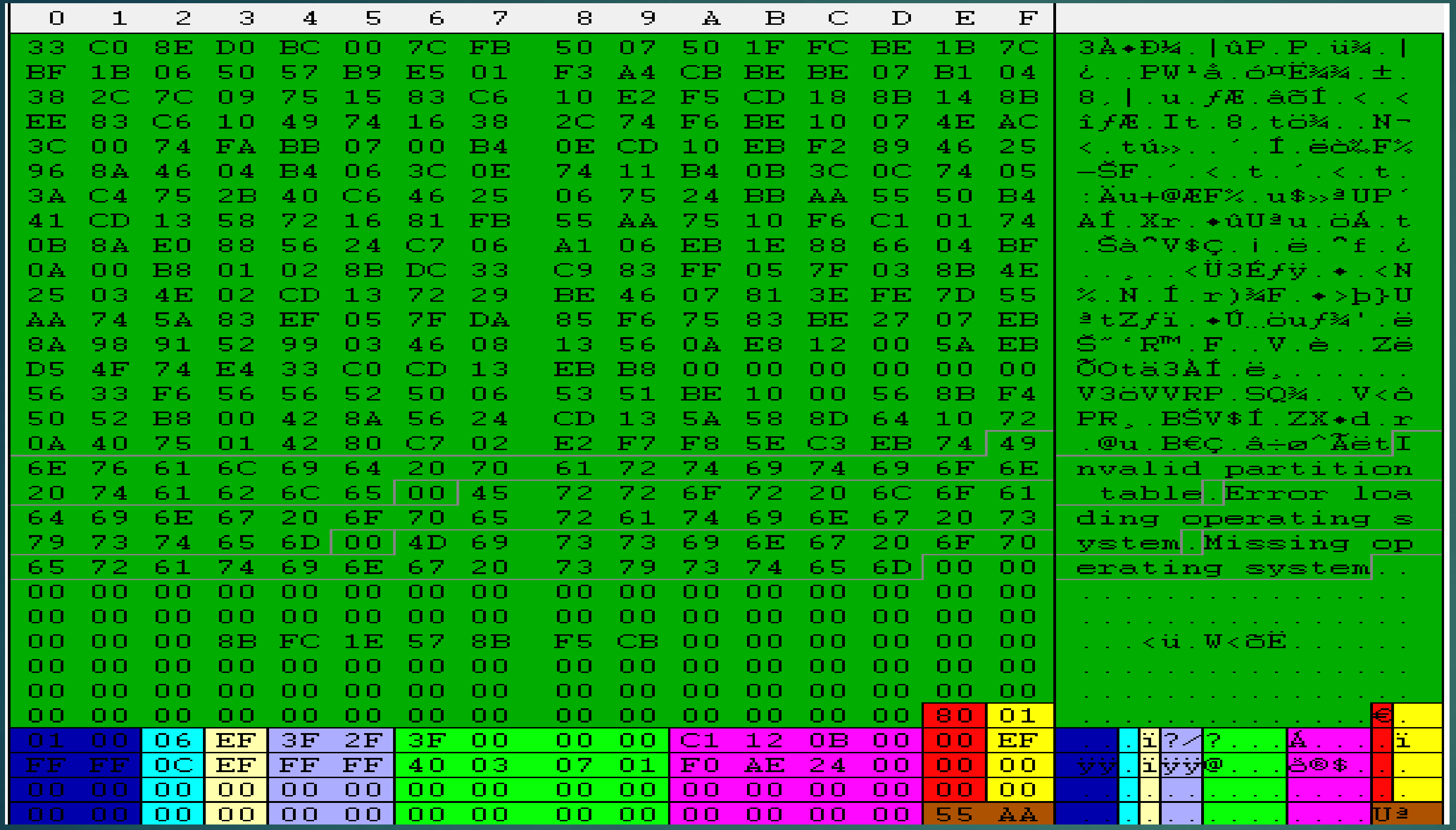
- The partition table only has four entries, which is not enough for modern systems.
- An “Extended Partition” contains another partition table and more partitions.
- Each extended partition can only have one file system and one extended partition.

Master Boot Record (MBR)

- The Master Boot Record is the first record on a hard disk 0,0,1. It is 512 bytes in size (1 sector).
- Master boot record contains the Partition table.
  - First partition -> offset 0x1BE or byte 446
  - Second partition -> offset 0x1CE or byte 462
  - Third partition -> offset 0x1DE or byte 478
  - Fourth partition -> offset 0x1EE or byte 494

- Each Partition entry is 16 bytes long
- End of MBR marker will always be 0x55AA

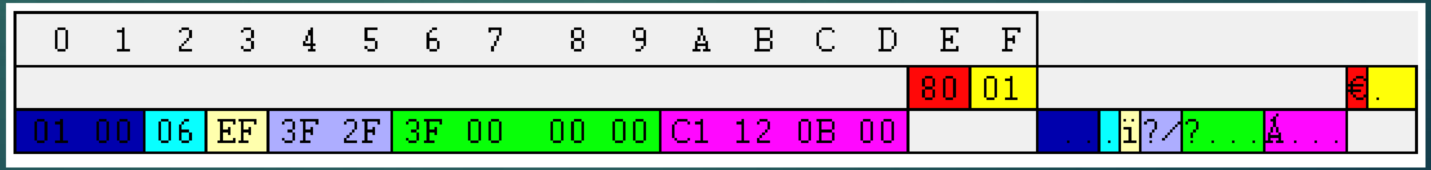
Master Boot Record



```
 0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
33 C0 8E D0 BC 00 7C FB  50 07 50 1F FC BE 1B 7C   3À◆Ð¼.|ûP.P.ü¾.|
BF 1B 06 50 57 B9 E5 01  F3 A4 CB BE BE 07 B1 04   ¿..PW¹å.ó¤Ë¾¾.±.
38 2C 7C 09 75 15 83 C6  10 E2 F5 CD 18 8B 14 8B   8,|.u.ƒÆ.âõÍ.<.<
EE 83 C6 10 49 74 16 38  2C 74 F6 BE 10 07 4E AC   îƒÆ.It.8,tö¾..N¬
3C 00 74 FA BB 07 00 B4  0E CD 10 EB F2 89 46 25   <.tú»..´.Í.ëò‰F%
96 8A 46 04 B4 06 3C 0E  74 11 B4 0B 3C 0C 74 05   –ŠF.´.<.t.´.<.t.
3A C4 75 2B 40 C6 46 25  06 75 24 BB AA 55 50 B4   :Äu+@ÆF%.u$»ªUP´
41 CD 13 58 72 16 81 FB  55 AA 75 10 F6 C1 01 74   AÍ.Xr.◆ûUªu.öÁ.t
0B 8A E0 88 56 24 C7 06  A1 06 EB 1E 88 66 04 BF   .Šà^V$Ç.¡.ë.^f.¿
0A 00 B8 01 02 8B DC 33  C9 83 FF 05 7F 03 8B 4E   ..¸..<Ü3Éƒÿ.◆.<N
25 03 4E 02 CD 13 72 29  BE 46 07 81 3E FE 7D 55   %.N.Í.r)¾F.◆>þ}U
AA 74 5A 83 EF 05 7F DA  85 F6 75 83 BE 27 07 EB   ªtZƒï.◆Ú…öuƒ¾'.ë
8A 98 91 52 99 03 46 08  13 56 0A E8 12 00 5A EB   Š˜'R™.F..V.è..Zë
D5 4F 74 E4 33 C0 CD 13  EB B8 00 00 00 00 00 00   ÕOtä3ÀÍ.ë¸......
56 33 F6 56 56 52 50 06  53 51 BE 10 00 56 8B F4   V3öVVRP.SQ¾..V<ô
50 52 B8 00 42 8A 56 24  CD 13 5A 58 8D 64 10 72   PR¸.BŠV$Í.ZX◆d.r
0A 40 75 01 42 80 C7 02  E2 F7 F8 5E C3 EB 74 49   .@u.B€Ç.â÷ø^ÃëtI
6E 76 61 6C 69 64 20 70  61 72 74 69 74 69 6F 6E   nvalid partition
20 74 61 62 6C 65 00 45  72 72 6F 72 20 6C 6F 61    table.Error loa
64 69 6E 67 20 6F 70 65  72 61 74 69 6E 67 20 73   ding operating s
79 73 74 65 6D 00 4D 69  73 73 69 6E 67 20 6F 70   ystem.Missing op
65 72 61 74 69 6E 67 20  73 79 73 74 65 6D 00 00   erating system..
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 8B FC 1E 57 8B  F5 CB 00 00 00 00 00 00   ...<ü.W<õË......
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 80 01   ..............€.
01 00 06 EF 3F 2F 3F 00  00 00 C1 12 0B 00 00 EF   ...ï?/?...Á....ï
FF FF 0C EF FF FF 40 03  07 01 F0 AE 24 00 00 00   ÿÿ.ïÿÿ@...ð®$...
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ................
00 00 00 00 00 00 00 00  00 00 00 00 00 00 55 AA   ..............Uª
```

- 🟩 > Executable code
- 🟥 ➢Boot indicator
- 🟨 ➢Starting head
- 🟦 ➢Starting sector & cylinder
- 🟦 ➢Partition type
- 🟨 ➢Ending head
- 🟪 ➢Ending sector & cylinder
- 🟩 ➢The starting sector
- 🟪 ➢No. of sectors in partition
- 🟫 ➢Executable signature

1 Partition entry



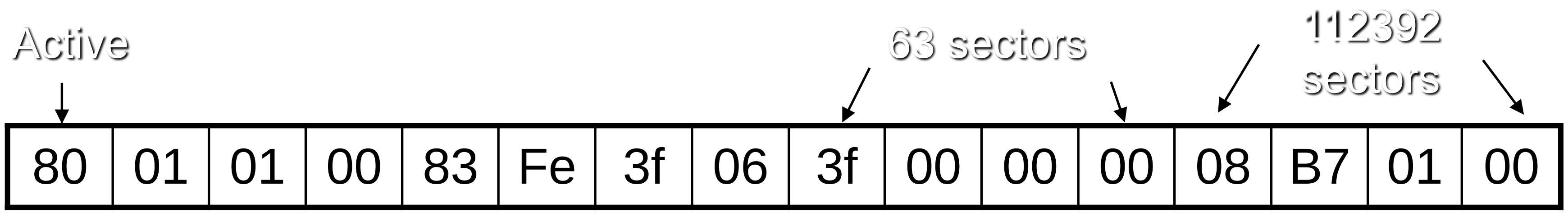
```
 0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
                                            80 01   €.
01 00 06 EF 3F 2F 3F 00  00 00 C1 12 0B 00          ...ï?/?...Á...
```

Read as

80 01 01 00 06 EF 3F 2F 3F 00 00 00 C1 12 0B 00

Partition Table contents

Offset (decimal)	Length (bytes)	Content
0	1	State of partition : 00h if not active, 80h if active
1	1	Head where the partition starts.
2	2	Sector and cylinder where partition starts.
4	1	Type of partition. See next slide
5	1	Head where partition ends.
6	2	Sector and cylinder where partition ends.
8	4	Distance in sectors, from the partition table to the first sector of the partition (starting sector)
12	4	Number of sectors in the partition (Partition length)



80	01	01	00	83	Fe	3f	06	3f	00	00	00	08	B7	01	00

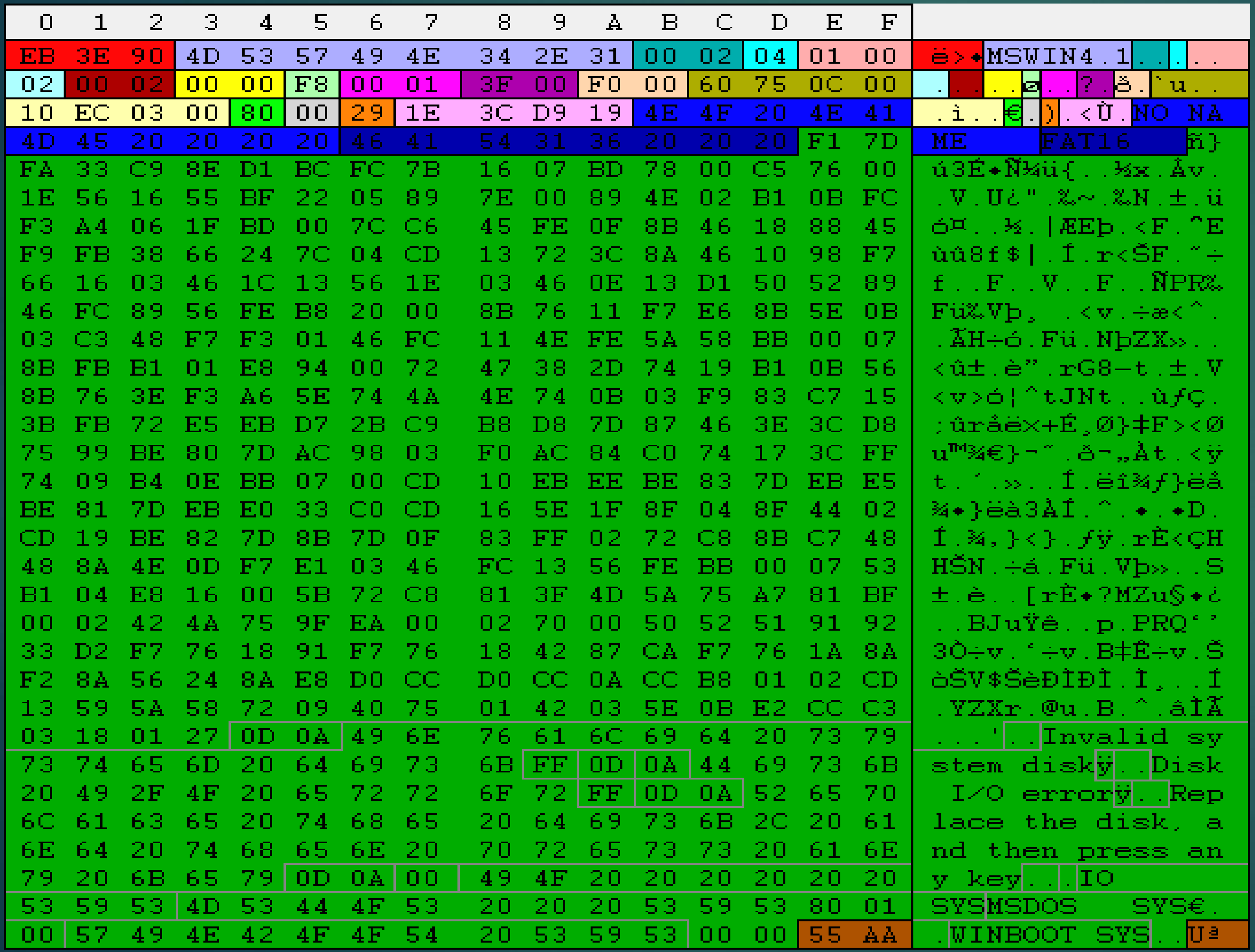
Common Types of Partition

Hex Value	Type
0x01	FAT 12
0x0E	FAT 16
0x0C	FAT 32
0x83	Linux Native
0x82	Linux Swap
0xA5	BSD/386
0x05	Extended
0x07	NTFS

Boot Sector (Boot Record)

- This is a vital sector.
- Disk will be unusable if this sector gets damaged
- At CHS 0, 0, 1 in hard disks, we have the MBR which contains the Partition Table
- Each partition has its own boot sector.
- Each operating system has its own boot sector format.
- For Booting, Bootstrap Loader loads Boot Sector data in to a particular address of memory (0000:7C00h) and sets the PC
- In hard disks, the small program in MBR attempts to locate an active (bootable) partition in partition table
- If found, the boot record of that partition is read into memory (location 0000:7C00) and runs

Boot Record



```
 0  1  2  3  4  5  6  7   8  9  A  B  C  D  E  F
EB 3E 90 4D 53 57 49 4E  34 2E 31 00 02 04 01 00   ë>◆MSWIN4.1.....
02 00 02 00 00 F8 00 01  3F 00 F0 00 60 75 0C 00   .....ø..?.ð.`u..
10 EC 03 00 80 00 29 1E  3C D9 19 4E 4F 20 4E 41   .ì..€.).<Ù.NO NA
4D 45 20 20 20 20 46 41  54 31 36 20 20 20 F1 7D   ME    FAT16   ñ}
FA 33 C9 8E D1 BC FC 7B  16 07 BD 78 00 C5 76 00   ú3É◆Ñ¼ü{..½x.Åv.
1E 56 16 55 BF 22 05 89  7E 00 89 4E 02 B1 0B FC   .V.U¿".‰~.‰N.±.ü
F3 A4 06 1F BD 00 7C C6  45 FE 0F 8B 46 18 88 45   ó¤..½.|ÆEþ.‹F.ˆE
F9 FB 38 66 24 7C 04 CD  13 72 3C 8A 46 10 98 F7   ùû8f$|.Í.r<ŠF.˜÷
66 16 03 46 1C 13 56 1E  03 46 0E 13 D1 50 52 89   f..F..V..F..ÑPR‰
46 FC 89 56 FE B8 20 00  8B 76 11 F7 E6 8B 5E 0B   Fü‰Vþ¸ .‹v.÷æ‹^.
03 C3 48 F7 F3 01 46 FC  11 4E FE 5A 58 BB 00 07   .ÃH÷ó.Fü.NþZX»..
8B FB B1 01 E8 94 00 72  47 38 2D 74 19 B1 0B 56   ‹û±.è”.rG8-t.±.V
8B 76 3E F3 A6 5E 74 4A  4E 74 0B 03 F9 83 C7 15   ‹v>ó¦^tJNt..ùƒÇ.
3B FB 72 E5 EB D7 2B C9  B8 D8 7D 87 46 3E 3C D8   ;ûråë×+É¸Ø}‡F><Ø
75 99 BE 80 7D AC 98 03  F0 AC 84 C0 74 17 3C FF   u™¾€}¬˜.ð¬„Àt.<ÿ
74 09 B4 0E BB 07 00 CD  10 EB EE BE 83 7D EB E5   t.´.»..Í.ëî¾ƒ}ëå
BE 81 7D EB E0 33 C0 CD  16 5E 1F 8F 04 8F 44 02   ¾◆}ëà3ÀÍ.^.◆.◆D.
CD 19 BE 82 7D 8B 7D 0F  83 FF 02 72 C8 8B C7 48   Í.¾‚}‹}.ƒÿ.rÈ‹ÇH
48 8A 4E 0D F7 E1 03 46  FC 13 56 FE BB 00 07 53   HŠN.÷á.Fü.Vþ»..S
B1 04 E8 16 00 5B 72 C8  81 3F 4D 5A 75 A7 81 BF   ±.è..[rÈ◆?MZu§◆¿
00 02 42 4A 75 9F EA 00  02 70 00 50 52 51 91 92   ..BJuŸê..p.PRQ‘’
33 D2 F7 76 18 91 F7 76  18 42 87 CA F7 76 1A 8A   3Ò÷v.‘÷v.B‡Ê÷v.Š
F2 8A 56 24 8A E8 D0 CC  D0 CC 0A CC B8 01 02 CD   òŠV$ŠèÐÌÐÌ.Ì¸..Í
13 59 5A 58 72 09 40 75  01 42 03 5E 0B E2 CC C3   .YZXr.@u.B.^.âÌÃ
03 18 01 27 0D 0A 49 6E  76 61 6C 69 64 20 73 79   ...'..Invalid sy
73 74 65 6D 20 64 69 73  6B FF 0D 0A 44 69 73 6B   stem diskÿ..Disk
20 49 2F 4F 20 65 72 72  6F 72 FF 0D 0A 52 65 70    I/O errorÿ..Rep
6C 61 63 65 20 74 68 65  20 64 69 73 6B 2C 20 61   lace the disk, a
6E 64 20 74 68 65 6E 20  70 72 65 73 73 20 61 6E   nd then press an
79 20 6B 65 79 0D 0A 00  49 4F 20 20 20 20 20 20   y key...IO
53 59 53 4D 53 44 4F 53  20 20 20 53 59 53 80 01   SYSMSDOS   SYS€.
00 57 49 4E 42 4F 4F 54  20 53 59 53 00 00 55 AA   .WINBOOT SYS..Uª
```

- 🟥 ▶ Jump code
- ■ ▶ oem/id name
- ■ ▶ Bytes per sector
- ■ ▶ Sectors per allocation
- ■ ▶ Reserved sectors
- ■ ▶ No. FAT's
- ■ ▶ Root entries
- 🟨 ▶ Total sectors (16)
- ■ ▶ Media type
- ■ ▶ Sectors per FAT
- 🟪 ▶ Sectors per track
- ■ ▶ No. heads
- ■ ▶ Hidden sectors
- 🟩 ▶ Total sectors
- ■ ▶ Drive id
- 🟧 ▶ Nt reserved
- ■ ▶ Extended boot signature
- 🟦 ▶ Volume serial number
- 🟩 ▶ Volume/partition name
- ▶ FAT type
- 🟫 ▶ Executable boot(strap) code
- ▶ Executable signature

DOS/Windows Formatted Disk

- A DOS/Windows formatted floppy/hard disk's Boot Sector contains
  - A jump and a NOP opcode
  - BPB (BIOS Parameter Block)
    - Sectors per cluster
    - Number of Root directory entries
    - Sectors per FAT (File Allocation Table)
    - Volume Label
  - A program, to load OS if bootable or show an error msg if OS not present
    - e.g. NON SYSTEM DISC or DISC ERROR REPLACE DISC AND STRIKE ANY KEY WHEN READY
  - In hard drives it locates the active partition and then loads the OS or displays the error messages.

DOS/Windows Formatted Disk con’t

- This piece of code is essential to the Operation of the system.
- After the formatter has created the BOOT SECTOR it creates the FILE ALLOCATION TABLE (FAT).
- This area of the disc contains all the information concerning where your Software/Programs are stored

Formatting con’t

- In addition if the formatter finds BAD areas on your disc during Formatting it will mark these areas as BAD in the FAT so that your programs are not accidentally stored in a defective area.

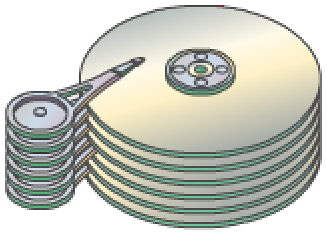
- Finally the Formatter creates the ROOT DIRECTORY and then the rest of the disc is user space.

FAT

- FAT-12/FAT-16/FAT-32 were Microsoft’s favorite File Allocation Tables (before NTFS)
- FAT-12
  - 12 bits for addressing.
  - Cluster size = 512 bytes to 8K
  - This gives 4096 clusters therefore a maximum volume size of 32MB can be addressed
- FAT-16
  - 16 bits for addressing
  - Cluster size 512 bytes to 64KB
  - 64KB clusters maximum volume size of 4GB, this is why Win95 could not support more than 4GB partitions
- FAT-32, the latest/last version.
  - 32 bit fields for addressing.
    - Reserves the high 4 bits so really only has 28-bit identifier
  - Cluster size 512 bytes to 8KB
  - 268435456 clusters max. for Maximum volume size of 8 Terabytes

FAT con’t

- No security
  - User access
  - Anyone can access every file
- Root Directory is an ordinary cluster chain
  - No limit on size
- Limited error recovery.



FAT Format

- The FAT is divided into multiple regions.

Reserved Sectors	**FAT**	**DATA**

Boot Sector	FAT TABLE	FAT TABLE	Dir	Directories & Files

Data layer

- Data will either be:
  - Allocated
    - Data block is actively being used by a file.
    - Data exists in a file on the system.
    - Not deleted.
  - Unallocated
    - Data block is not being used by a file.
    - Data may or may not exist in the block or cluster.
    - May contain deleted or unused data.
    - Pieces of files are called file **FRAGMENTS**

FAT Directory Entry (METADATA AREA)

- File name, 8 main letters and 3 extension (i.e. exe, com, txt, doc, etc.)
- Long File name
- Modified, Access, and Creation date/times (MAC)
- File size
- First cluster number of the data area.

- All the files or folders are contained in the root directory in FAT12/16 which limits it to 512 entries because the value was pre-assigned.
- This is not true for FAT 32 there is no size limit.

HDD Data Transfer Speed

- Mechanical nature of the disk limits the data transfer speed
  - **Seek time** – the time takes the head to travel to the track of the disk that contains data
  - **Rotational delay** – the time takes to rotate the desired sector to the location under the head.
  - To minimize delay

Defragmentation is a procedure that moves related items to physically proximate areas on the disk.

Solid state Usually SATA interface upto 6Gb/s

Max. Random Read 4K:
  97000 IOPS

Max. Random Write 4K:
  89000 IOPS

Enterprise drives less than 500 µs