Hệ Điều Hành

(*Nguyên lý các hệ điều hành*)

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Chapter 4 file system management

- To keep information for long time and later use -> store on external memory (disk, magnetic tape, optical disk,..) => file
  - Data or program file
  - Many files ⇒ file system
  - Files system combined of 2 parts
    - files: Contain data/program
    - directory : provide information about file
- Files system is large ⇒ How to manage?
  - File's properties, required operation?
- How to store and access file on storage devices?
  - Storage space allocation, free memory management

Chapter 4 File system management

① File system
② File system’s implementation
③ Information organization on disk
④ FAT system

- File's notion
- Directory structure

Introduction

- Information is stored on different medias/devices
  - Example: Disk, tape, optical disk...
  - Storage device is modeled as an array of memory block

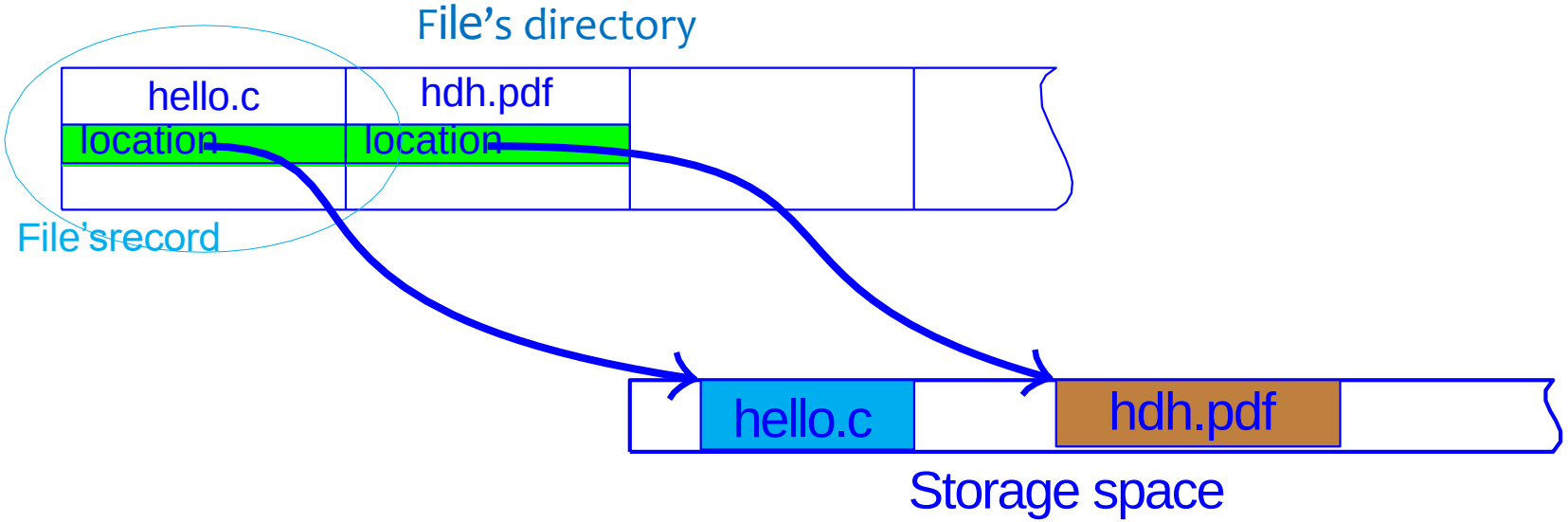
- File is a set of information stored on storage devices
  - File is a storage unit of OS on external devices
  - File contains sequence of bits, bytes, lines, records,... Contain meaning defined by creator
- Structure of file is defined by type of file
  - Text file: Sequence of character organized into lines
  - Object file: Bytes organized into block to be read and edited by the linker
  - Executive File: Sequence of codes can be run in memory
  - . . .

File's attributes

- File name: sequence of character (e.g. "hello.c")
  - Information store in the format that is readable by user
  - Can be distinguished by upper-case/lower-case
  - Guarantee the independence of file from process, user…
    - A created file hello.c by notepad on Windows
    - B uses emacs on Linux to modify a file specified by name hello.c
- Identifier: A tag to define an unique file
- Type: Used in system supports many types of file
  - Type of file is defined based on one part of file name
    - Example: .exe, .com/ .doc, .txt/ .c, .jav, .pas/ .pdf, .jpg,…
  - Based on type, OS decides corresponding operation
    - Run an execution file that source is modified ⇒ Recompile
    - Double click on a text file (*.doc) ⇒ Call word processor
- Position: Point to device and location of file on that device
- Size: Current/maximum size of file
- Protection: Control access: who can read/write…
- Time: Creation time, modified time, last used time …

File's attributes (cont.)

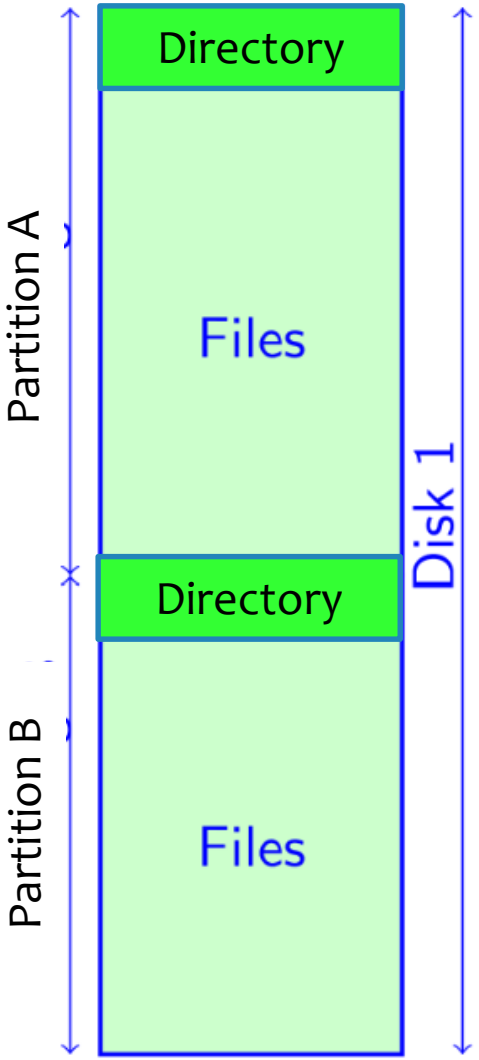
- File's attributes are stored in data structure: File's record
  - May contain only file's name and file's identifier; file's identifier define other information
  - Size from several bytes to kilobytes
- File's record are stored in File's directory
  - Size may be up to Megabytes
  - Often stored on external memory
  - Directory parts are loaded into memory when necessary



- File’s notion

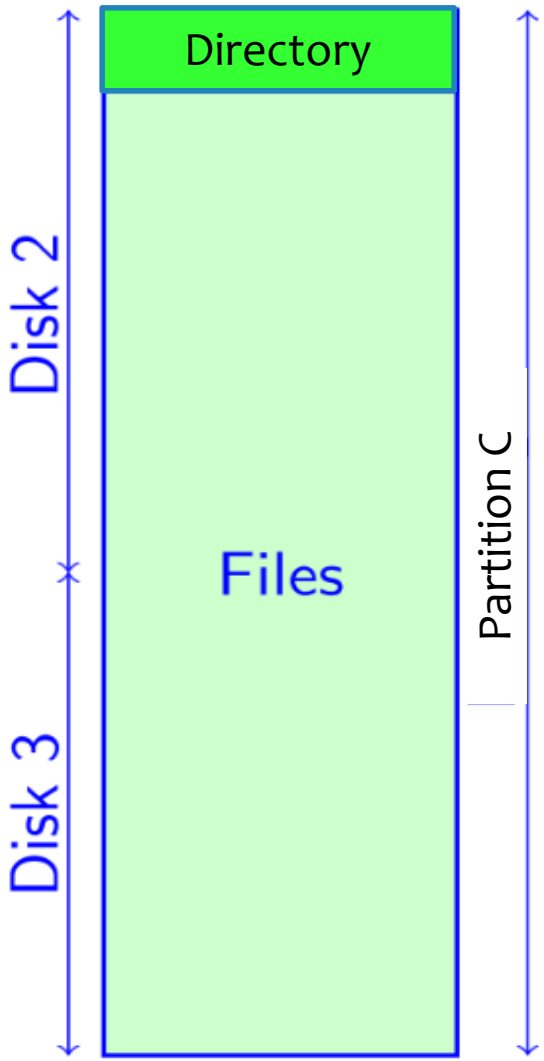
- Directory structure

Partition



- Disk is divided into Partitions, Minidisks, Volumes
- Each partition is processed as an independent storage area
- Can store an individual OS

Partition



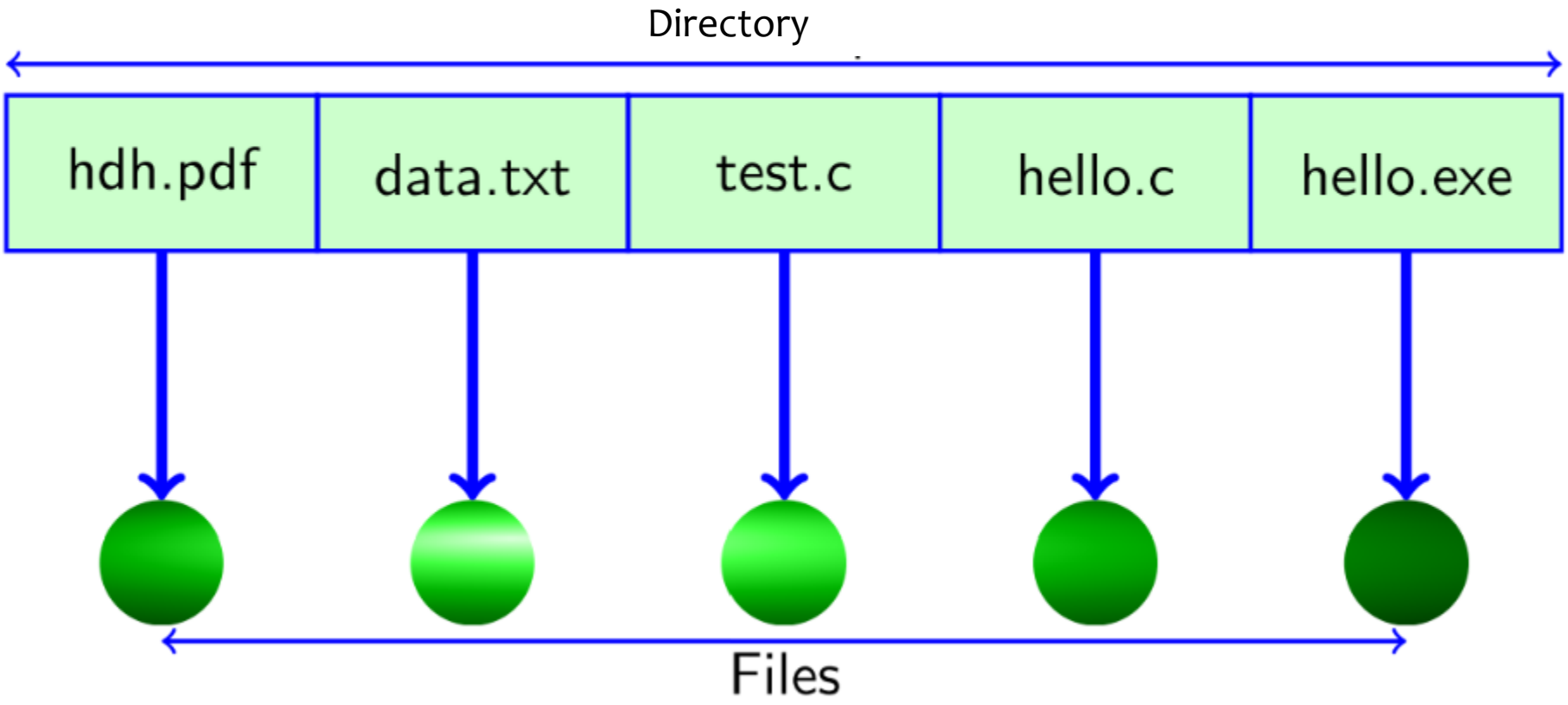
Merge several disks into a large logic structure

- User only care about file and directory ’s structure
- Do not care about how physical memory space is allocated to files

Operations with directory

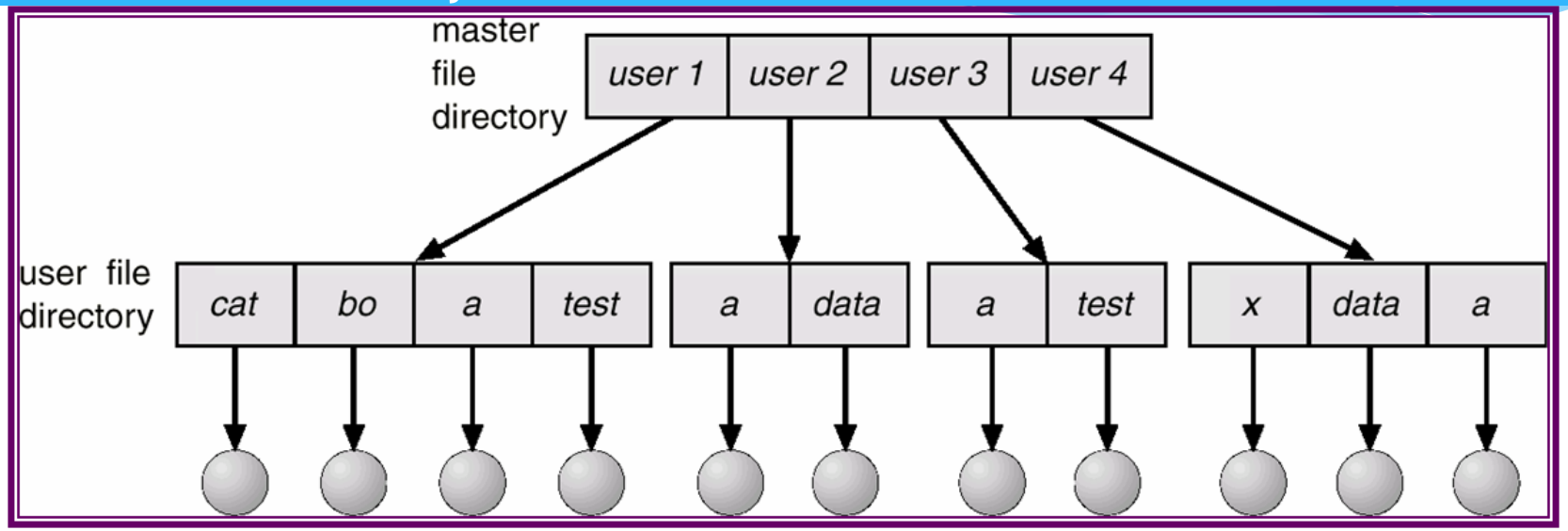
- Each partition contain information about contained files
  - File's information is stored in device's directory
- Directory is a translation table allow mapping from one name (file) to a member inside directories
  - Directory can be implemented by different methods
- Require operations for insert, create, delete or show the list
- Operations
  - Seek file: Search for an item corresponding to a file name
  - Create file: Create new file require to create new item in directory
  - Delete file: When delete a file, remove corresponding item in the directory
  - Listing file: Show the list of files and corresponding item in directory
  - Rename file: Rename file, position in the directory's structure
  - Traverse the file system: Access all directory and content of all files in the directory (backup data to tape)

One level directory



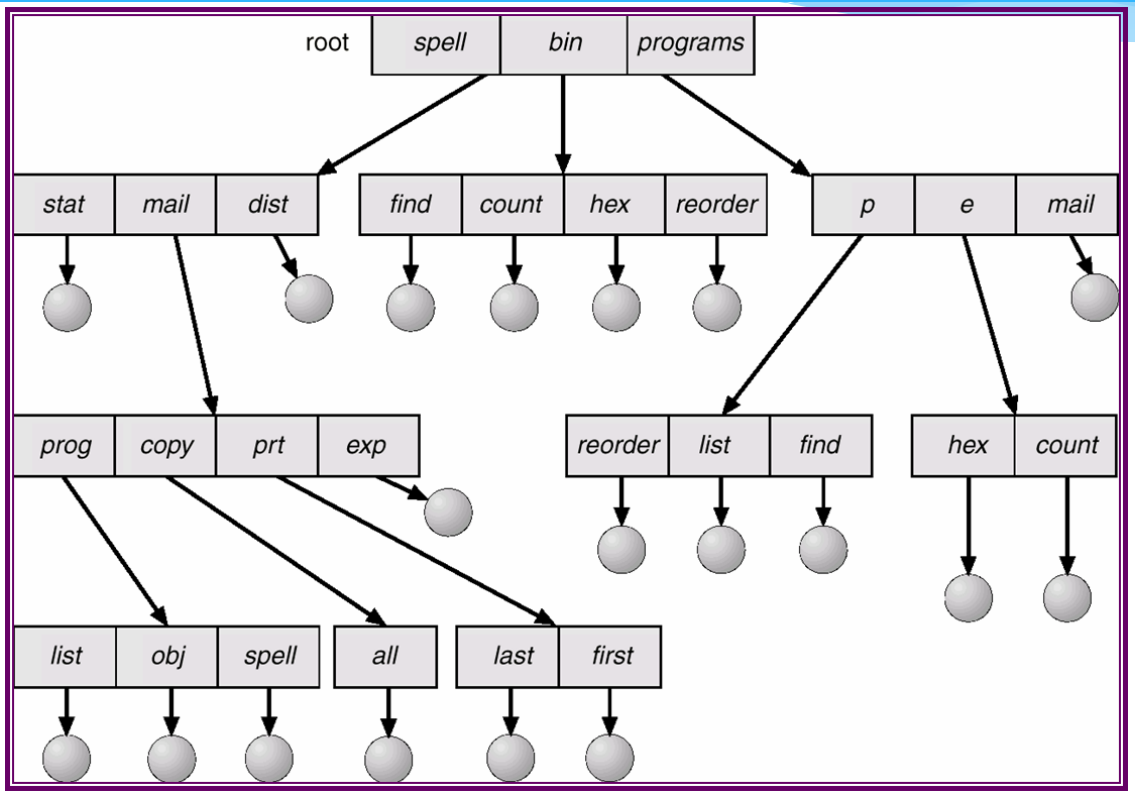
- Simplest structure, files are stored in the same directory
- If number of user and file is large, it's possible for the filename to be duplicated
  - Each user has his own directory riêng

One level directory



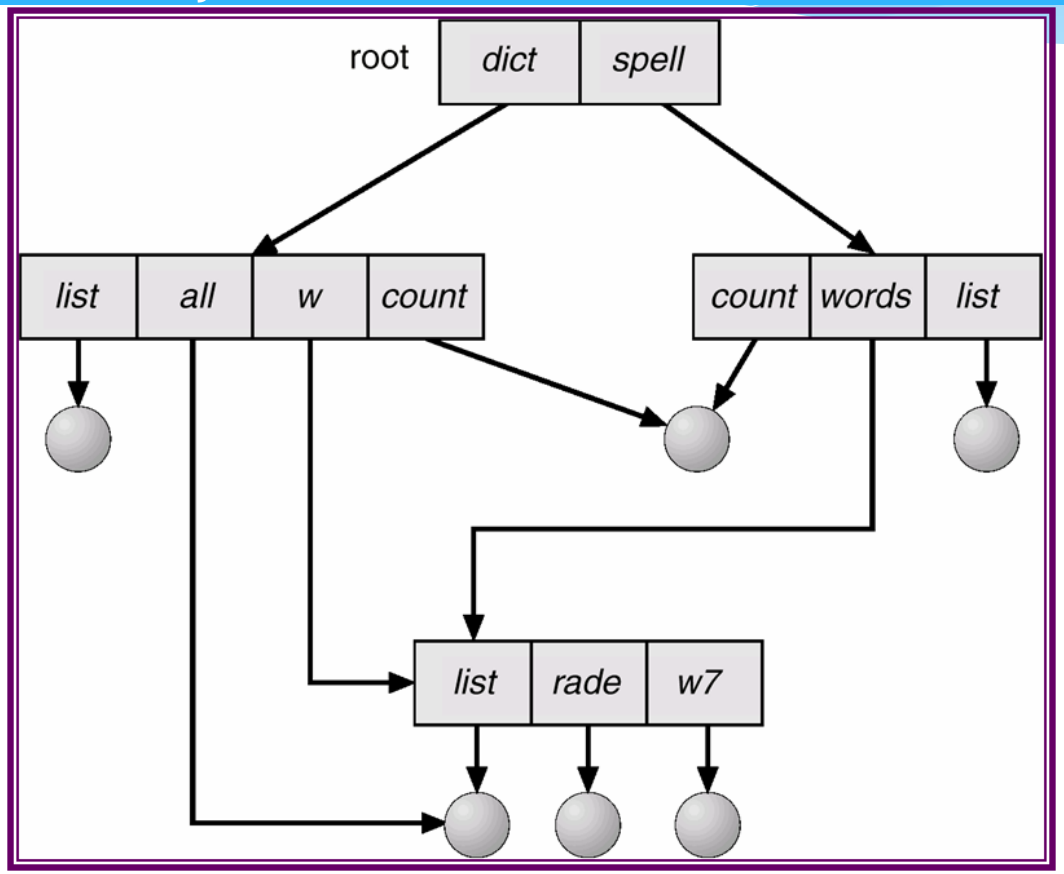
- Each user has his own private folder, when working, only work with private folder
- When log in, system check and allow user to work with private folder
- When a user is added
  - System create a new member in *Master file directory*
  - Create *User file directory*
- Solve the duplicate file name problem; Effect when user are independent
- Problem when user want to share a file

Tree structure directory



- A (relative/absolute) path to file exist
- Sub-directory is a file is treated specially (bit for marking)
- Operations create/delete/add... performed on current directory
  - Delete a sub-directory ⇒ delete its sub-tree

Sharing a directory



- User can link to a file from other user
- When traversing the directory (backup), file can be traversed many time
- Delete file: link/ content (file-created-user /last link)

Chapter 4 File system management

1. File system
2. File system's implementation
3. Information organization on disk
4. FAT system

Chapter 4: File system management
2. File system's implementation
2.1 Directory implementation

- Directory implementation
- Storage area allocation methods
- Free storage area management

Method

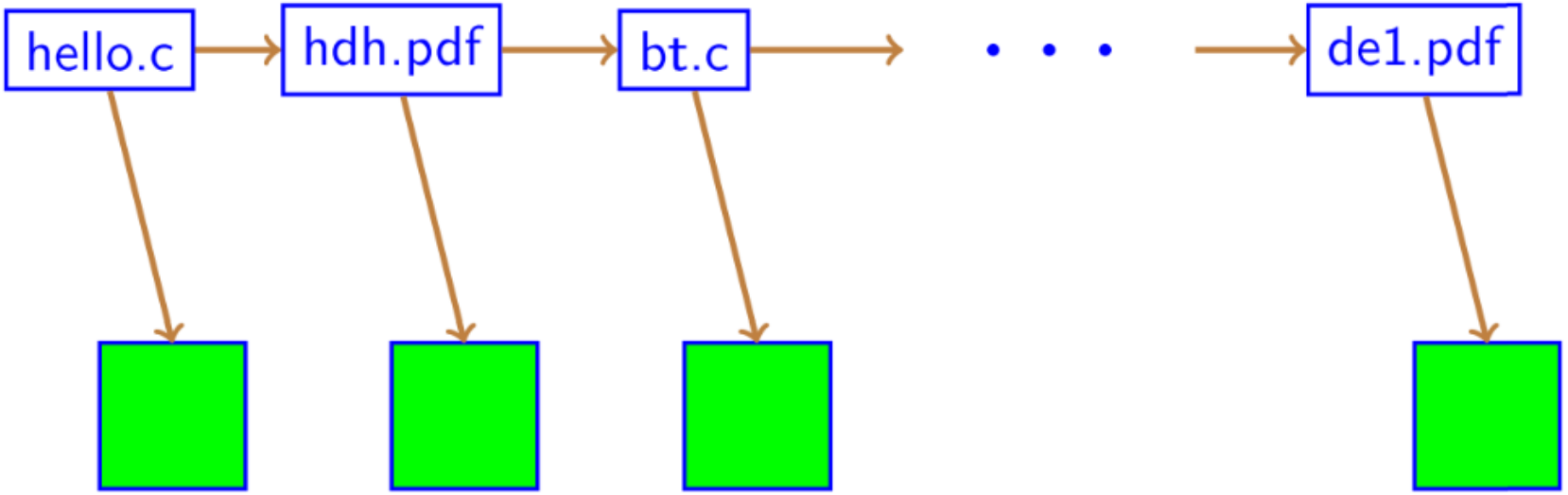
① Linear list with pointer to data blocks
- Simple for programming
- Time consuming when operate with directories
  - Must traverse all the list ⇐ Use binary tree?

② Hash table – Hash table with linear list
- Reduce directory traversing time
- Require an effective hash function

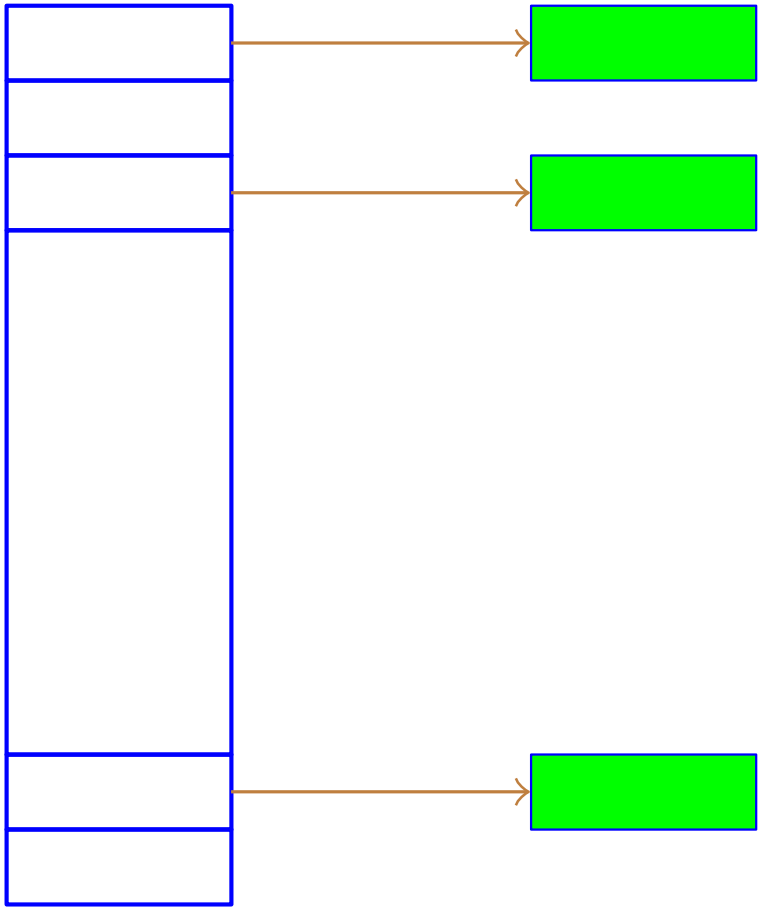
$$h(Name) = \frac{\sum_{i=1}^{Len(Name)} ASCII(Name[i])}{Table\_Size}$$

- Collision problem: hash function return same result with 2 different file name
- Fixed table size problem: Increase size has to recalculate existed numbers

Linear list



Hash table



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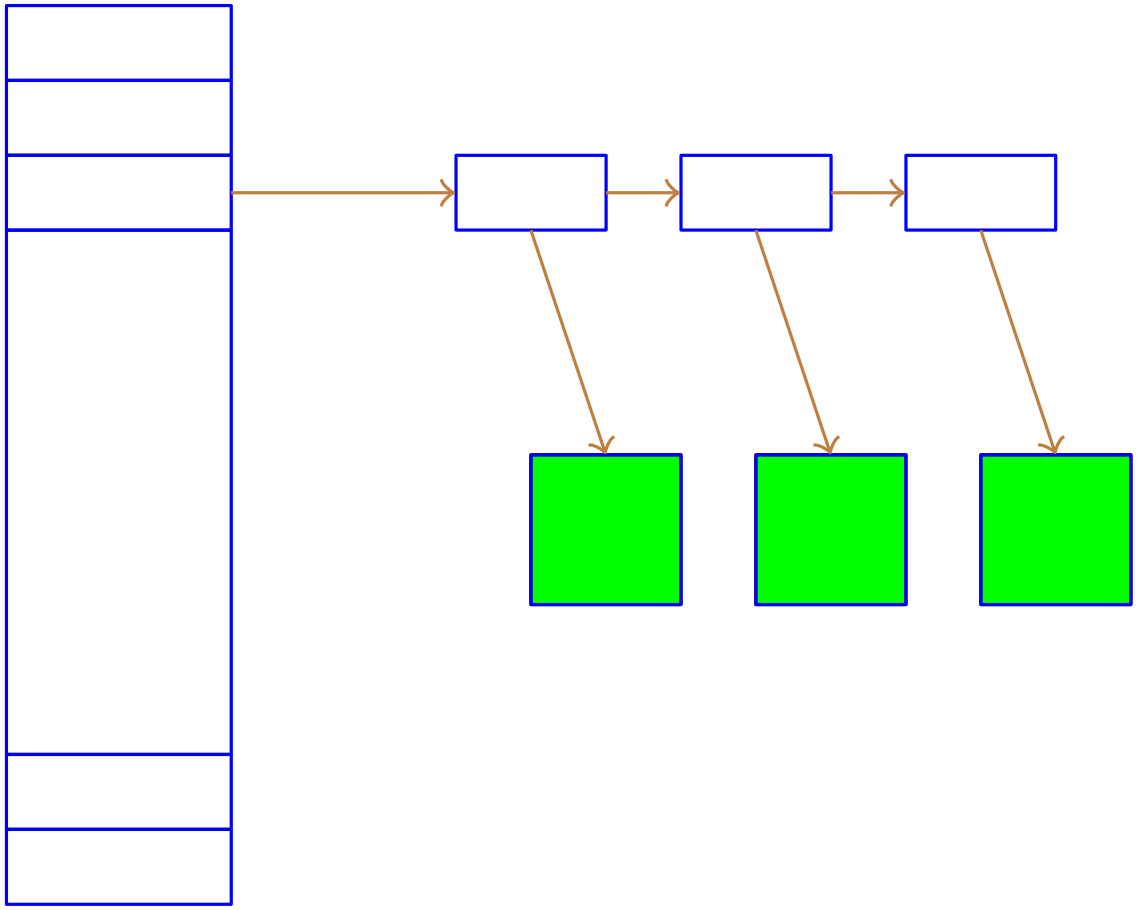


Chapter 4: File system management
2. File system's implementation
2.2 Storage area allocation methods

- Directory implementation
- Storage area allocation methods
- Free storage area management

Methods

Objective

- Increase performance of sequence access
- Easy to randomly access file
- Easy to manage file

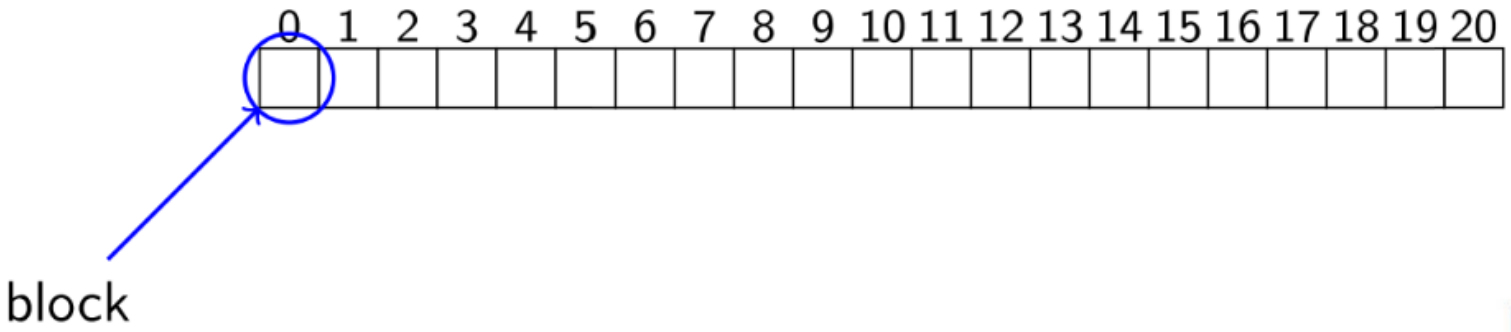
Methods

- Continuous Allocation
- Linked List Allocation
- Indexed Allocation

Continuous Allocation

Rule: File is allocated with continuous memory block

File	*Pos*	*Size*
file-1	15	4
file-2	4	5
file-3	11	3
Directory		



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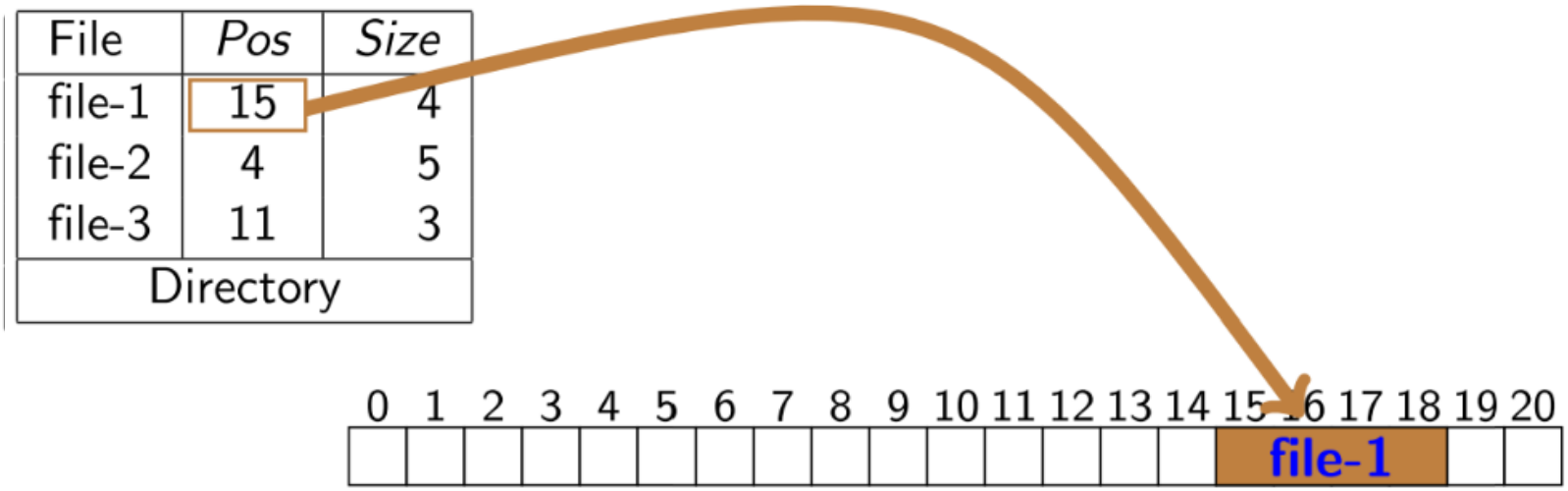

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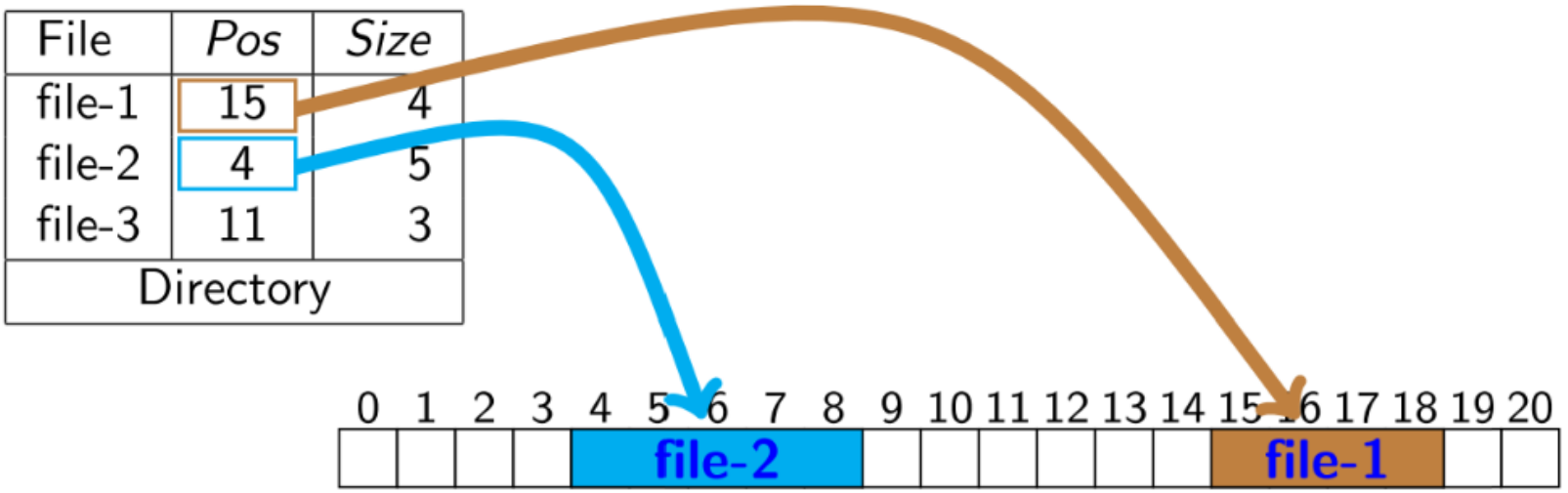

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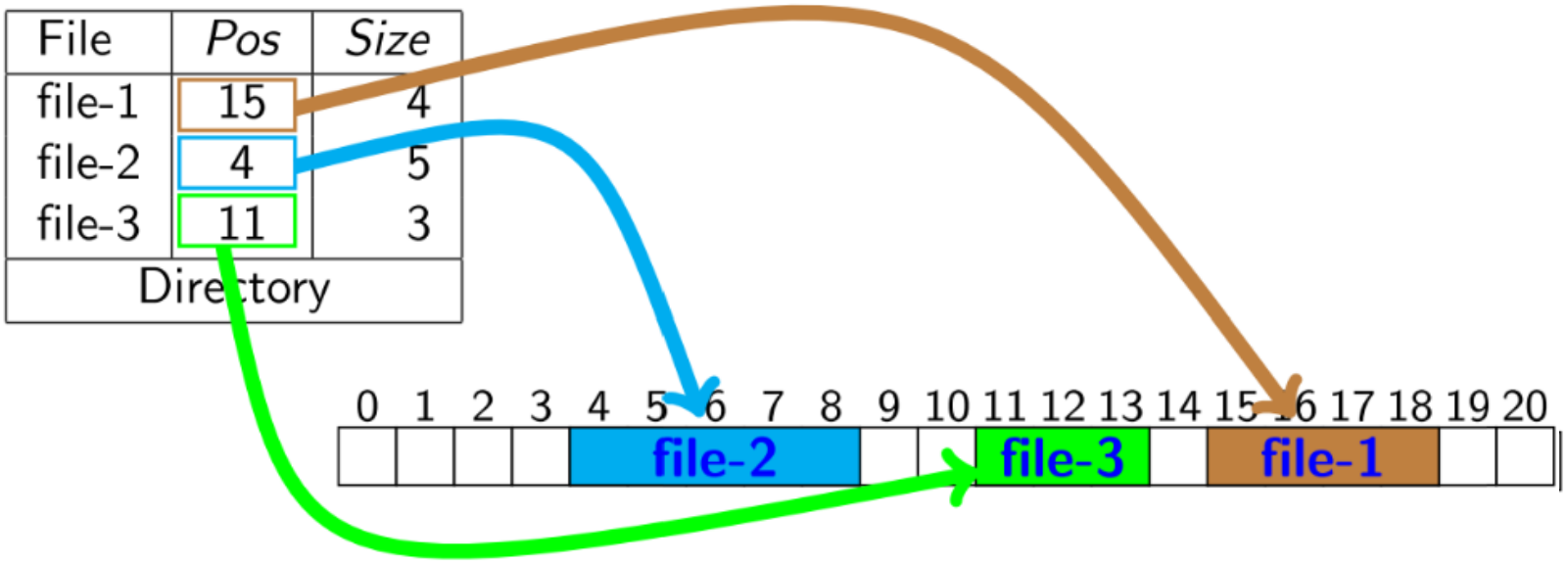

Continuous Allocation

- File has the length **n** and begin at block **b** will occupy blocks **b, b + 1, . . . , b + n – 1**
  - Two block **b** and **b + 1** are continuous
    ⇒ No need to move the header (except the last sector)
    ⇒ High speed access
  - Allow directly access block **i** of file
    ⇒ access block b + i – 1 on storage device
- Select empty space when there are request?
  - Strategies First-Fit /Worst Fit /Best Fit
  - External fragmentation phenomenon
- Difficult when the size of file increase

Linked List Allocation

Rule: File is allocated with non continuous memory blocks.
End of each block is a pointer, point to next block

File	*Pos*	*End*
abc	12	3
def	5	11
Directory		

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	3	-1	0	6	8	14	9	11	7	-1	10	0	15	2	0	0

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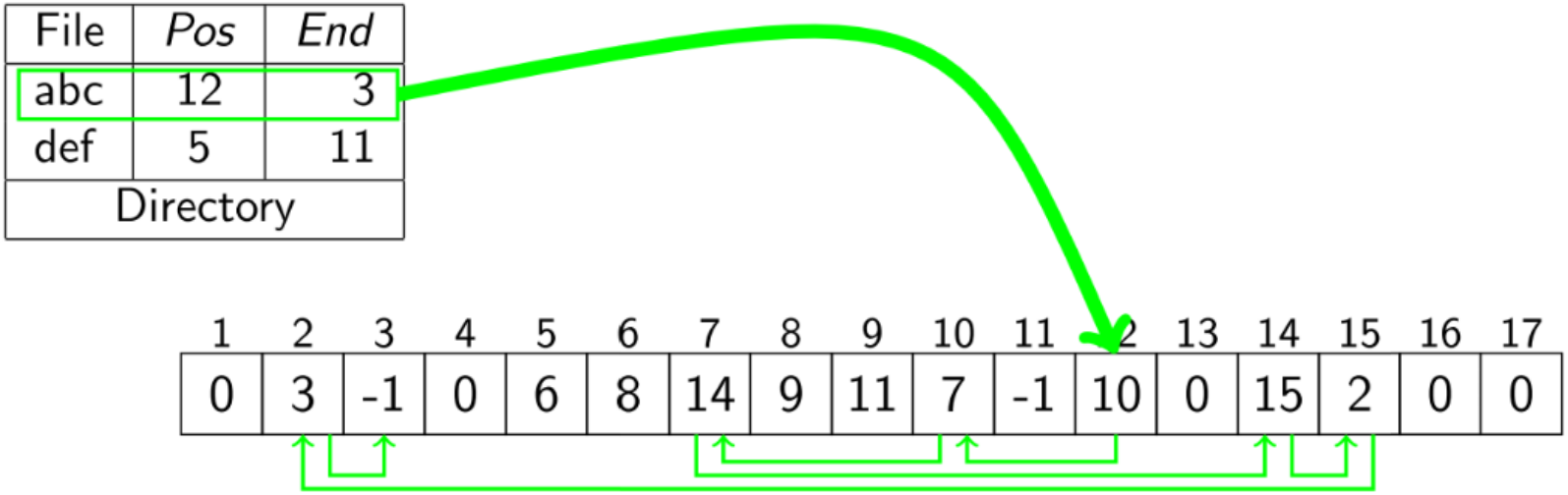

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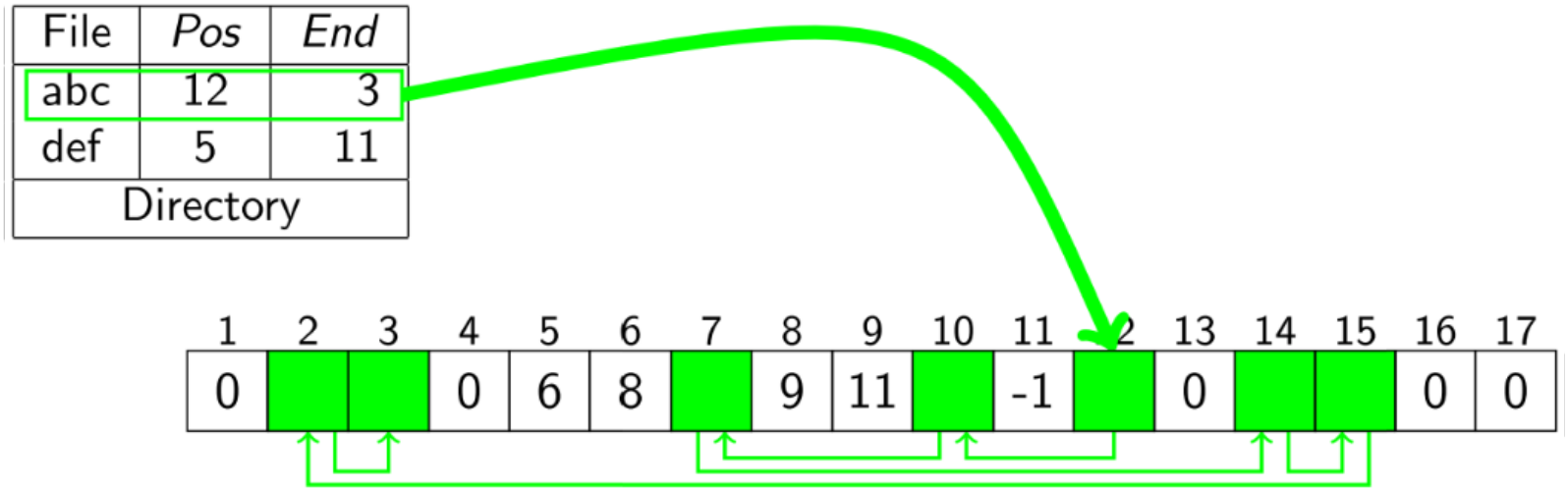

Files abc consists of 7 blocks: 12, 10, 7, 14, 15, 2, 3

Linked List Allocation

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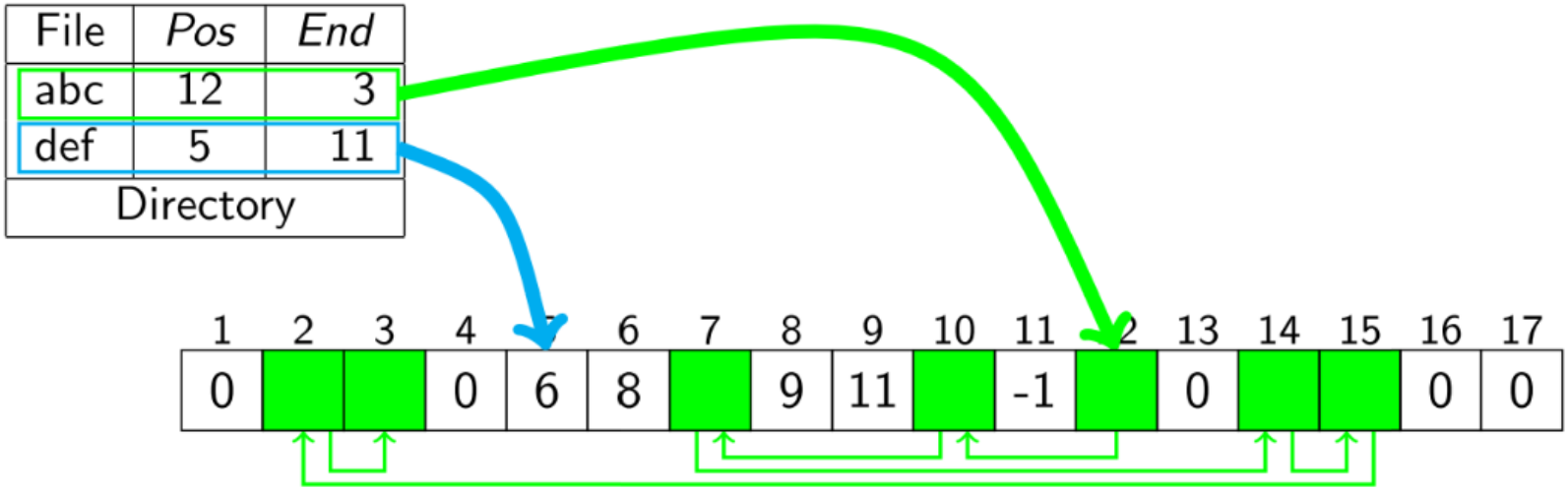

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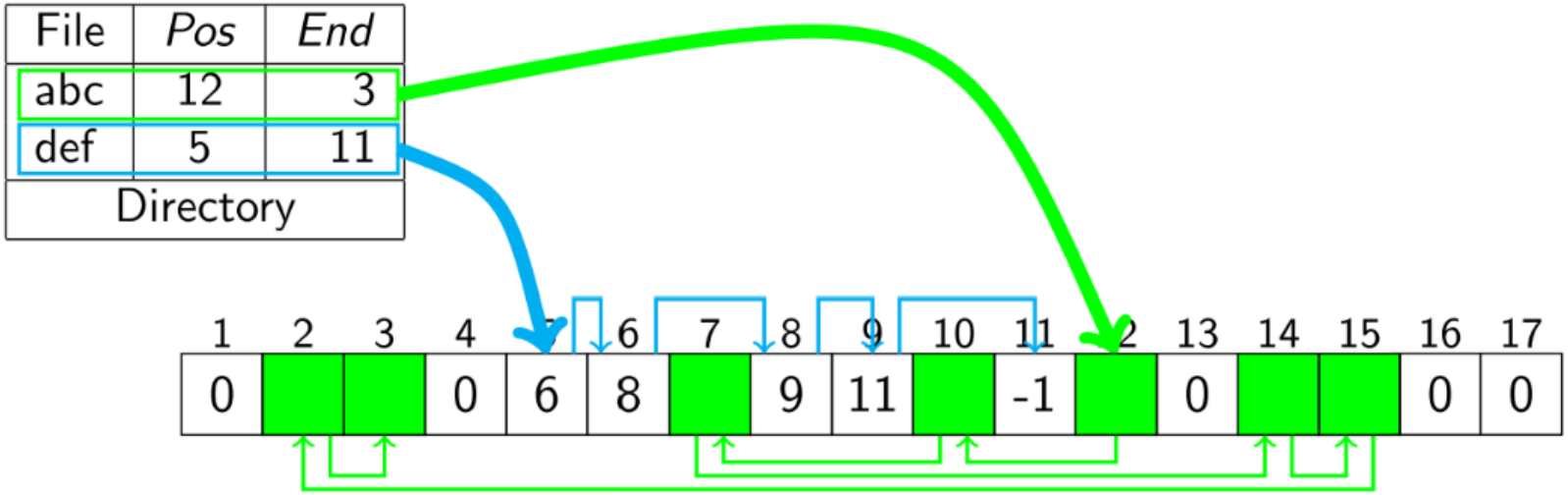

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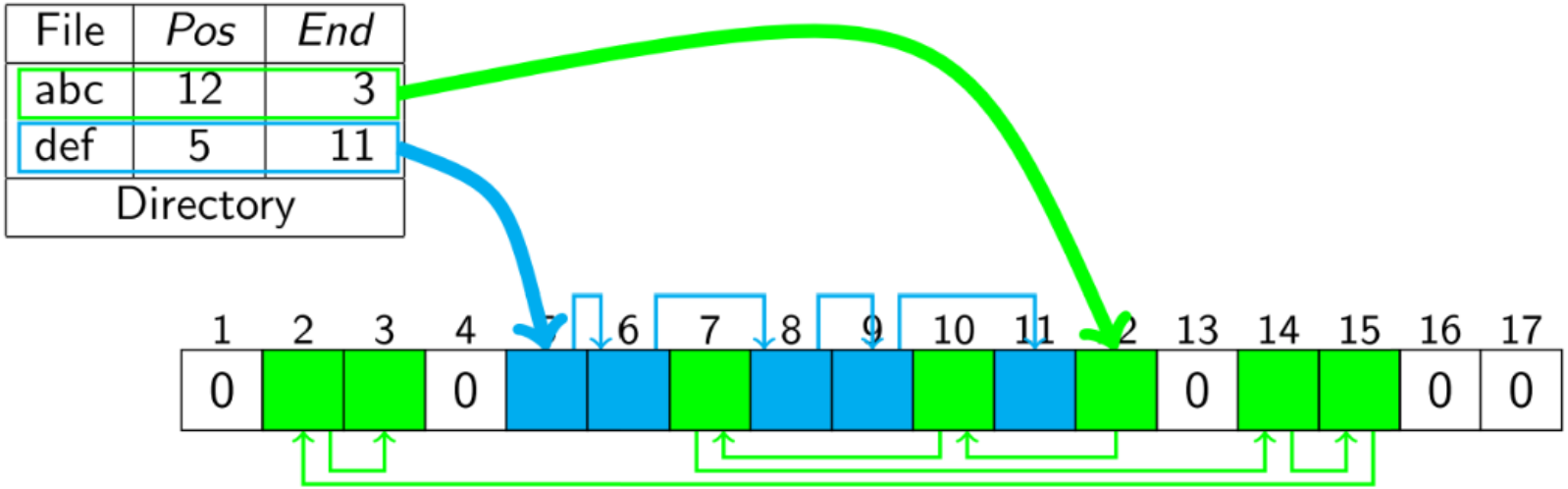


Files abc consists of 7 blocks: 12, 10, 7, 14, 15, 2, 3

Files def consists of 5 blocks: : 5, 6, 8, 9, 11

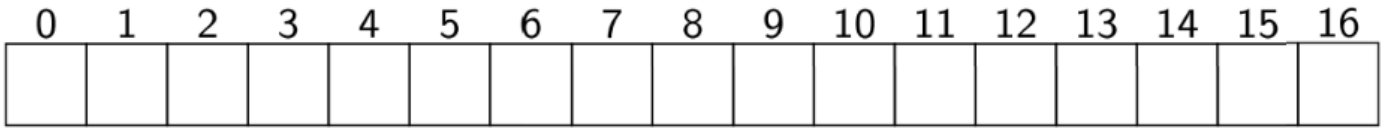
Linked List Allocation

- Only effective for sequent access file
- To access block n, must traverse $n - 1$ blocks before it
  - Blocks are noncontiguous, has to relocation from start
  - Slowly access speed
- Blocks in file are linked by pointers -> if pointer broke?
  - Lost data due to link to block is lost
  - Link to block without data or block belongs to other file
- **Solution:** Apply many pointer in each block ⇒Consume memory
- Apply: FAT
  - Utilized as a linked list
  - Combined of many members, each member corresponding to a block
  - Each member in FAT, contain next block of file
  - Last block has special value (FFFF)
  - Error block has value (FFF7)
  - Unused block has value (0)
  - **Location** field in **file record** contains the first block of file

Index allocation

Rule: Each file has a main index block which contains list of file block

File	*Index block*
abc	5
def	12
Directory	



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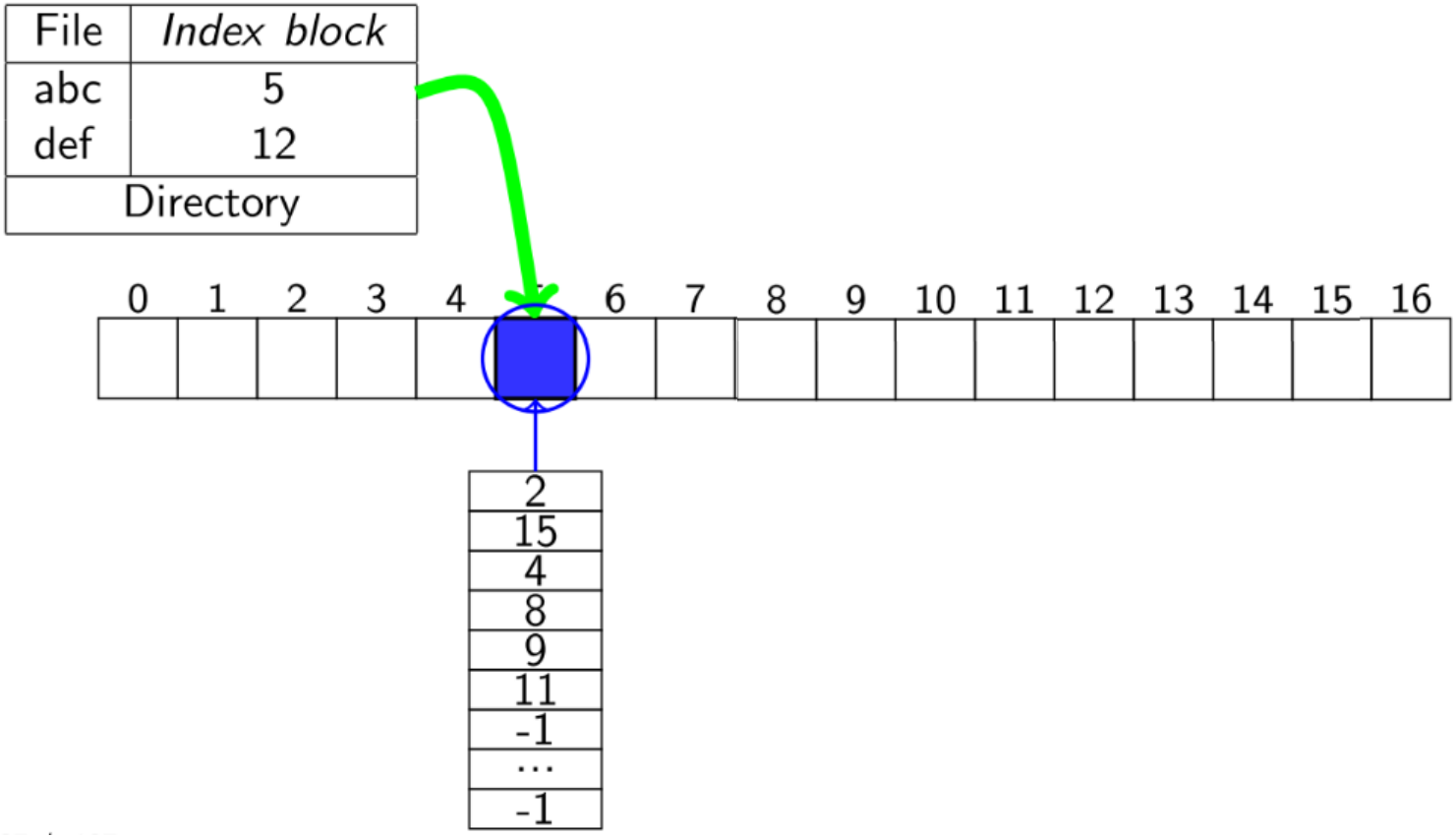

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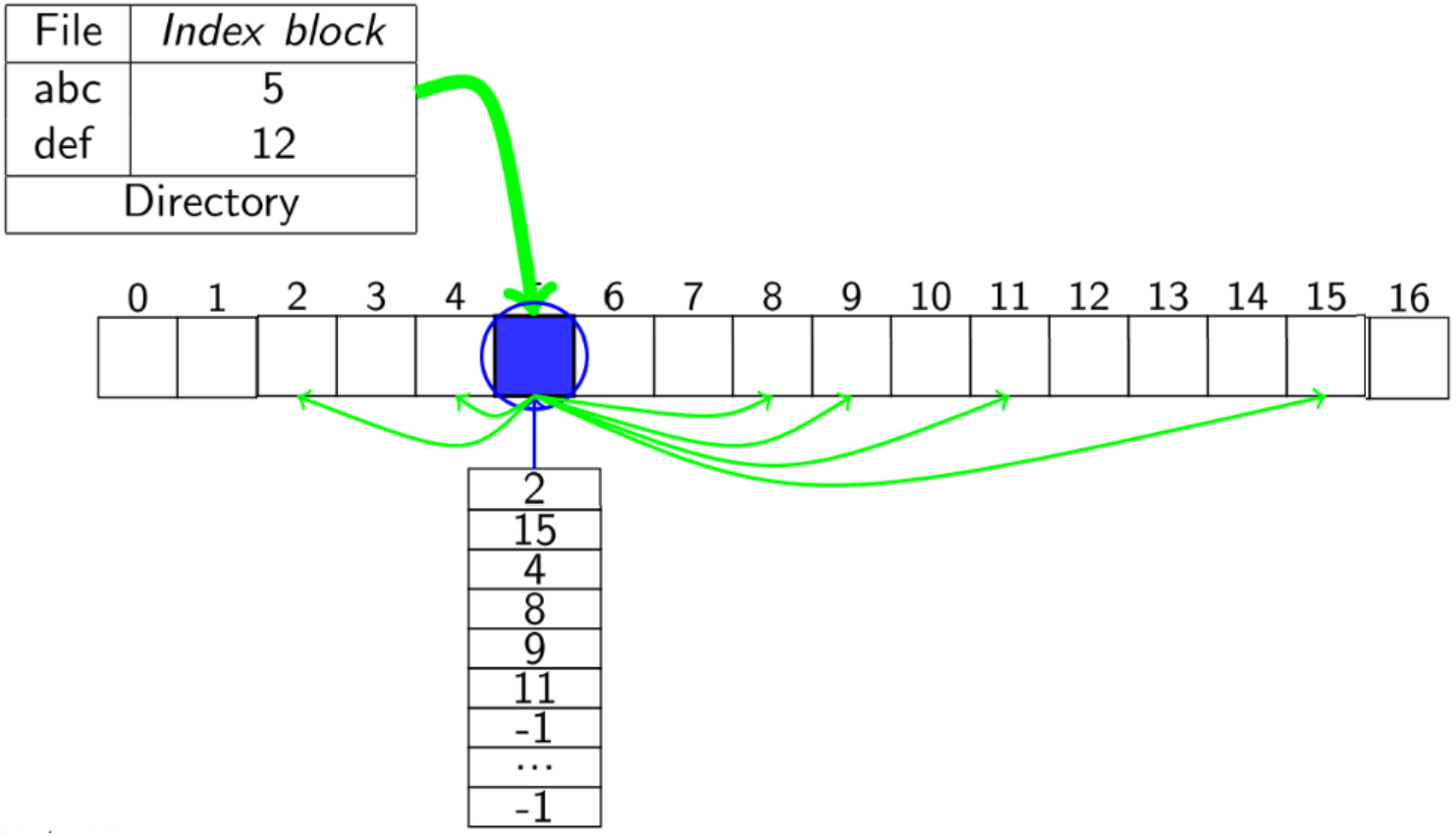

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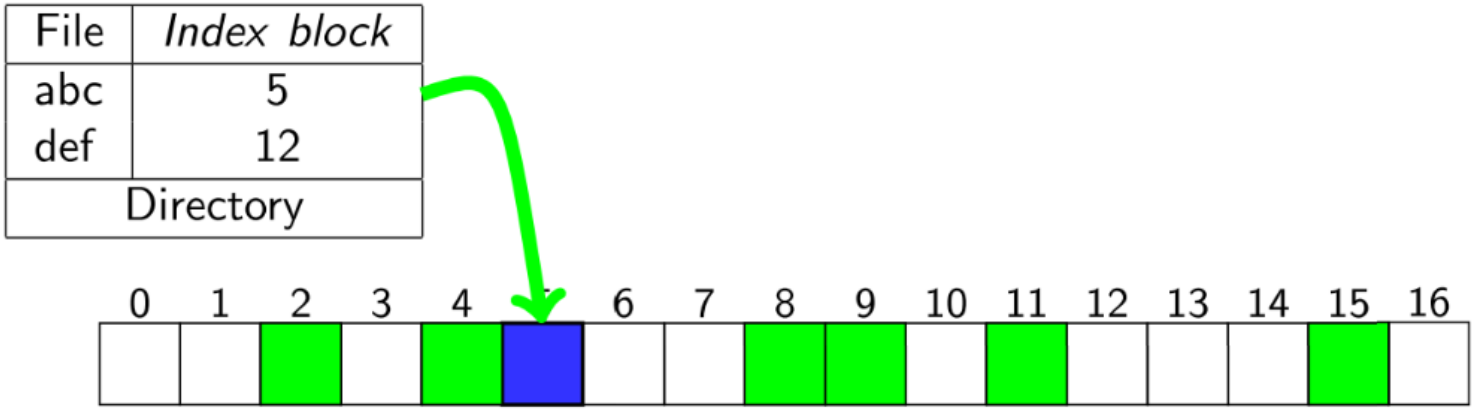

Files abc consists of 6 blocks: 2, 15, 4, 8, 9, 11

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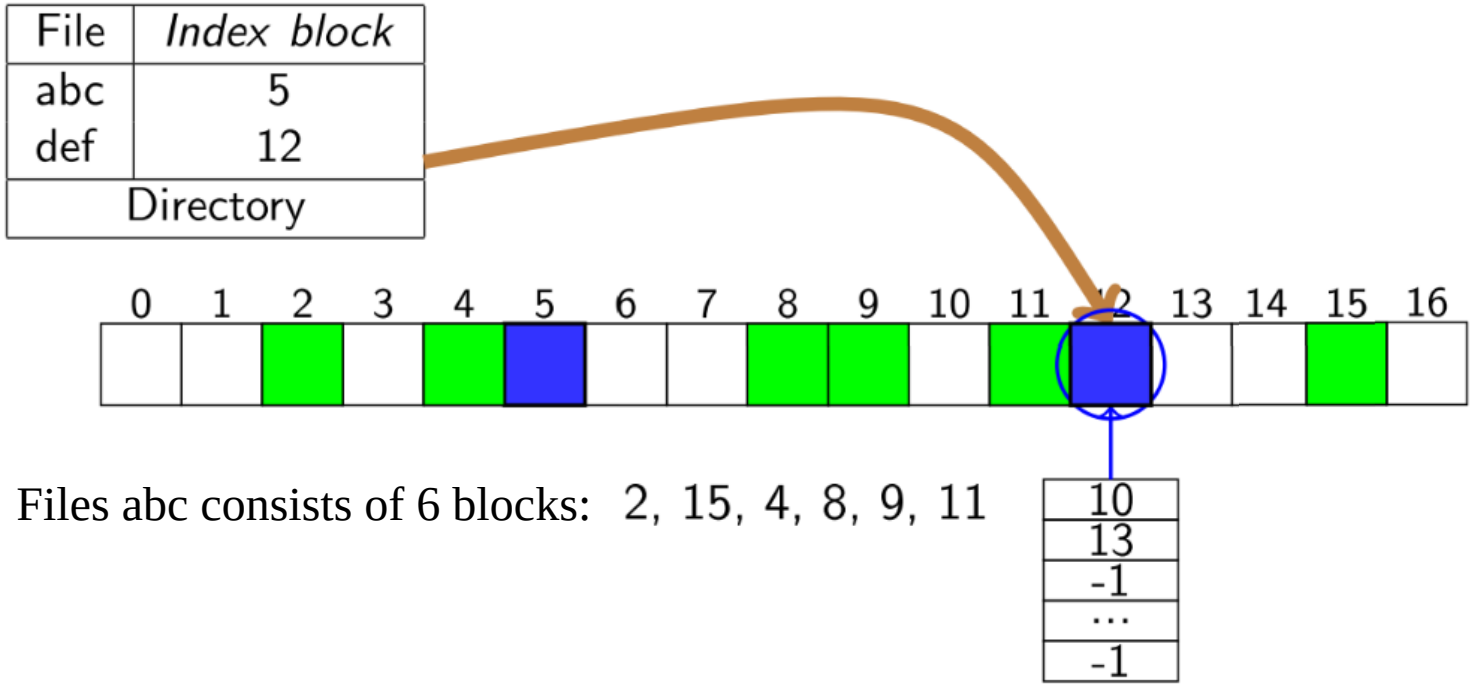

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Index allocation

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abc	5
def	12
Directory	

Files abc consists of 6 blocks: 2, 15, 4, 8, 9, 11

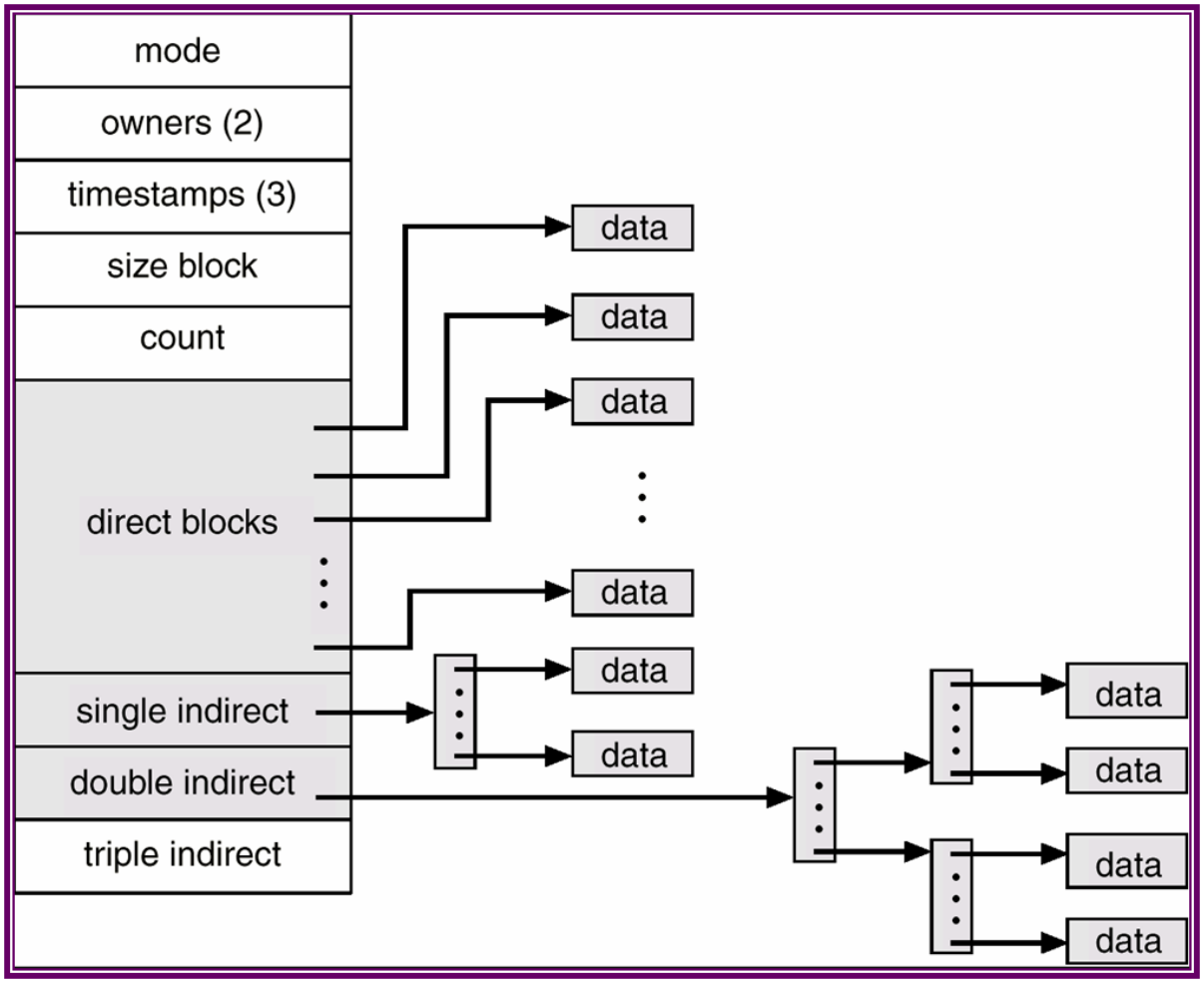
Files abc consists of 2 blocks: 10, 13

Index allocation

- Member **i** of index block point to block i of file
  - Read block **i** use pointer declared at member **i** of index block
- Create file, members of index block has null value (-1)
- Require block **i**, block address is allocated, putted into member **i**
- Remark
  - No external fragmentation
  - Allow direct access
  - Require index block: file has small size require 2 blocks
    - Block for data
    - Block for index (use 1 member)

    Solution: Reduce block size ⇒ Reduce cost of memory ⇒ file's size storing problem.
- Linked map
  - Connects index block
  - Last member of index block point to other index block if it's necessary
- Multi level Index
  - Use an index block point to other index block

Link map (UNIX)



- 12 direct block point to data block
- Single indirect block contains address of direct block
- Double indirect block contains address of Single indirect block
- Triple indirect block contain address of Double indirect

Chapter 4: File system management
2. File system's implementation
2.3 Free storage area management

- Directory implementation
- Storage area allocation methods
- Free storage area management

Methods

- Bit vector
  - Each block represented by 1 bit (1: free; 0: allocated)
  - Easy to find n contiguous memory block
  - Need instruction to work with bit
- Link list
  - Hold pointer to first free disk block
  - This memory block contain pointer to next free disk block
  - Not effective when traversing the list
- Grouping
  - Hold address of n free block in the first free block
  - $n - 1$ first free block, block n contain address of next n free block
  - Pros: Fast to find free memory area
- Counting
  - Due to memory block continuously allocated and free concurrently
  - Rule: Store address of the first free block and size of contiguous memory area in free-memory-area management list
  - Effective when the counter larger than 1

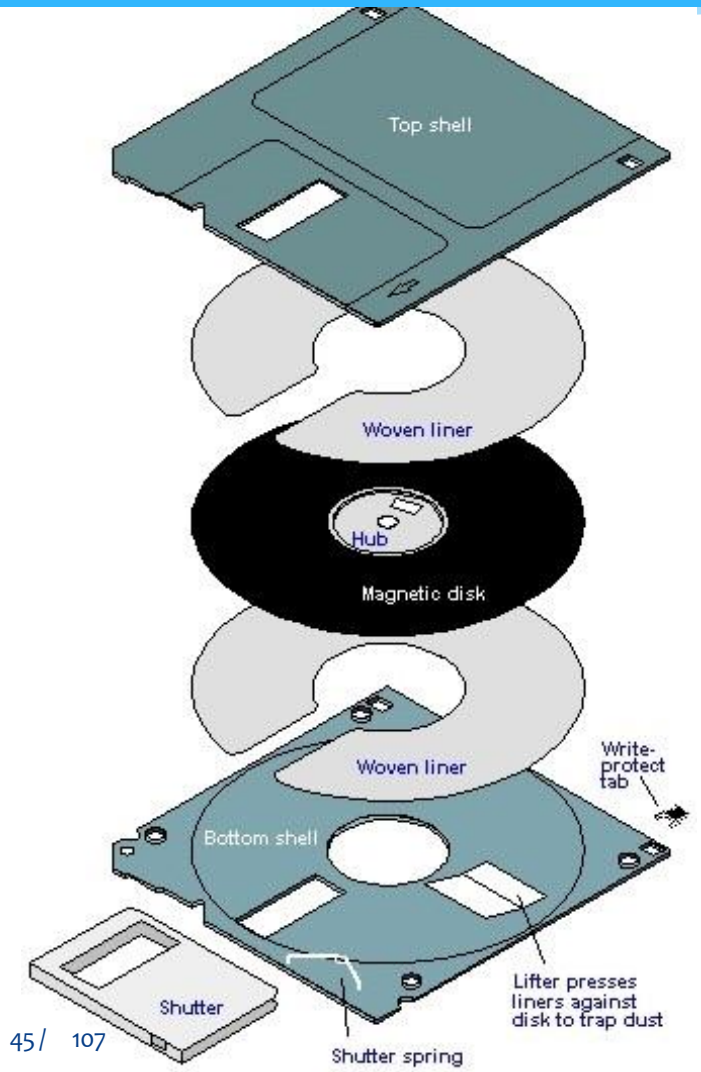
Chapter 4 File system management

1. File system
2. File system's implementation
3. Information organization on disk
4. FAT system

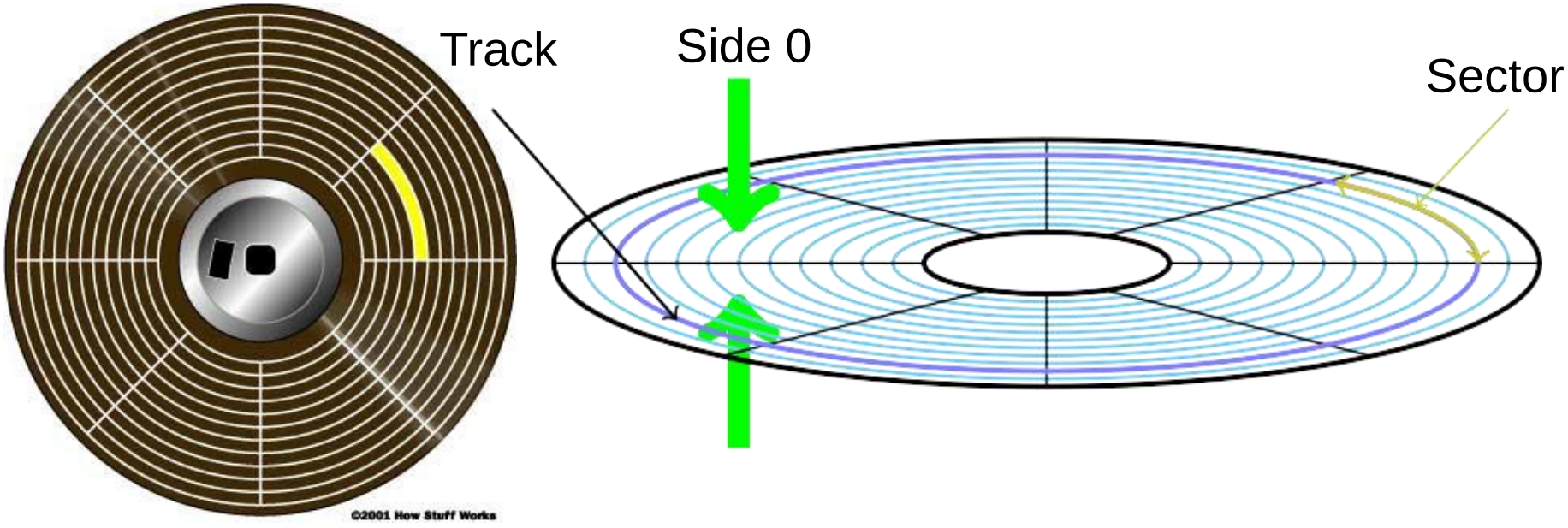
- Disk's physical structure
- Disk's logical structure

Floppy disk $5\frac{1}{4}$

Floppy disk $3\frac{1}{2}$



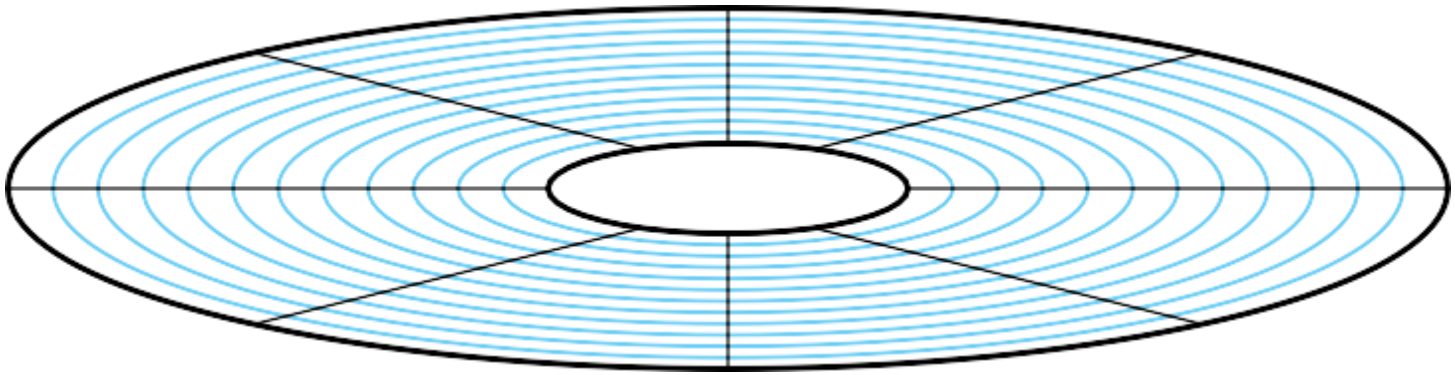
Floppy disk's physical structure



- Track: concentric circles around the disk
  - Numbered 0, 1,. . . From outer to inner
- Side. Each side is read by a Header
  - Headers are numbered 0, 1
- Sector
  - Numbered 1, 2,. . .

Information positioning on floppy disk

- Sector: information unit for working with disk
- Sector defined via 3 dimension position: Header, Track, Sector
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector



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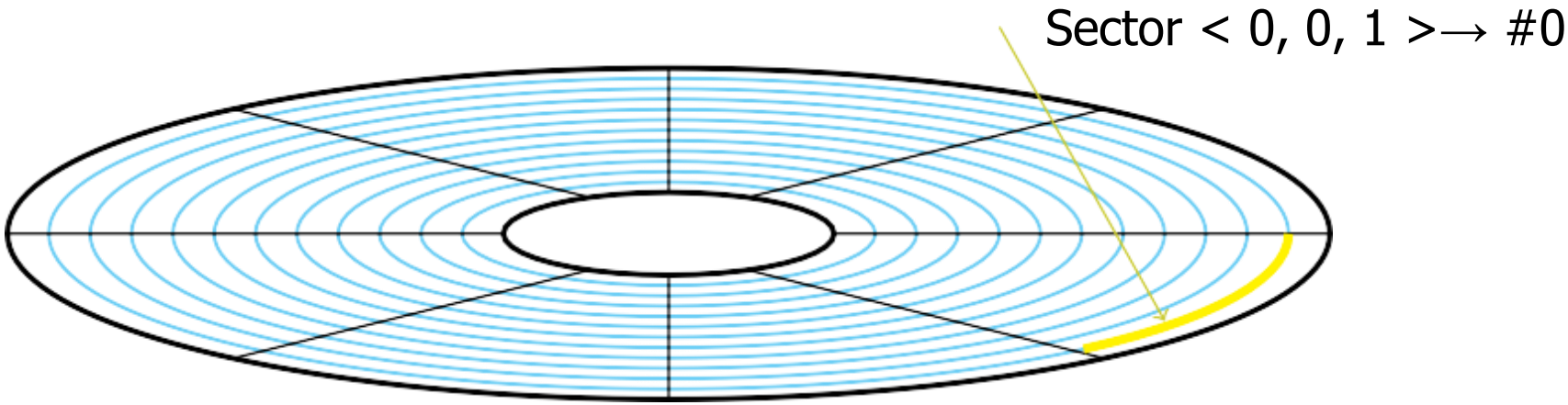

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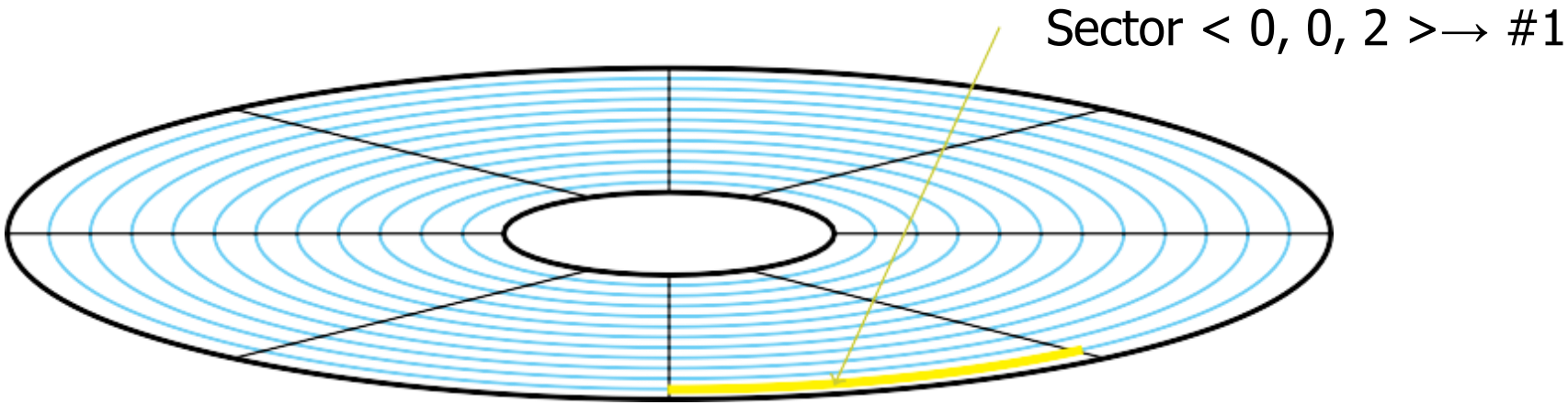
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector



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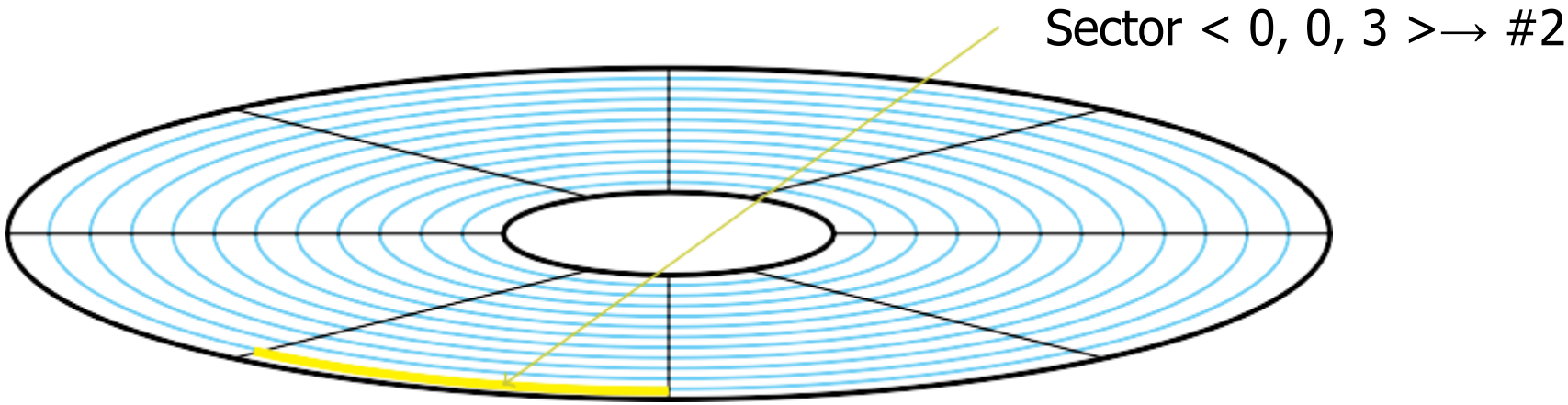

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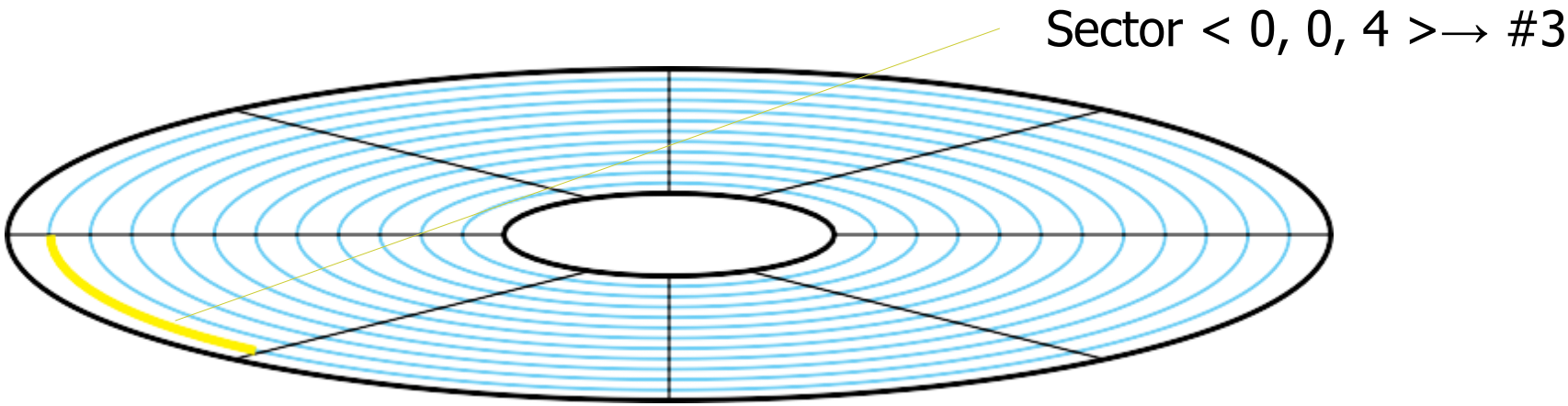

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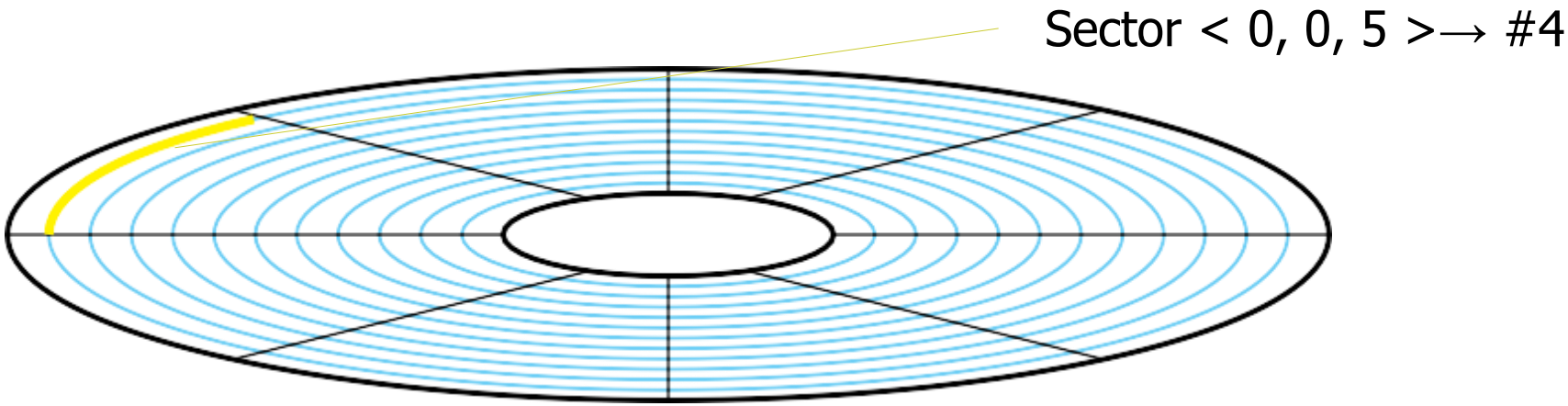

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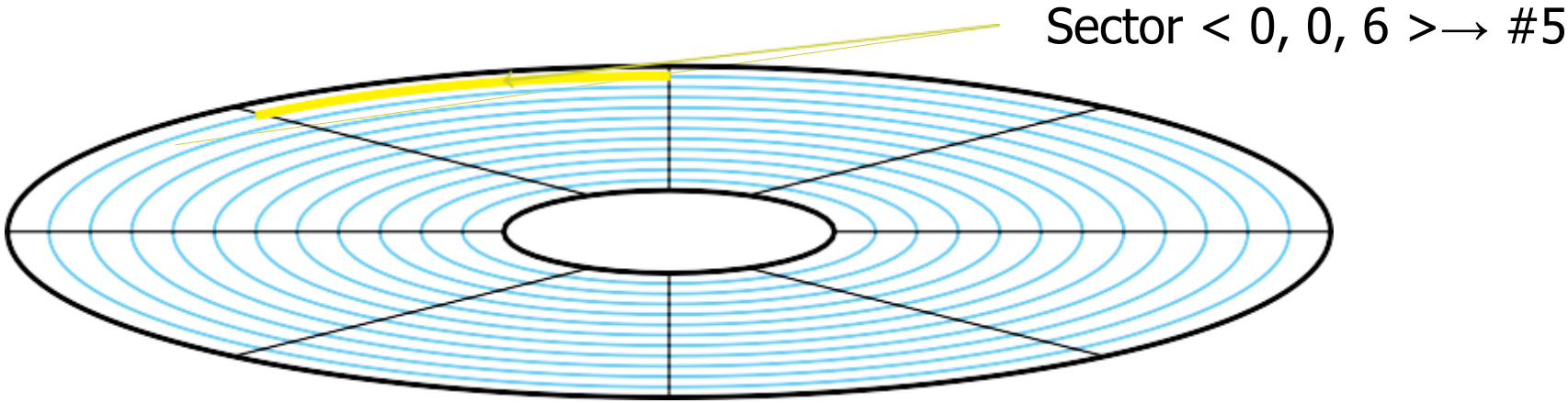

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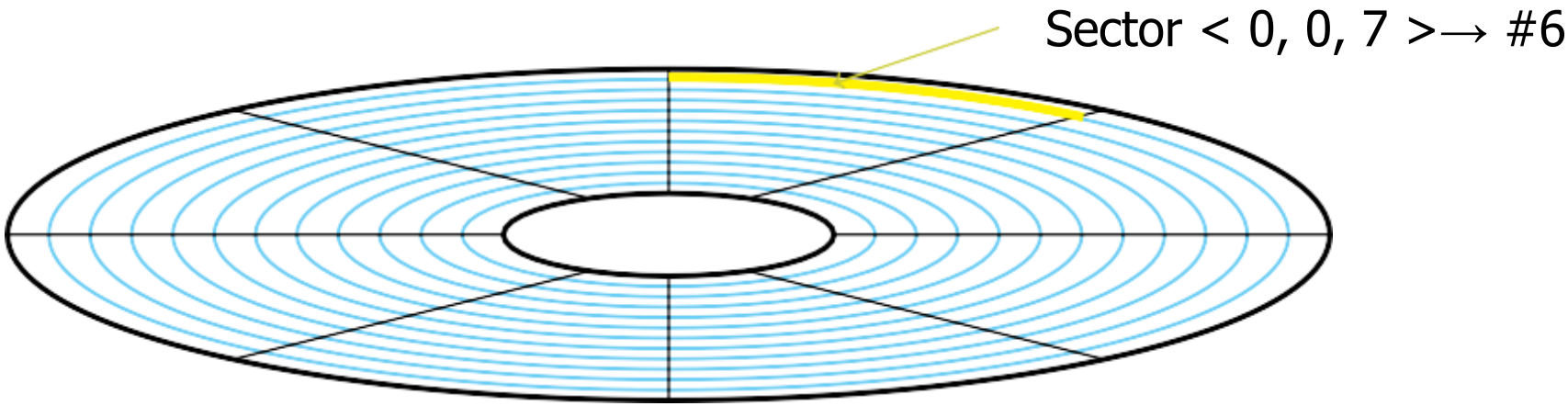

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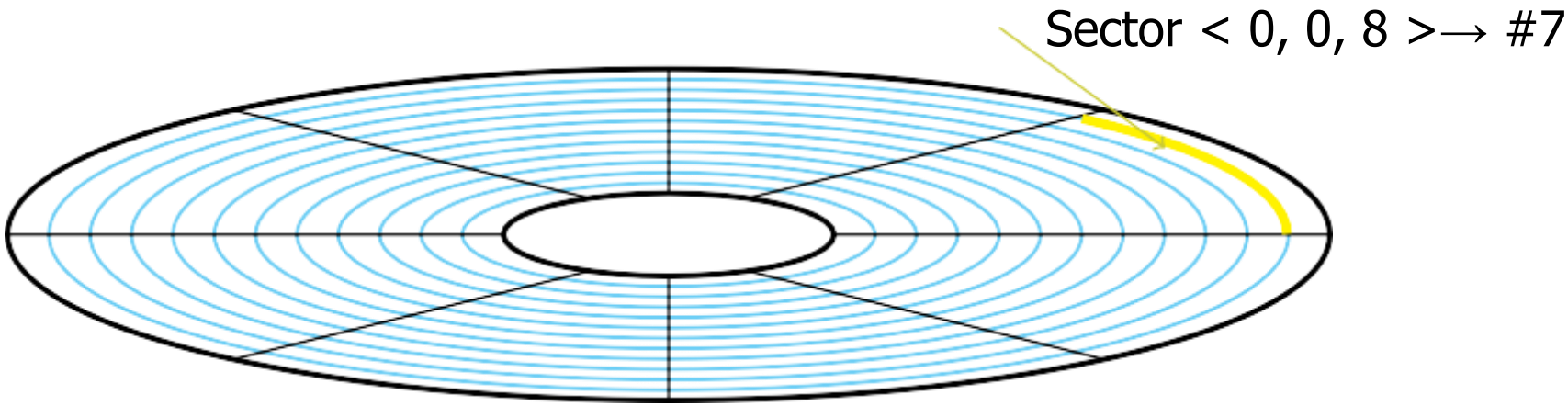

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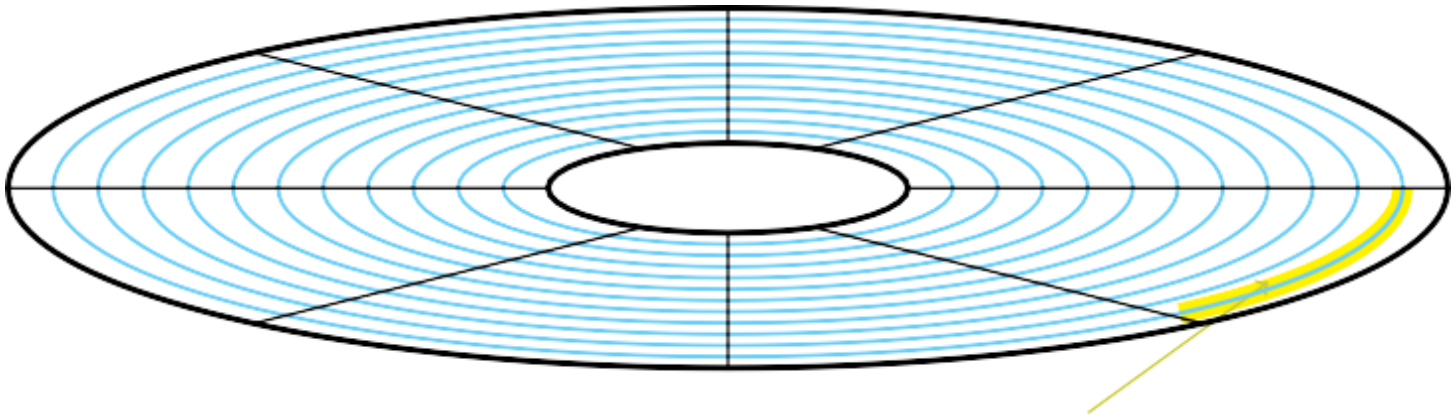
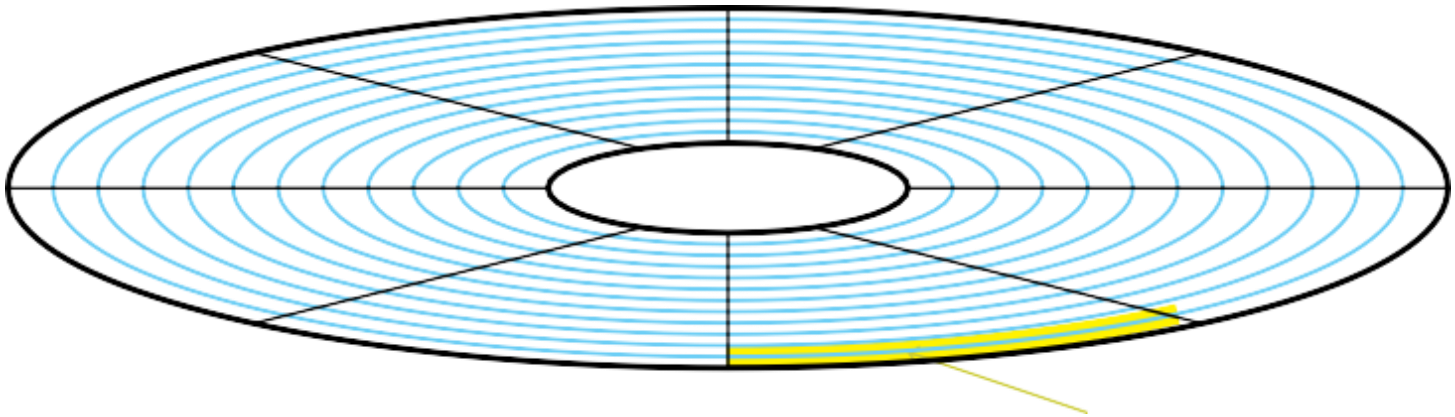


Sector < 1, 0,1>→ #8

Information positioning on floppy disk

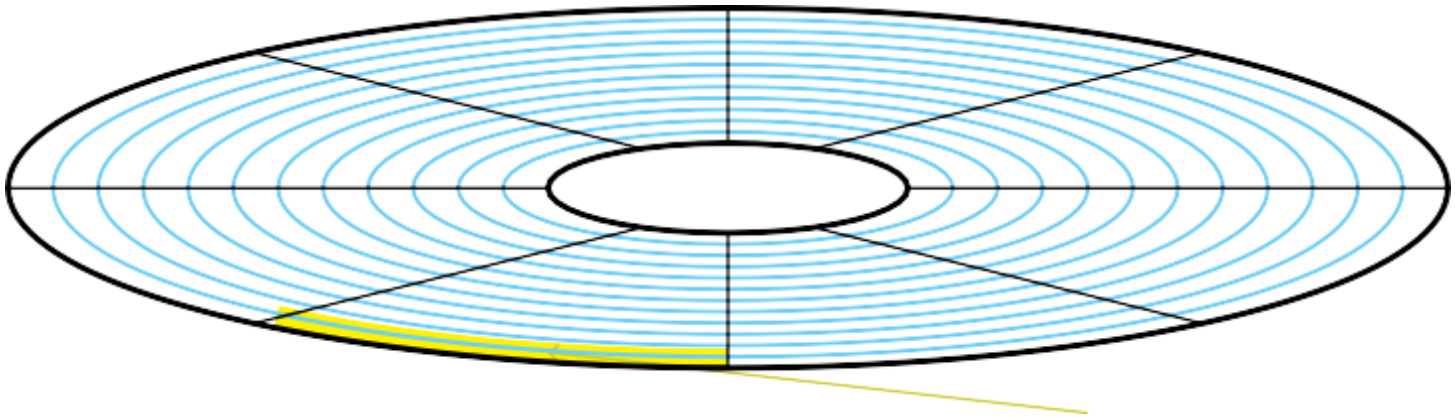
- Sector: information unit for working with disk
- Sector defined via 3 dimension position: Header, Track, Sector
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector



Sector < 1, 0,2>→ #9

Information positioning on floppy disk

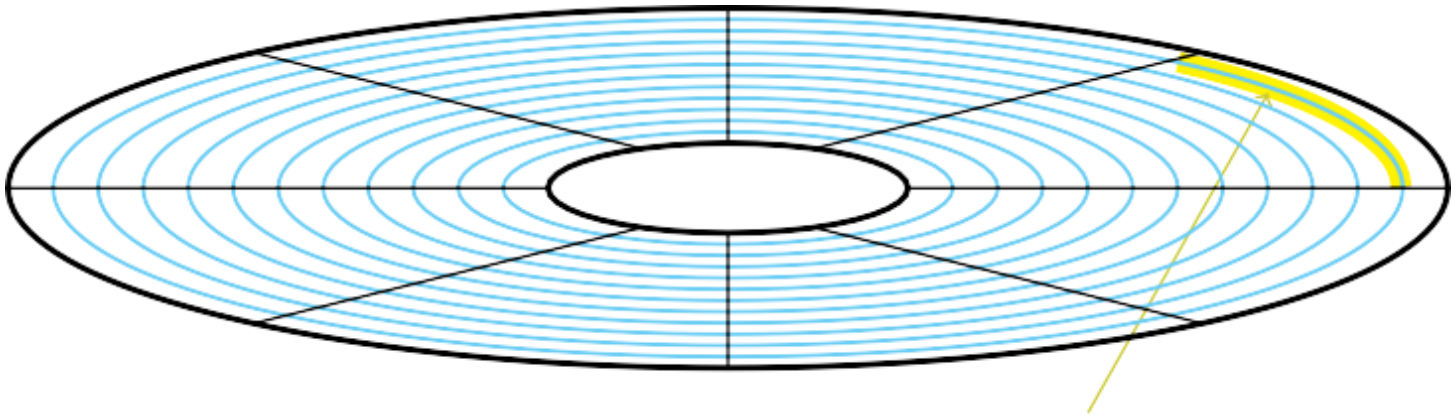
- Sector: information unit for working with disk
- Sector defined via 3 dimension position: Header, Track, Sector
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector



Sector < 1, 0,3>→ #10

Information positioning on floppy disk

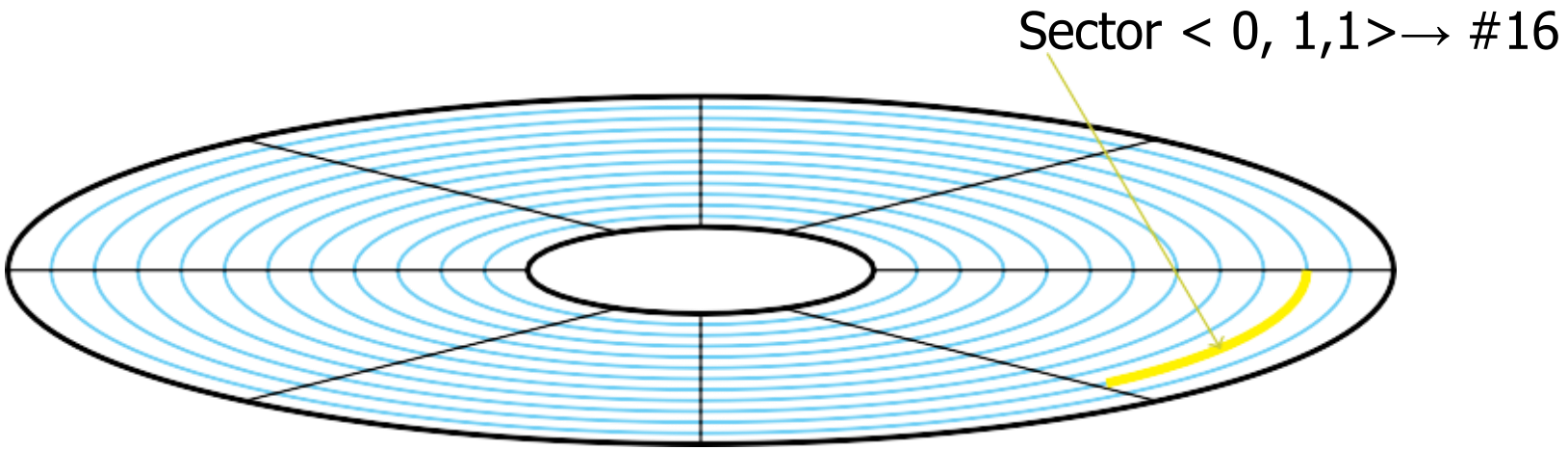
- Sector: information unit for working with disk
- Sector defined via 3 dimension position: Header, Track, Sector
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector



Sector < 1, 0,8>→ #15

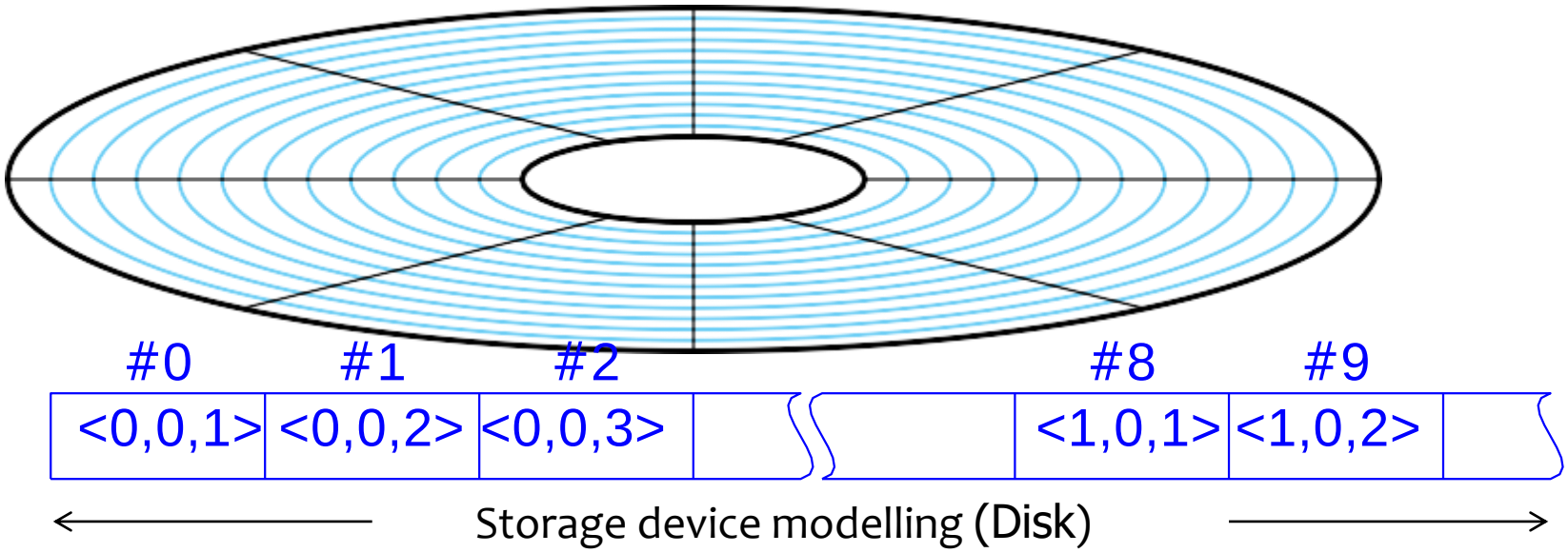
Information positioning on floppy disk

- Sector: information unit for working with disk
- Sector defined via 3 dimension position: Header, Track, Sector
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector



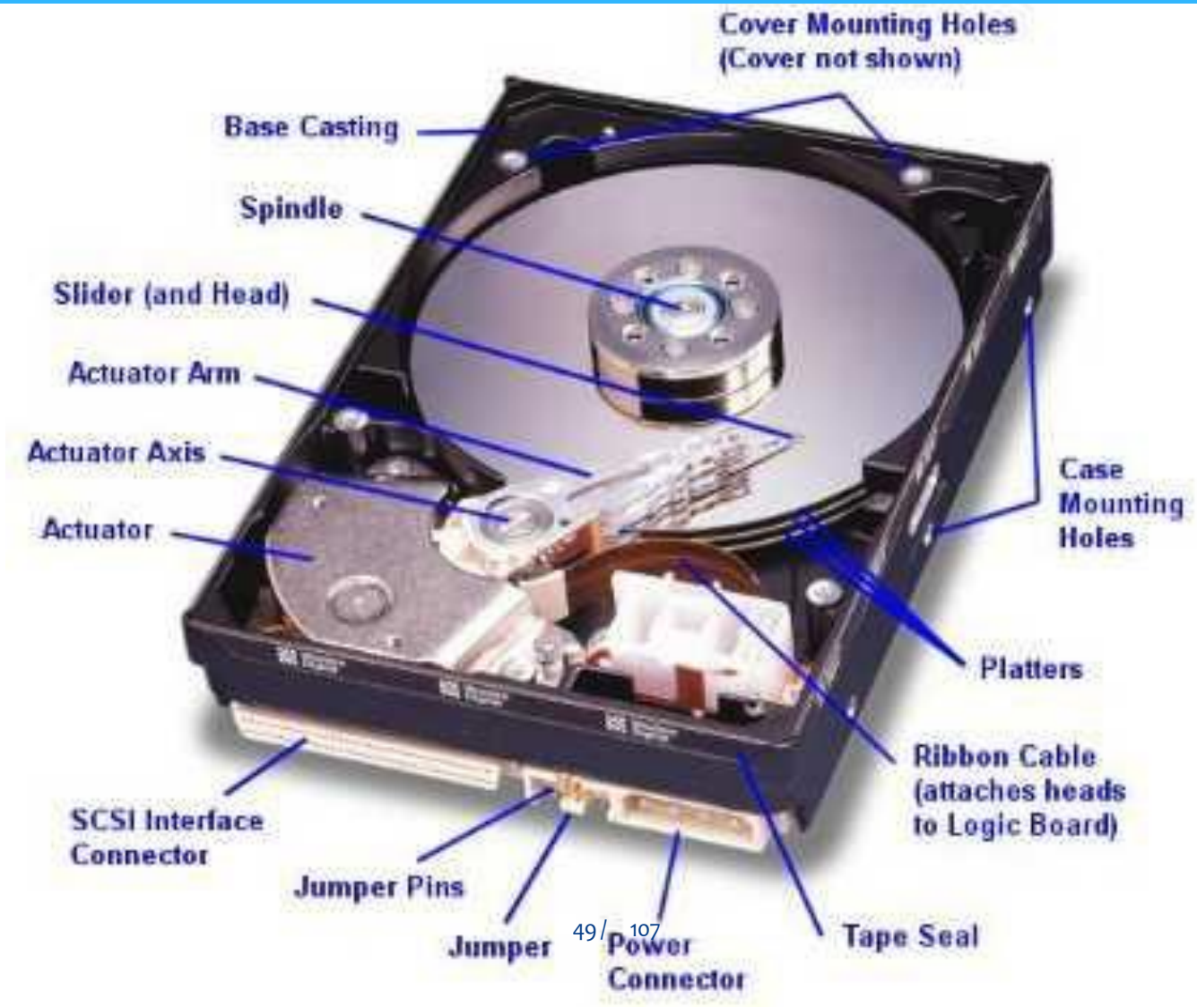
Information positioning on floppy disk

- Sector: information unit for working with disk
- Sector defined via 3 dimension position: Header, Track, Sector
  - Example: Floppy disk's Boot Sector: Sector <0, 0, 1>
- Sector defined via sector number (1 direction position)
  - Relative position from disk's first sector

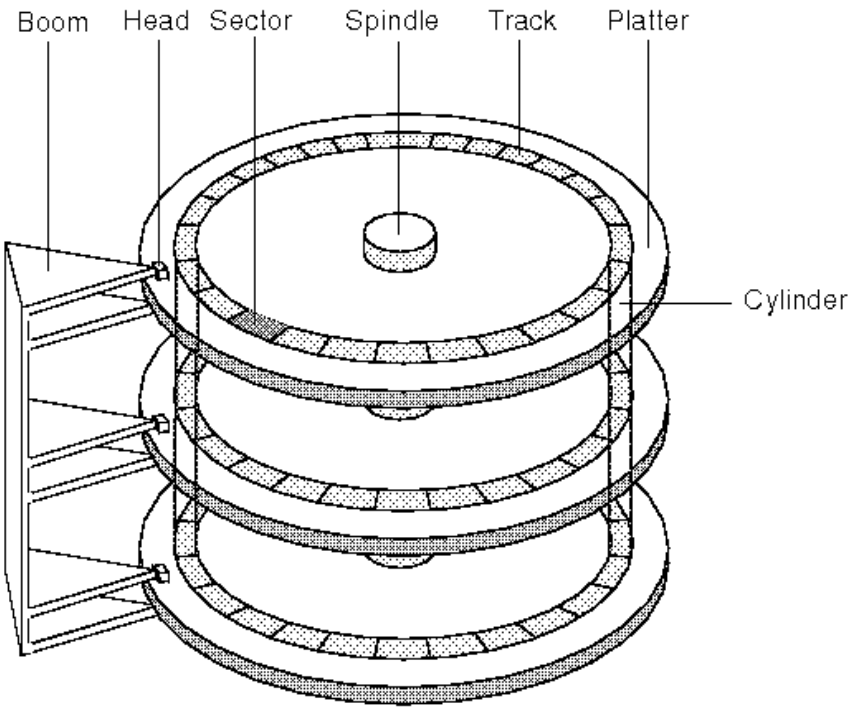


Hard disk

Hard disk


Cover Mounting Holes
(Cover not shown)
Base Casting
Spindle
Slider (and Head)
Actuator Arm
Actuator Axis
Actuator
Case
Mounting
Holes
Platters
Ribbon Cable
(attaches heads
to Logic Board)
SCSI Interface
Connector
Jumper Pins
Jumper
Power
Connector
Tape Seal

Hard disk's physical structure



Structure

- Consist of many headers, numbered from 0,1
- Tracks with the same radius create a cylinder, numbered from 0, 1,..
- Sectors on each side of cylinder, numbered from 1,2,...

Information positioning

- 3 dimensions (H, C, S)
- 1 dimension: sector's number
  - Rule similar to floppy disk: Sector→Header→Cylinder

Accessing sector on disk

- Sector: information unit to work with disks
- Can access (read/write/format/...) to each sector
- Access via BIOS 13h interrupt (function 2, 3, 5,...)
  - Not depend on operating system
  - Sector is determined by address <H,C,S>
- Access via system call
  - Operating system's interrupt
    - Example: MSDOS provide 25h/26h interrupt allow read/write sectors at linear address
  - Use WIN32 API functions
    - CreateFile()/ReadFile()/WriteFile()...

Interrupt 13h

Register	Meaning
AH	2h:Read sector; 3h: write Sector
AL	Number of sector to read Sectors must be on the same side, track
DH	Header number
DL	Disk's number. 0h:A; 80h: First hard disk; 81h Second hard disk 2
CH	Track/Cylinder's number (Use 10 bits, borrow 2 high bits from CL)
CL	Sector's number (only use 6 lower bits)
ES:BX	Point to buffer area where data will be read (when AH=2h) or write to disk (when AH=3h)
CarryFlag	CF=0 no error; CL contains number of sector read CF=1 Had error, AH contains error's code

WinXP limit the use on interrupt 13h to direct access

Use interrupt 13h (Example)

```
#include <stdio.h>
#include <dos.h>
int main(int argc, char *argv[]){
        union REGS regs;
        struct SREGS sregs;
        int Buf[512];
        int i;
        regs.h.ah = 0x02;
        regs.h.al = 0x01;
        regs.h.dh = 0x00;
        regs.h.dl = 0x80;
        regs.h.ch = 0x00;
        regs.h.cl = 0x01;
        regs.x.bx = FP_OFF(Buf);
        sregs.es = FP_SEG(Buf);
        int86x(0x13,&regs,&regs,&sregs);
        for(i=0;i<512;i++) printf("%4X",Buf[i]);
        return 0;
}
```

Use WIN32 API

- HANDLE CreateFile(. . .): Open file/IO device
  - LPCTSTR lpFileName, ⇒ file/IO device's name
    - ” "□□?□□□□□□.□□C : ” Partition / Drive C
    - ”□□□□□.□□PhysicalDrive0” First hard drive
  - DWORD dwDesiredAccess,⇒ Operation with device
  - DWORD dwShareMode,⇒ Allow sharing
  - LPSECURITY_ATTRIBUTES lpSecurityAttributes (NULL),
  - DWORD dwCreationDisposition,⇒ Operation to perform
  - DWORD dwFlagsAndAttributes, ⇒ Attribute
  - HANDLE hTemplateFile (NULL)
- BOOL ReadFile(. . .)
  - HANDLE hFile,⇒ File to read
  - LPVOID lpBuffer, ⇒ Buffer to store data
  - DWORD nNumberOfBytesToRead,⇒, number of byte to read
  - LPDWORD lpNumberOfBytesRead,⇒ number of read bytes
  - LPOVERLAPPED lpOverlapped (NULL)
- BOOL WriteFile(. . .) ⇒Parameters similar to ReadFile()

Use WIN32 API (Example)

```
#include <windows.h>
#include <stdio.h>
int main(int argc, char *argv[]){
   HANDLE   hDisk;
   BYTE  Buf[512];
   int byteread,i;
   hDisk=CreateFile("¥¥¥¥.¥¥PhysicalDrive0",GENERIC_READ,
                    FILE_SHARE_READ | FILE_SHARE_WRITE,
                    NULL, OPEN_EXISTING,0,NULL);
   if (hDisk==INVALID_HANDLE_VALUE) printf("Device's error");
   else {
       ReadFile(hDisk,Buf,512,&byteread,NULL);
       for(i=0;i<512;i++)       printf("%4X",Buf[i]);
       CloseHandle(hDisk);
   }
   return 0;
}
```

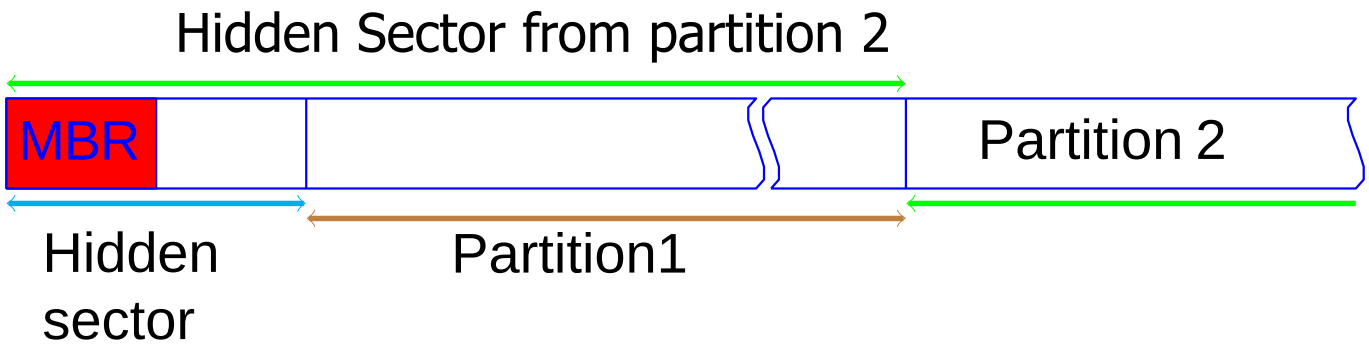
Result

```
33  C0  8E  D0  BC  00  7C  FB  50  07  50  1F  FC  BE  1B  7C  BF  1B  06  50
57  B9  E5  01  F3  A4  CB  BD  BE  07  B1  04  38  6E  00  7C  09  75  13  83
C5  10  E2  F4  CD  18  8B  F5  83  C6  10  49  74  19  38  2C  74  F6  A0  B5
07  B4  07  8B  F0  AC  3C  00  74  FC  BB  07  00  B4  0E  CD  10  EB  F2  88
4E  10  E8  46  00  73  2A  FE  46  10  80  7E  04  0B  74  0B  80  7E  04  0C
74  05  A0  B6  07  75  D2  80  46  02  06  83  46  08  06  83  56  0A  00  E8
21  00  73  05  A0  B6  07  EB  BC  81  3E  FE  7D  55  AA  74  0B  80  7E  10
00  74  C8  A0  B7  07  EB  A9  8B  FC  1E  57  8B  F5  CB  BF  05  00  8A  56
00  B4  08  CD  13  72  23  8A  C1  24  3F  98  8A  DE  8A  FC  43  F7  E3  8B
D1  86  D6  B1  06  D2  EE  42  F7  E2  39  56  0A  77  23  72  05  39  46  08
73  1C  B8  01  02  BB  00  7C  8B  4E  02  8B  56  00  CD  13  73  51  4F  74
4E  32  E4  8A  56  00  CD  13  EB  E4  8A  56  00  60  BB  AA  55  B4  41  CD
13  72  36  81  FB  55  AA  75  30  F6  C1  01  74  2B  61  60  6A  00  6A  00
FF  76  0A  FF  76  08  6A  00  68  00  7C  6A  01  6A  10  B4  42  8B  F4  CD
13  61  61  73  0E  4F  74  0B  32  E4  8A  56  00  CD  13  EB  D6  61  F9  C3
49  6E  76  61  6C  69  64  20  70  61  72  74  69  74  69  6F  6E  20  74  61
62  6C  65  00  45  72  72  6F  72  20  6C  6F  61  64  69  6E  67  20  6F  70
65  72  61  74  69  6E  67  20  73  79  73  74  65  6D  00  4D  69  73  73  69
6E  67  20  6F  70  65  72  61  74  69  6E  67  20  73  79  73  74  65  6D  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  00  00  00  00  00  00  00  00  00  00  00  2C  44  63
0A  08  0B  08  00  00  80  01  01  00  07  FE  FF  FF  3F  00  00  00  2C  92
00  02  00  00  C1  FF  0F  FE  FF  FF  31  41  8A  03  0E  D3  1D  01  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  55  AA
```

- Disk's physical structure
- Disk's logical structure

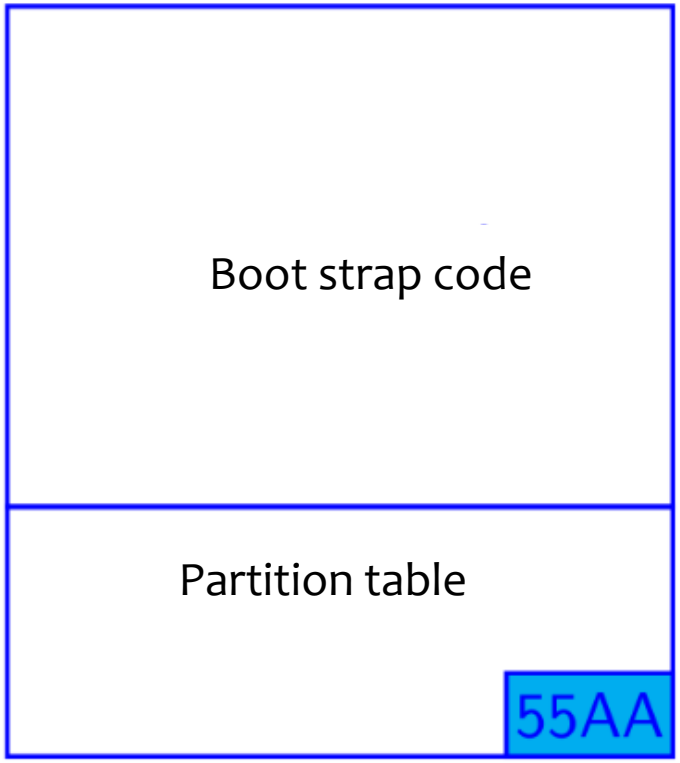
logical structure

- Floppy disk: Each OS has their own management strategy
- Hard disk (mass storage)
  - Divided into sections (Partitions, Volumes,..)
    - Each section is a set of contiguous Cylinders
    - User cab set the size (Example: use fdisk command)
  - Each partition can be manage by an independent OS
    - OS format partition in an usable format
    - Different systems exist: FAT, NTFS, EXT3,...
  - In front of partitions are masked sector
    - Master Boot Record (MBR): Disk's first Sector



Master Boor Record

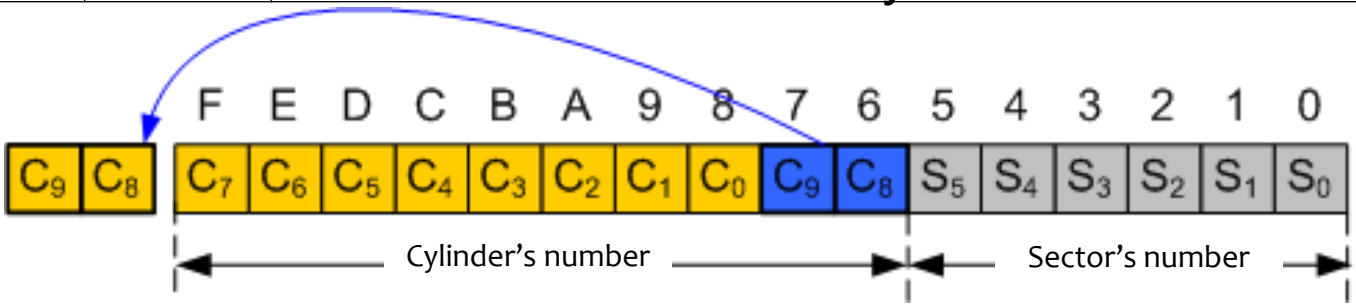
- Disk's most important Sector
- Disk's first sector (Number 0 or address <0, 0, 1>)
- Structure consist of 3 parts



1. Bootstrap code
   - Read partition table to know
     - Position of partitions
     - Active partition (contains OS)
   - Read and execute first sector of active partition
2. Partition table (64bytes)
   - Consist of 4 elements, each element 16 bytes
   - Element contains information of one partition: Position, size, owned system
3. OS's signature (always 55AA)

Structure of one partition table's element

	Stt	Ofs	Size	Meaning
	1	0	1B	Active partition? 80h if yes; 0: Data
Start address	2	1	1B	Partition's first header number
	3	2	1W	Partition's first sector and cylinder's number
	4	4	1B	Recognition code. 05/0F: extended Partition 06:Big Dos; 07:NTFS; 0B: FAT32,..
Last address	5	5	1B	Last header's number
	6	6	1W	Last sector and cylinder 's number *(sector's number only use 6 lower bits)*
	7	8	1DW	Start address, (in sector's numbering)
	8	12	1DW	Number of sectors in partition



Example 1

```
00 01 01  00   07 FE 3F  F8   3F 00  00 00   7A 09  3D 00
80 00 01  F9   0B FE  BF 30   B9 09  3D 00   38  7B 4C 00
00 00 81  EB   0F FE  FF FF   2B 1D  B7 00   72 13 7A  00
00 00 00  00   00 00 00  00   00 00 00  00   00 00 00  00
55 AA
```

Decode

Boot	Start position			End position			#sector	Number of sector
	Hdr	Cyl	Sec	HdR	Cyl	Sec		
No	1	0	1	254	248	63	63	4000122
Yes	0	249	1	254	560	63	4000185	5012280
No	0	747	1	254	1023	63	12000555	8000370
-	0	0	0	0	0	0	0	0

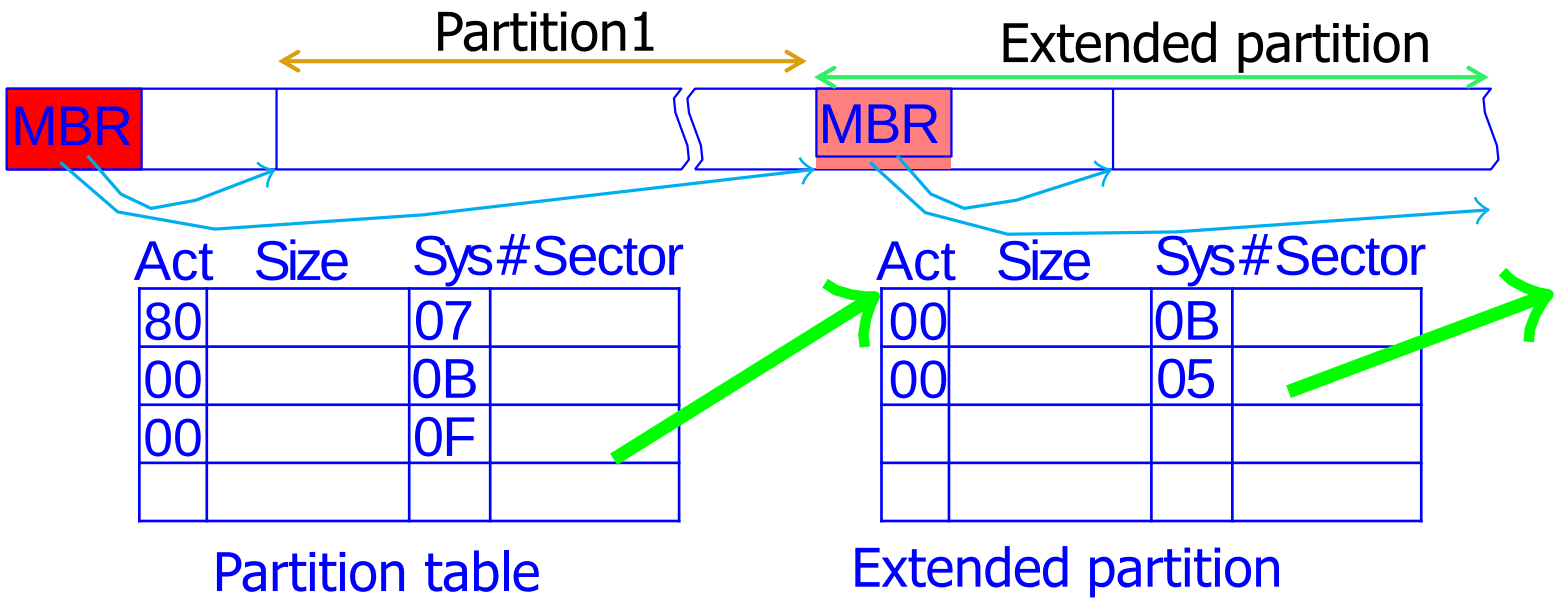
Example 2

```
 80   01   01   00   07   FE   FF   FF   3F   00   00   00   2C   92   00   02
 00   00   C1   FF   0F   FE   FF   FF   31   41   8A   03   0E   D3   1D   01
 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
 55   AA
```

Active	Begin Hdr	Begin Cyl	Begin Sct	Sys	End Hdr	End Cyl	End Sct	Relative Sector	Number Of Sector
YES	1	0(0)	1	07	254	1023(2090)	63	63	33591852
NO	0	1023(3697)	1	0F	254	1023(4862)	63	59392305	18731790
NO	0	0(0)	0	00	0	0	0	0	0
NO	0	0(0)	0	00	0	0	0	0	0

Extended partition

- When recognition code is 05 or 0F -> extended partition
- Organized as a physical hard disk
  - First Sector is MBR, contain information of partitions inside this extended partition
    - Element in extended partition can be an extended partition
  - Allow to create more than 4 logic drive



Example of extended partition 1

```
 80   01   01   00   07   EF   FF   FF   3F   00   00   00   11   2F   F7   01
 00   00   C1   FF   0F   EF   FF   FF   50   2F   F7   01   B0   23   B1   02
 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
 55   AA
```

Active	Begin			Sys	End			Relative	Number
	Hdr	Cyl	Sct		Hdr	Cyl	Sct	Sector	Of Sector
YES	1	0	1	07	239	1023	63	63	32976657
NO	0	1023	1	0F	239	1023	63	32976720	45163440
NO	0	0	0	00	0	0	0	0	0
NO	0	0	0	00	0	0	0	0	0

Example of extended partition 2

```
Extended Partition (Sector number 32976720)...
  00   01   C1   FF   06   EF   FF   FF   3F   00   00   00   51   E8   76   01
  00   00   C1   FF   05   EF   FF   FF   90   E8   76   01   20   3B   3A   01
  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
  55   AA
```

Active	Begin			Sys	End			Relative	Number
	Hdr	Cyl	Sct		Hdr	Cyl	Sct	Sector	Of Sector
NO	1	1023	1	06	239	1023	63	63	24569937
NO	0	1023	1	05	239	1023	63	24570000	20593440
NO	0	0	0	00	0	0	0	0	0
NO	0	0	0	00	0	0	0	0	0

Example of extended partition 3

```
Extended Partition (Sector number 57546720)...
  00   01   C1   FF   0B   EF   FF   FF   3F   00   00   00   E1   3A   3A   01
  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   00   00
  55   AA
```

Active	Begin Hdr	Begin Cyl	Begin Sct	Sys	End Hdr	End Cyl	End Sct	Relative Sector	Number Of Sector
NO	1	1023	1	0B	239	1023	63	63	20593377
NO	0	0	0	00	0	0	0	0	0
NO	0	0	0	00	0	0	0	0	0
NO	0	0	0	00	0	0	0	0	0

Chapter 4 File system management

1. File system
2. File system's implementation
3. Information organization on disk
4. FAT system

File systems

Many file systems existed

- FAT system
  - FAT 12/ FAT16 for MSDOS
  - FAT32 from WIN98
  - 12/16/32: Number of bit to identify a cluster
- NTFS
  - Used in WINNT, WIN2000
  - Utilize 64 bits to identify a cluster
  - Better than FAT in security, encoding, compress data,...
- EXT3
  - Used in Linux
- CDFS
  - File system used for CDROM
  - Limited depth in directory tree and size of names
- UDF
  - Developed from CDFS for DVD-ROM, support long file name

- Boot sector
- FAT (File Allocation Table)
- Root directory

Partitioning structure for FAT

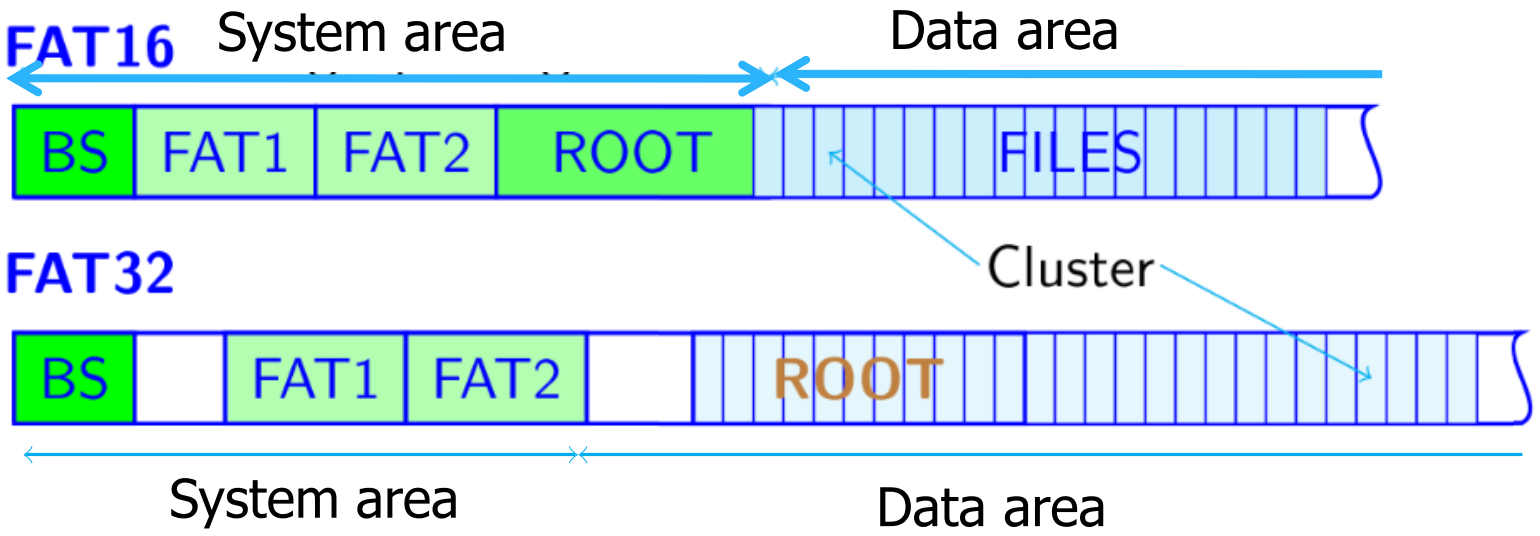
FAT12/16

- Maximum number of cluster FAT12: $2^{12} - 18$; FAT16 : $2^{16} - 18$
- Max size: FAT12: 32MB; FAT16: 2GB/4GB (32K/64K Cluster)

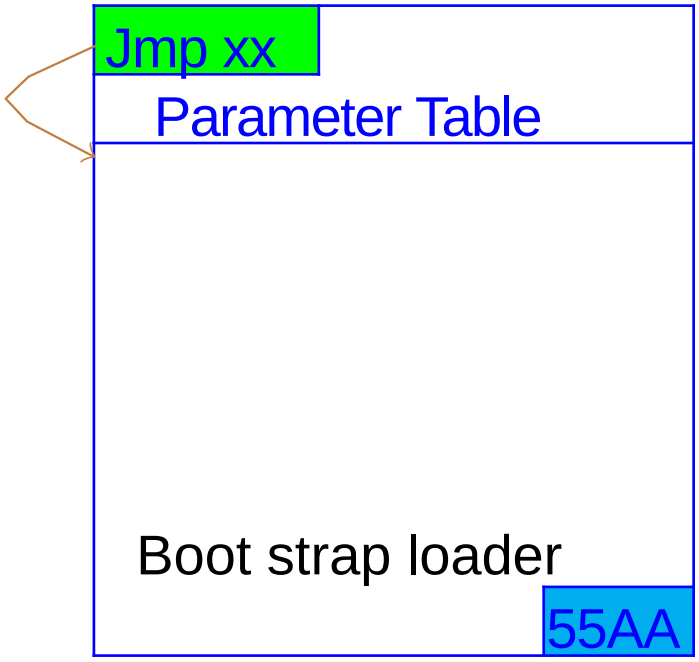
FAT32

- Only use 28 bits ⇒ Maximum Number of cluster: $2^{28} - 18$
- Max size: 2TB/8GB/16TB (8KB/32KB/64KB Cluster)

FAT's logical structure



Structure



EB	58	90	4D	53	44	4F	53	35	2E	30	00	02	10	24	00
02	00	00	00	00	F8	00	00	3F	00	F0	00	3F	00	00	00
E1	3A	3A	01	3E	27	00	00	00	00	00	00	02	00	00	00
01	00	06	00	00	00	00	00	00	00	00	00	00	00	00	00
80	00	29	D9	DF	92	BC	4E	4F	20	4E	41	4D	45	20	20
20	20	46	41	54	33	32	20	20	20	33	C9	8E	D1	BC	F4
7B	8E	C1	8E	D9	BD	00	7C	88	4E	02	8A	56	40	B4	08
CD	13	73	05	B9	FF	FF	8A	F1	66	0F	B6	C6	40	66	0F
B6	D1	80	E2	3F	F7	E2	86	CD	C0	ED	06	41	66	0F	B7
C9	66	F7	E1	66	89	46	F8	83	7E	16	00	75	38	83	7E
2A	00	77	32	66	8B	46	1C	66	83	C0	0C	BB	00	80	B9
01	00	E8	2B	00	E9	48	03	A0	FA	7D	B4	7D	8B	F0	AC
84	C0	74	17	3C	FF	74	09	B4	0E	BB	07	00	CD	10	EB
EE	A0	FB	7D	EB	E5	A0	F9	7D	EB	E0	98	CD	16	CD	19
66	60	66	3B	46	F8	0F	82	4A	00	66	6A	00	66	50	06
53	66	68	10	00	01	00	80	7E	02	00	0F	85	20	00	B4
41	BB	AA	55	8A	56	40	CD	13	0F	82	1C	00	81	FB	55
AA	0F	85	14	00	F6	C1	01	0F	84	0D	00	FE	46	02	B4
42	8A	56	40	8B	F4	CD	13	B0	F9	66	58	66	58	66	58
66	58	EB	2A	66	33	D2	66	0F	B7	4E	18	66	F7	F1	FE
C2	8A	CA	66	8B	D0	66	C1	EA	10	F7	76	1A	86	D6	8A
56	40	8A	E8	C0	E4	06	0A	CC	B8	01	02	CD	13	66	61
0F	82	54	FF	81	C3	00	02	66	40	49	0F	85	71	FF	C3
4E	54	4C	44	52	20	20	20	20	20	20	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	00	00	00	0D	0A	52	65
6D	6F	76	65	20	64	69	73	6B	73	20	6F	72	20	6F	74
68	65	72	20	6D	65	64	69	61	2E	FF	0D	0A	44	69	73
6B	20	65	72	72	6F	72	FF	0D	0A	50	72	65	73	73	20
61	6E	79	20	6B	65	79	20	74	6F	20	72	65	73	74	61
72	74	0D	0A	00	00	00	00	00	AC	CB	D8	00	00	55	AA

- Partition's First Sector
- Structure consist of 3 parts
  - BPB: Bios Parameter Block
  - Boot strap loader
  - System's signature (always 55AA)

Bios Parameter Block's structure – Common part

Stt	Ofs	Size	Sample value	Meaning
1	0	3B	EB 3C 90	Jump to begin position of boot strap loader
2	3	8B	MSDOS5.0	Name of system used formatted the disk
3	11	1W	00 02	Size of 1 sector, normally 512
4	13	1B	40	Number of sectors for 1 cluster (32K-Cluster)
5	14	1W	01 00	Num of scts before FAT/Num of reserved scts
6	16	1B	02	Num of FAT
7	17	1W	00 02	Num of ROOT's element. FAT32: 00 00
8	19	1W	00 00	Total sector on disk (< 32M) or 0000
9	21	1B	F8	Disk format (F8:HD, F0: Disk 1.44M)
10	22	1W	D1 00	Num of sector for one FAT(209)
11	24	1W	3F 00	Num of sector for one track (63)
12	26	1W	40 00	Num of headers (64)
13	28	1DW	3F 00 00 00	Num of hidden sector – Sectors before volume (63)
14	32	1DW	41 0C 34 00	Total sector on disk (3411009)

Bios Parameter Block's structure – Part for FAT12/FAT16 only

Stt	Ofs	Kt	Sample value	Meaning
15	36	1B	80h	Physical disk num 0: A drive; 80h: C drive
16	37	1B	00	Reserved, high byte is for disk number
17	38	1B	29h	Boot sector extension 29h
18	39	1DW	D513 5B24	Volumn Serial number(245B-13D5)
19	43	11B	NO NAME	Volume's Label
20	54	8B	FAT16	Reserved, normally for FAT description's text
21	62	-		Bootstrap loader

Example:

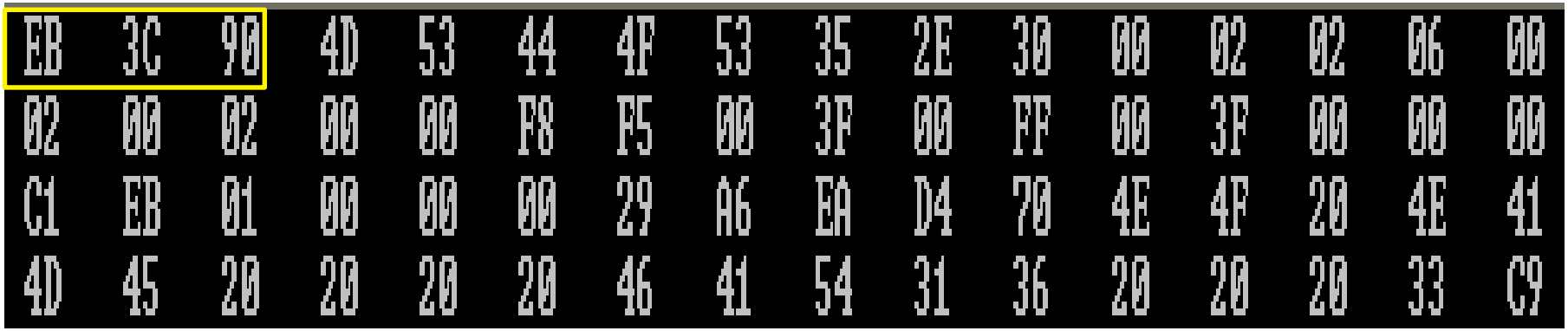
```
EB 3C 90 4D 53 44 4F 53 35 2E 30 00 02 02 06 00
02 00 02 00 00 F8 F5 00 3F 00 FF 00 3F 00 00 00
C1 EB 01 00 00 00 29 A6 EA D4 70 4E 4F 20 4E 41
4D 45 20 20 20 20 46 41 54 31 36 20 20 20 33 C9
```

FAT16's disk parameter decoding example

```
EB 3C 90 4D 53 44 4F 53 35 2E 30 00 02 02 06 00
02 00 02 00 00 F8 F5 00 3F 00 FF 00 3F 00 00 00
C1 EB 01 00 00 00 29 A6 EA D4 70 4E 4F 20 4E 41
4D 45 20 20 20 20 46 41 54 31 36 20 20 20 33 C9
```

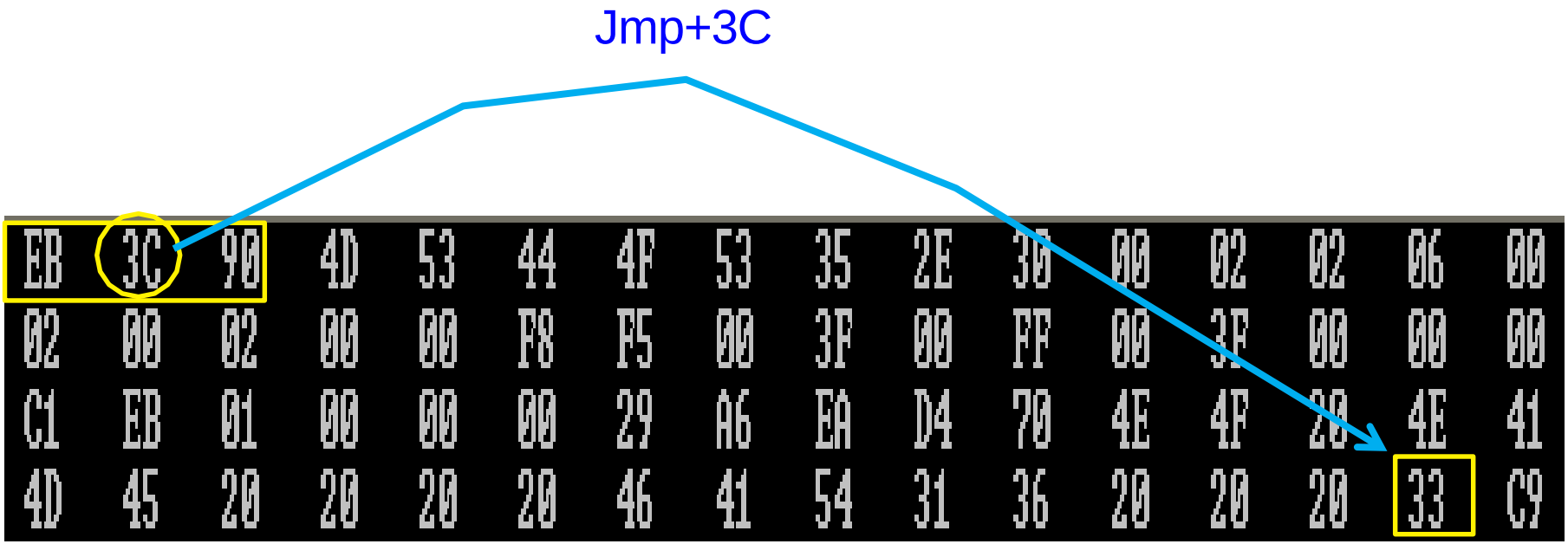
FAT16's disk parameter decoding example

First 3 Bytes đầu: Jump to the start of boot strap loader



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

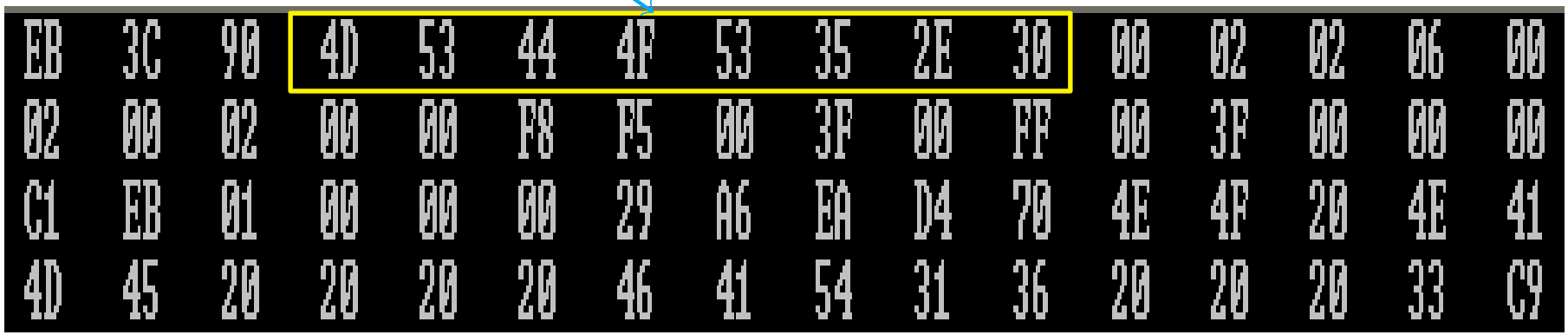


FAT16's disk parameter decoding example

8 Bytes

Name of the system utilized to format disk

OEName: MSDOS5.0

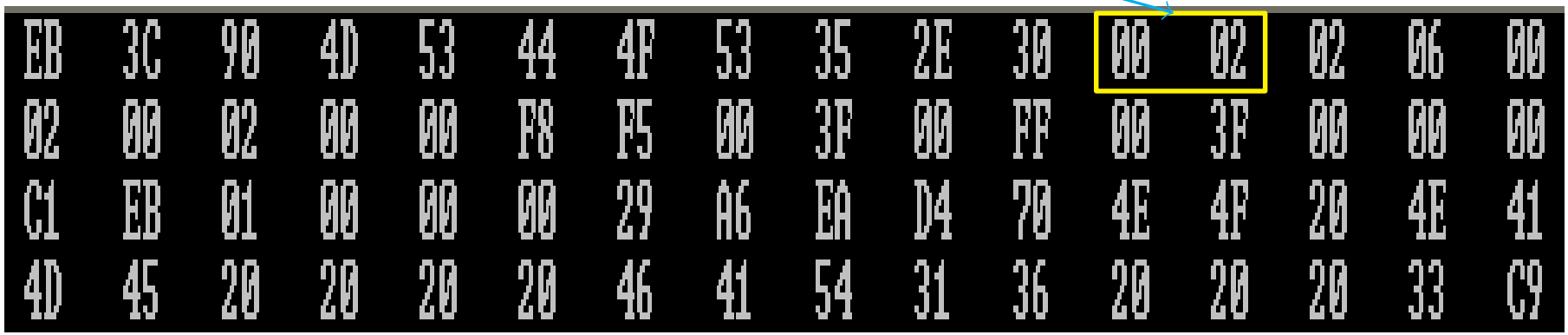


FAT16's disk parameter decoding example

1 Word

Size of 1 sector

Sector's size: 512

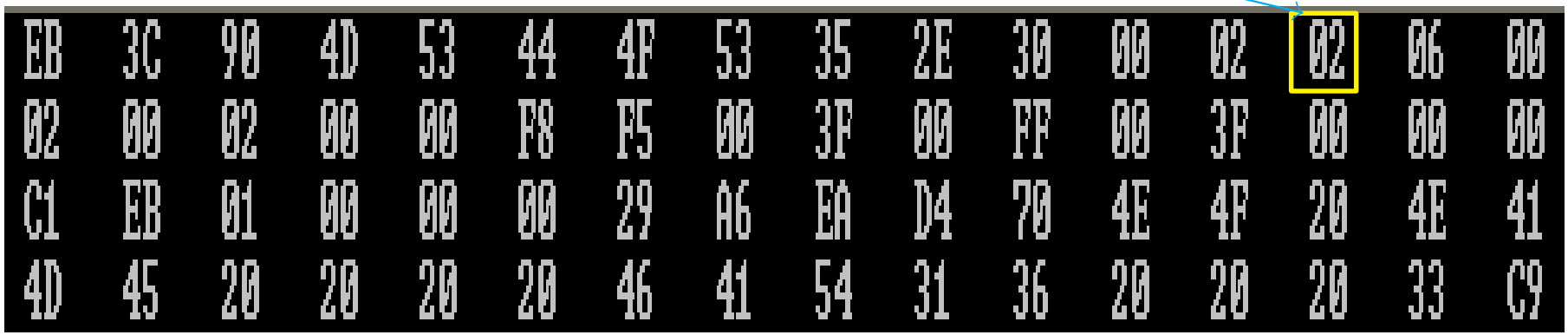


EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

Number of sector for 1 cluster

2 sector for 1 cluster

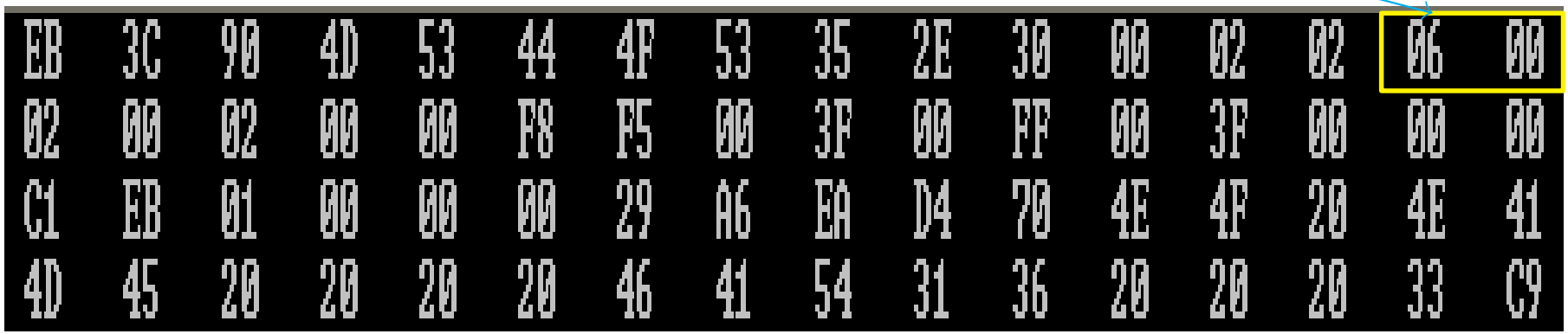


EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

Number of sector before FAT

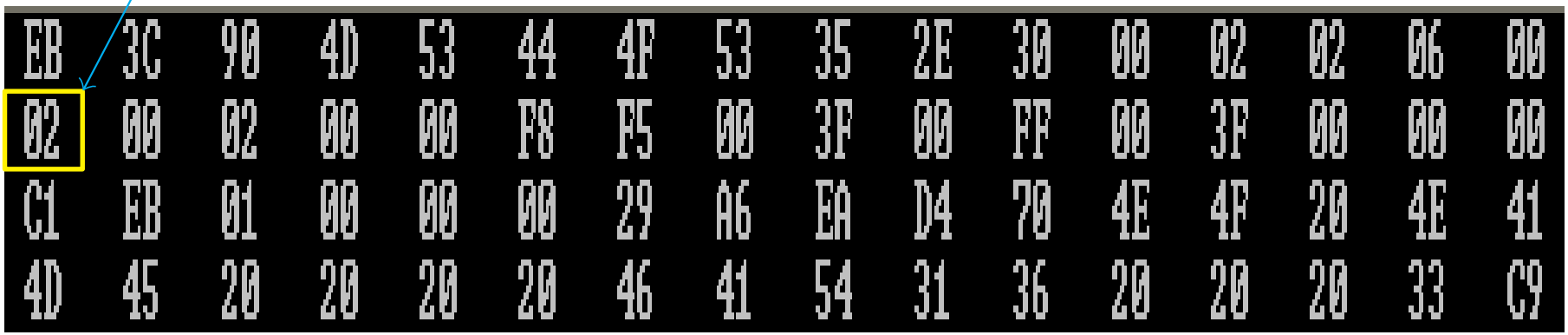
6 sectors before the first FAT



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

There are 2 FAT

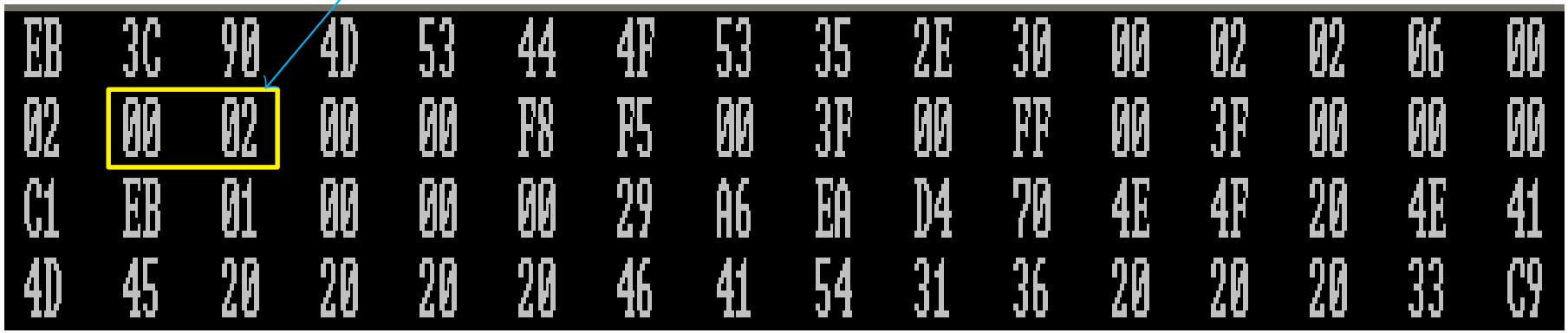


EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

Number of ROOT's elements

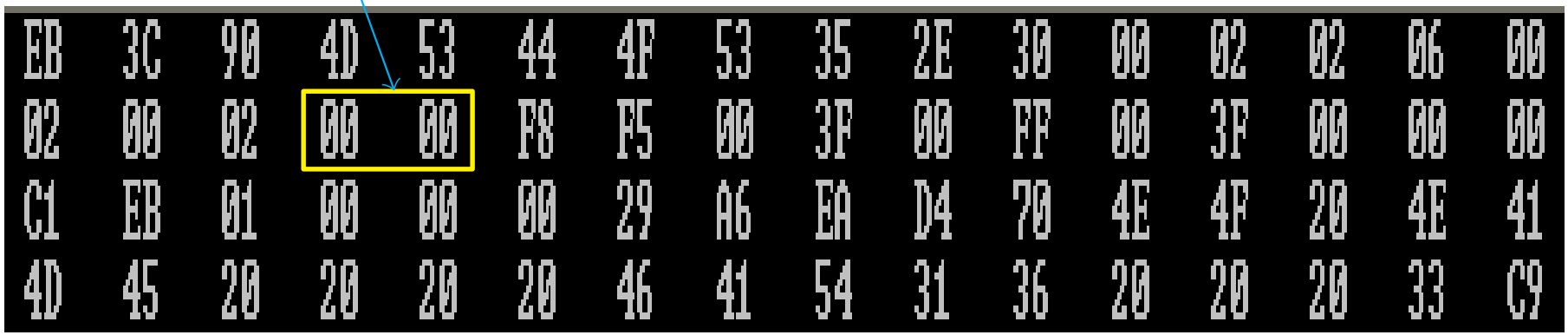
There are maximum 512 elements in Root's directory



FAT16's disk parameter decoding example

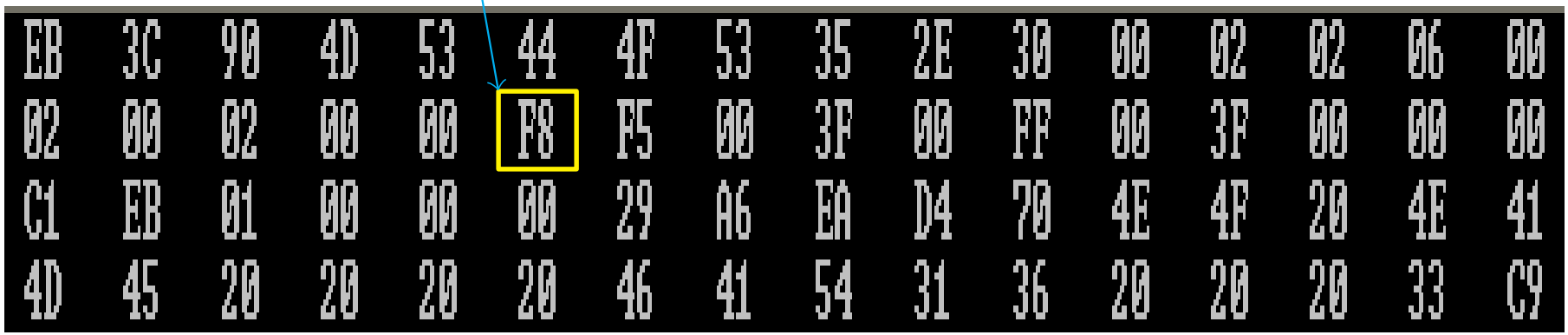
Total sector on disk

Disk larger than 32MB



FAT16's disk parameter decoding example

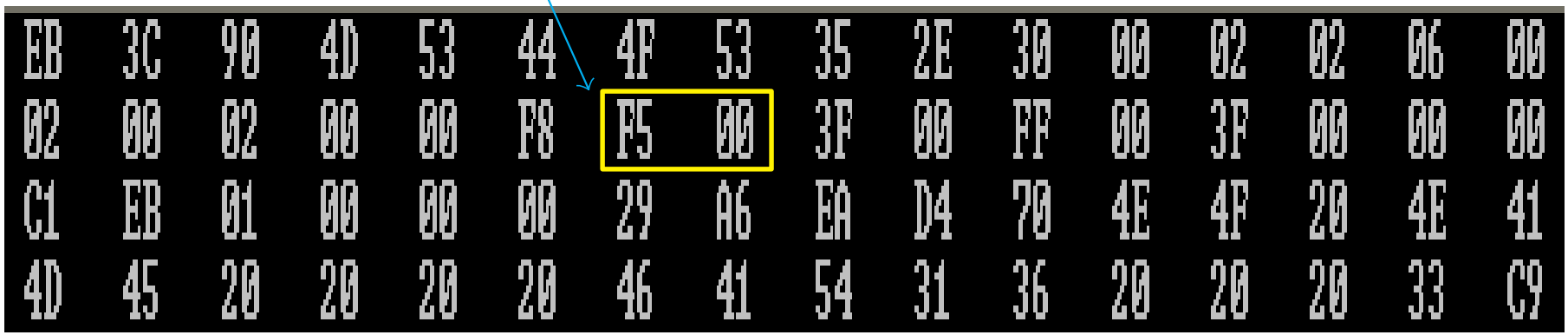
Disk format code: F8



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

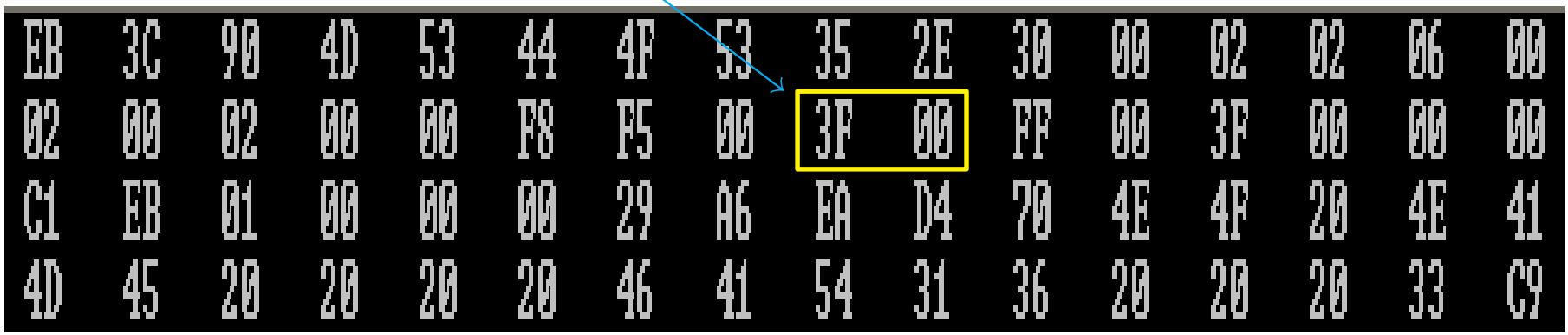
FAT16's disk parameter decoding example

Number of sector for 1 FAT:245



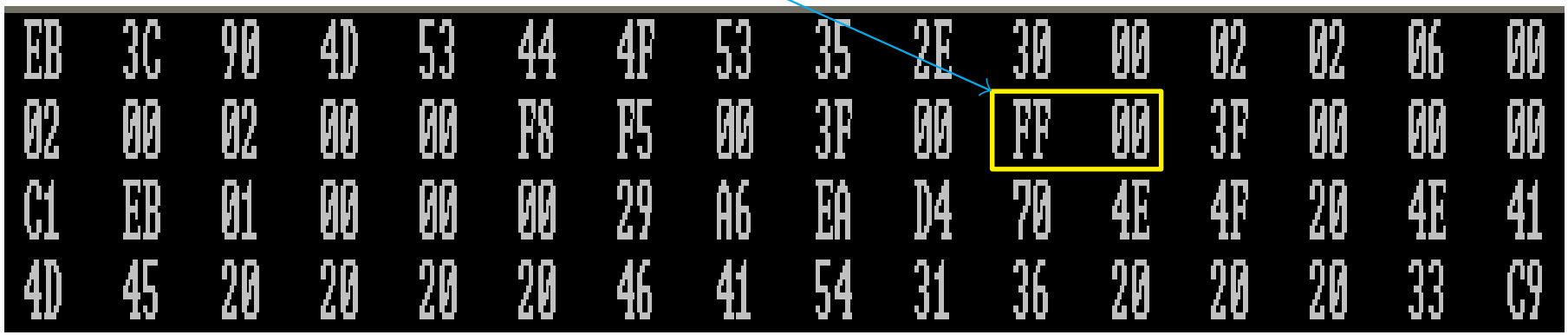
FAT16's disk parameter decoding example

Number of sector for 1 track: 63



FAT16's disk parameter decoding example

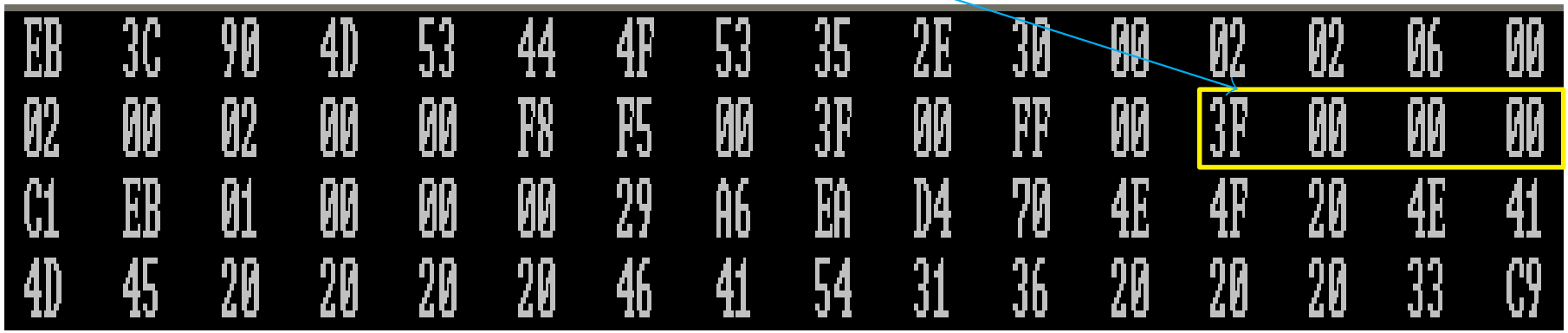
Number of headers: 255



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

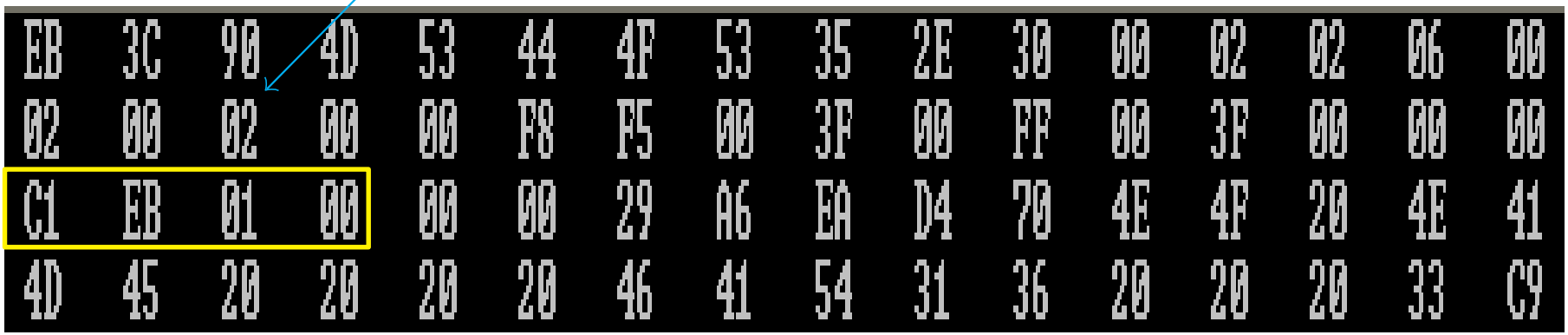
Number of hidden sectors: 63



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

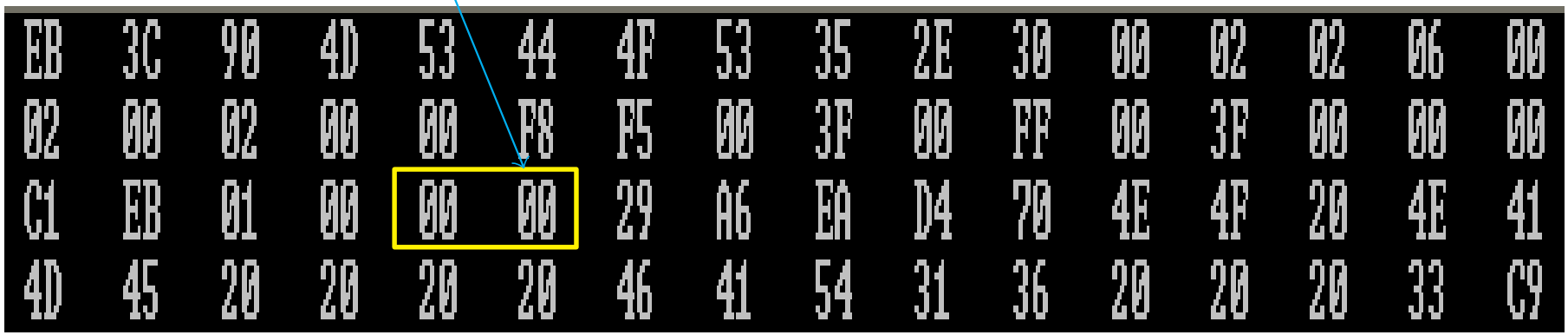
Total sector of Volume: 125889 (≈64MB)



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

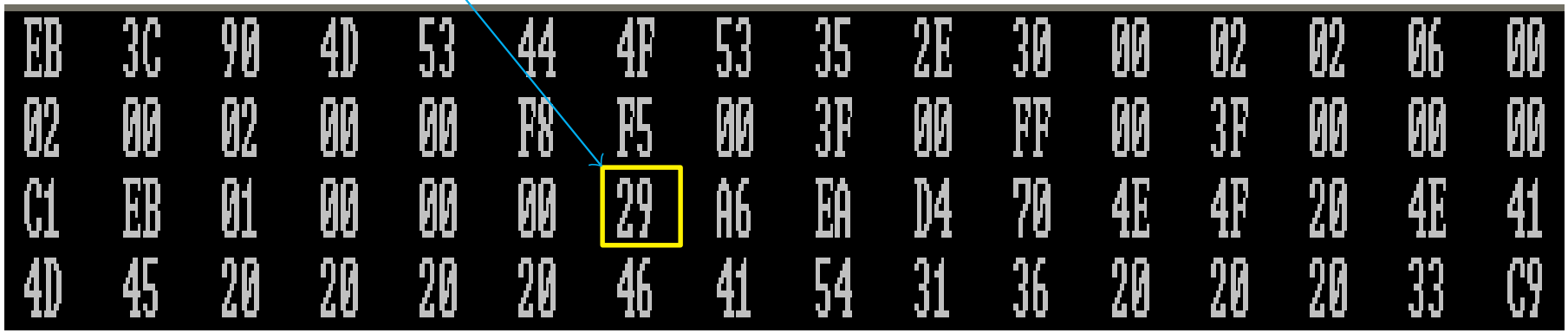
FAT16's disk parameter decoding example

Physical disk number: 00 00



FAT16's disk parameter decoding example

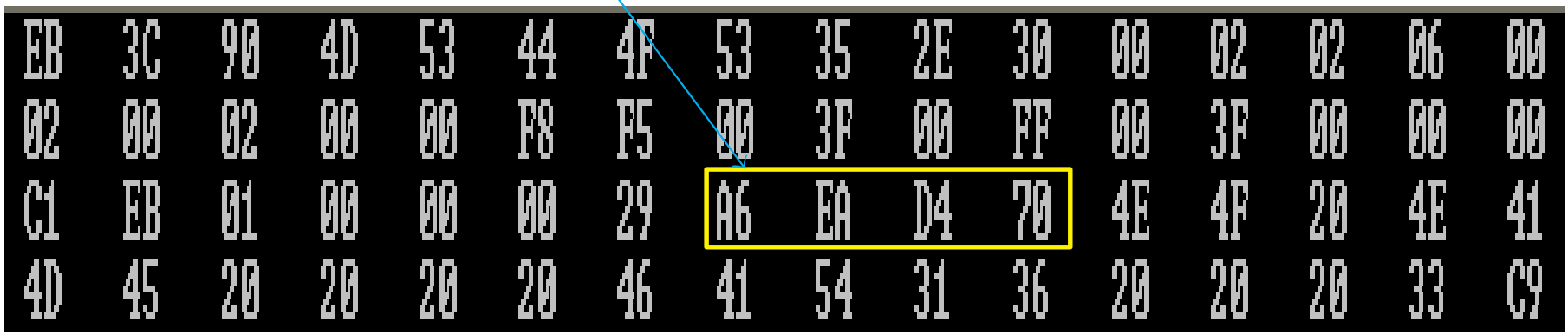
Bootsector extension: 29h



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

FAT16's disk parameter decoding example

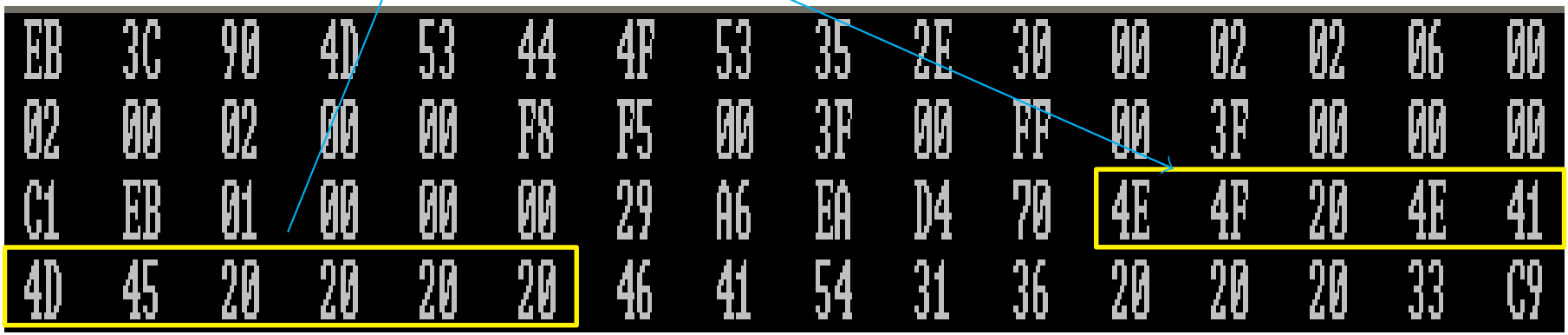
Volume serial number: 70D4-EAA6



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

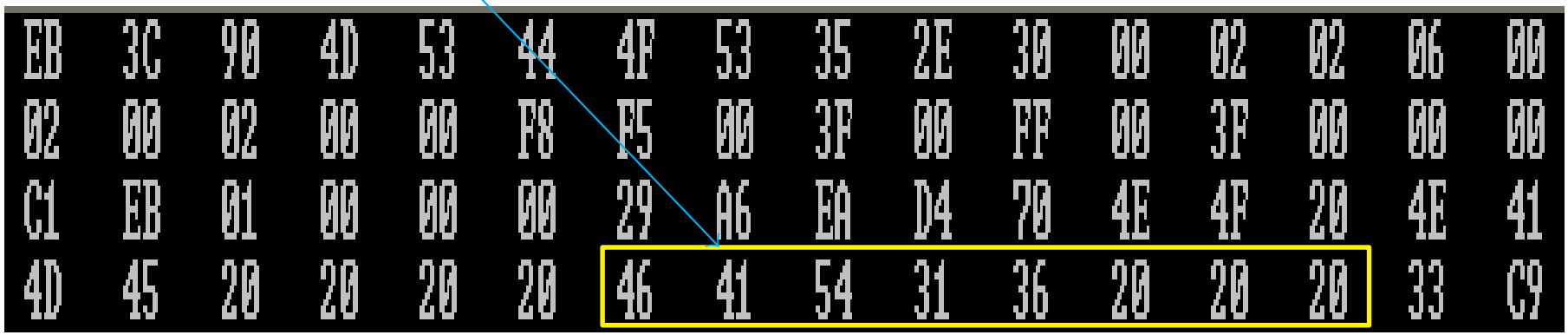
FAT16's disk parameter decoding example

Disk label: NO NAME



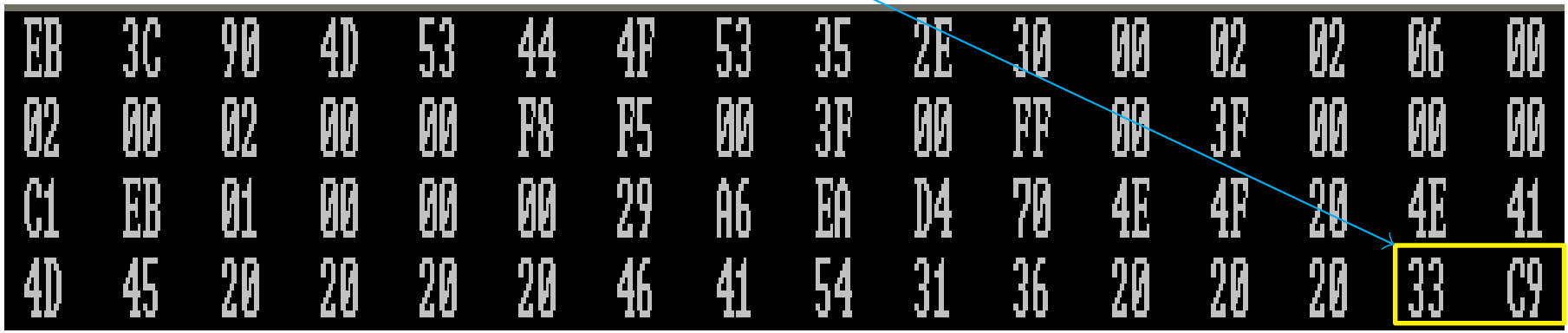
FAT16's disk parameter decoding example

FAT Type: FAT16



FAT16's disk parameter decoding example

Start of boot strap loader



EB	3C	90	4D	53	44	4F	53	35	2E	30	00	02	02	06	00
02	00	02	00	00	F8	F5	00	3F	00	FF	00	3F	00	00	00
C1	EB	01	00	00	00	29	A6	EA	D4	70	4E	4F	20	4E	41
4D	45	20	20	20	20	46	41	54	31	36	20	20	20	33	C9

Bios Parameter Block's structure – Part for FAT32

Stt	Ofs	Size	Sample value	Meaning
15	36	1DW	C9 03 00 00	Total sector for FAT
16	40	1W	00 00	Flags: main #FAT (not used)
17	42	1W	00 00	Version: FAT32 (*not used*)
18	44	1DW	02 00 00 00	cluster starting number of ROOT
19	48	1W	01 00	#sector contain File System information
20	50	1W	06 00	Number of sector to backup Bootsector
21	52	12B	00 . . . 00	Reserved
22	64	1B	00	Physical disk number 0: drive A; 80h: drive C
23	65	1B	00	Reserved/High Byte for #Driver
24	66	1B	29	Boot sector extension. Always 29h
25	67	1DW	62 0E 18 66	Volumn Serial number
26	71	11B	NO NAME	Volumn Label: (*not used*)
27	82	8B	FAT32	Reserved, for FAT's description text

FAT32 Boot sector example

EB	58	90	4D	53	44	4F	53	35	2E	30	00	02	10	24	00
02	00	00	00	00	F8	00	00	3F	00	F0	00	3F	00	00	00
E1	3A	3A	01	3E	27	00	00	00	00	00	00	02	00	00	00
01	00	06	00	00	00	00	00	00	00	00	00	00	00	00	00
80	00	29	D9	DF	92	BC	4E	4F	20	4E	41	4D	45	20	20
20	20	46	41	54	33	32	20	20	20	33	C9	8E	D1	BC	F4
7B	8E	C1	8E	D9	BD	00	7C	88	4E	02	8A	56	40	B4	08
CD	13	73	05	B9	FF	FF	8A	F1	66	0F	B6	C6	40	66	0F
B6	D1	80	E2	3F	F7	E2	86	CD	C0	ED	06	41	66	0F	B7
C9	66	F7	E1	66	89	46	F8	83	7E	16	00	75	38	83	7E
2A	00	77	32	66	8B	46	1C	66	83	C0	0C	BB	00	80	B9
01	00	E8	2B	00	E9	48	03	A0	FA	7D	B4	7D	8B	F0	AC
84	C0	74	17	3C	FF	74	09	B4	0E	BB	07	00	CD	10	EB
EE	A0	FB	7D	EB	E5	A0	F9	7D	EB	E0	98	CD	16	CD	19
66	60	66	3B	46	F8	0F	82	4A	00	66	6A	00	66	50	06
53	66	68	10	00	01	00	80	7E	02	00	0F	85	20	00	B4
41	BB	AA	55	8A	56	40	CD	13	0F	82	1C	00	81	FB	55
AA	0F	85	14	00	F6	C1	01	0F	84	0D	00	FE	46	02	B4
42	8A	56	40	8B	F4	CD	13	B0	F9	66	58	66	58	66	58
66	58	EB	2A	66	33	D2	66	0F	B7	4E	18	66	F7	F1	FE
C2	8A	CA	66	8B	D0	66	C1	EA	10	F7	76	1A	86	D6	8A
56	40	8A	E8	C0	E4	06	0A	CC	B8	01	02	CD	13	66	61
0F	82	54	FF	81	C3	00	02	66	40	49	0F	85	71	FF	C3
4E	54	4C	44	52	20	20	20	20	20	20	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	00	00	00	0D	0A	52	65
6D	6F	76	65	20	64	69	73	6B	73	20	6F	72	20	6F	74
68	65	72	20	6D	65	64	69	61	2E	FF	0D	0A	44	69	73
6B	20	65	72	72	6F	72	FF	0D	0A	50	72	65	73	73	20
61	6E	79	20	6B	65	79	20	74	6F	20	72	65	73	74	61
72	74	0D	0A	00	00	00	00	00	AC	CB	D8	00	00	55	AA

FAT32 boot sector decoding result

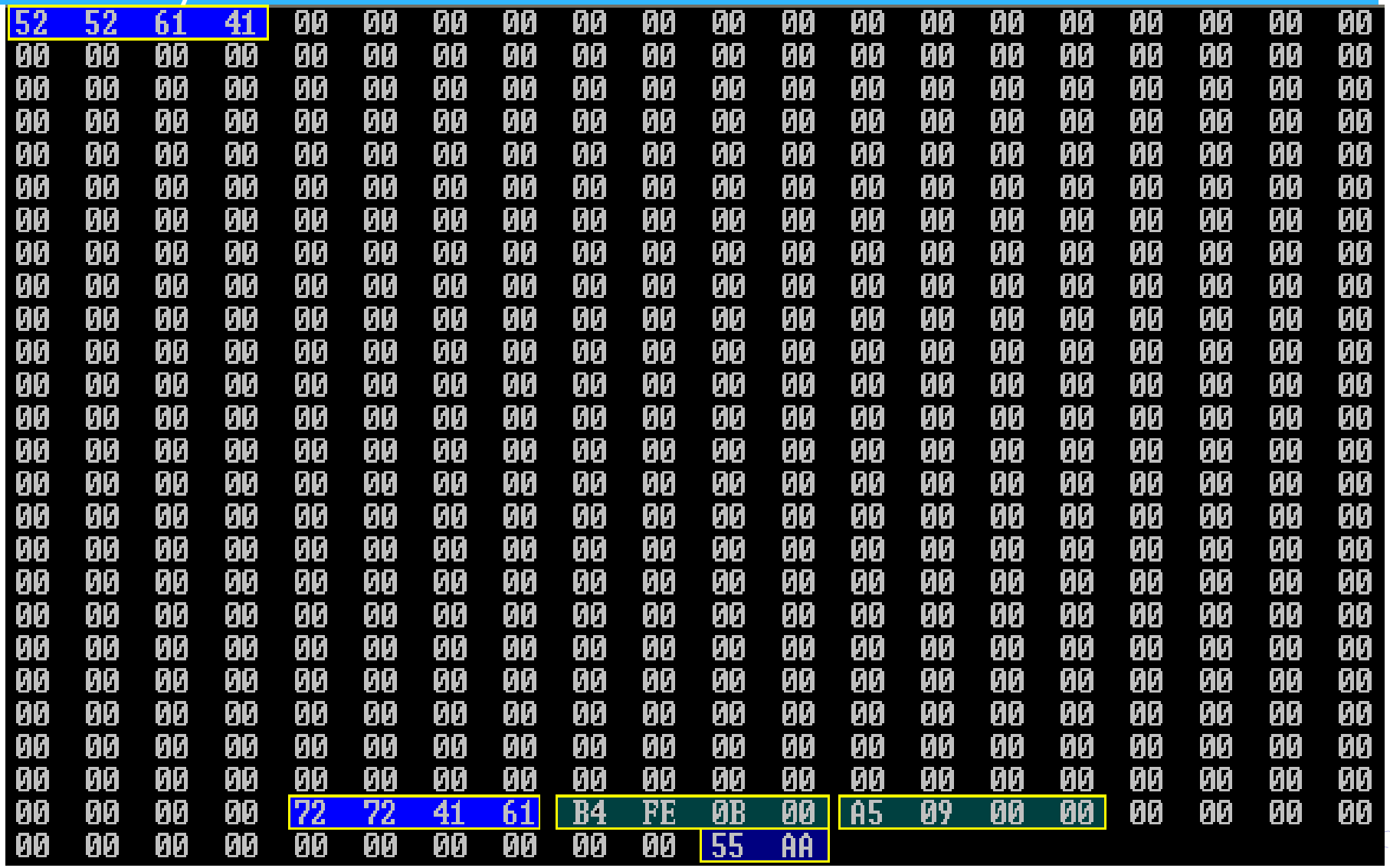
```
BIOS PARAMETER BLOCK (BPB)...
OEM Name                              :   MSDOS5.0
Bytes per sector                      :           512
Sectors per cluster                   :            16
Sectorss before the first FAT         :            36
Number of copies of FAT               :             2
Media Desctiptor                      :           F8h
Sectors per Tracks                    :            63
Number of Header                      :           240
Number of Hiden Scts in Volume        :            63
Number of Sectors in Volume           :      20593377
Number of Sectors per FAT             :         10046
Cluster num. of start of ROOT         :             2
Sct number of FileSystem Info         :             1
Sct number of Boot backup sct         :             6
Logical drive number of Volume        :           80h
Extend BPB Signature                  :           29h
Serial Number of Volume               :  BC92-DFD9
Volumn lable                          :    NO NAME
FAT Type                              :       FAT32
Boot signature                        :       55 AA
```

File System Information Sector

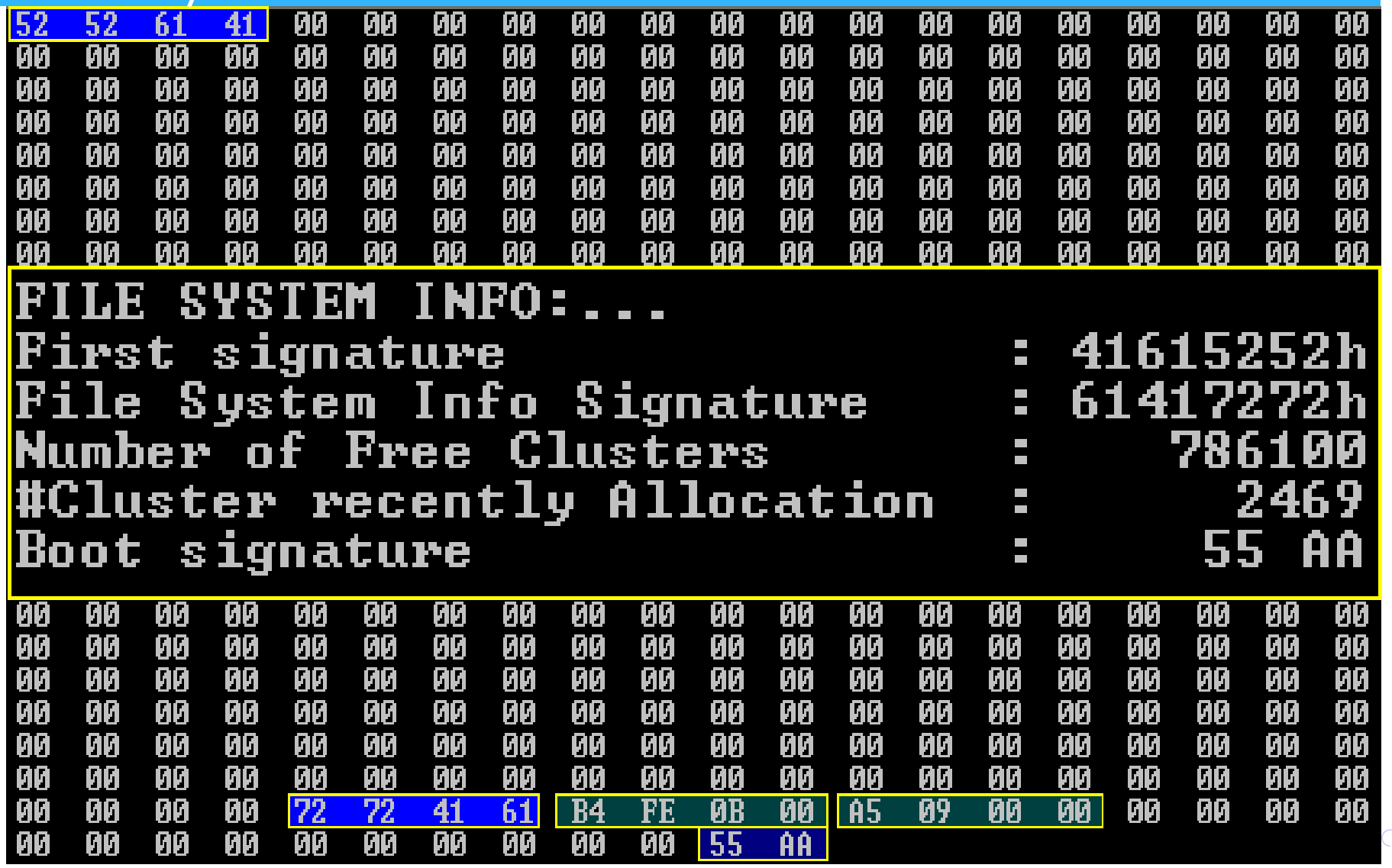
- Usually Sector # 2 of Volume
  - Right after Boot sector (Sector # 1)
- Structure

Stt	Ofs	Size	Meaning
1	0	1DW	First signature of FSInfo sector. Bytes' values in order: 52h 52h 61h 41h
2	4	480B	Not used, usually contain value 00
3	484	1DW	Signature of File System Information Sector. Bytes values in order: 72h 72h 41h 61h
4	488	1DW	Number of free cluster. *-1* if not defined
5	492	1DW	Number of cluster just provided
6	496	12B	Reserved
7	508	2B	Not defined, usually 0
8	510	2B	Bootsector's signature. Contain value 55 AA

File system information sector of 1volume use FAT32



File system information sector of 1 volume use FAT32



- Boot sector
- FAT (File Allocation Table)
- Root directory

Object

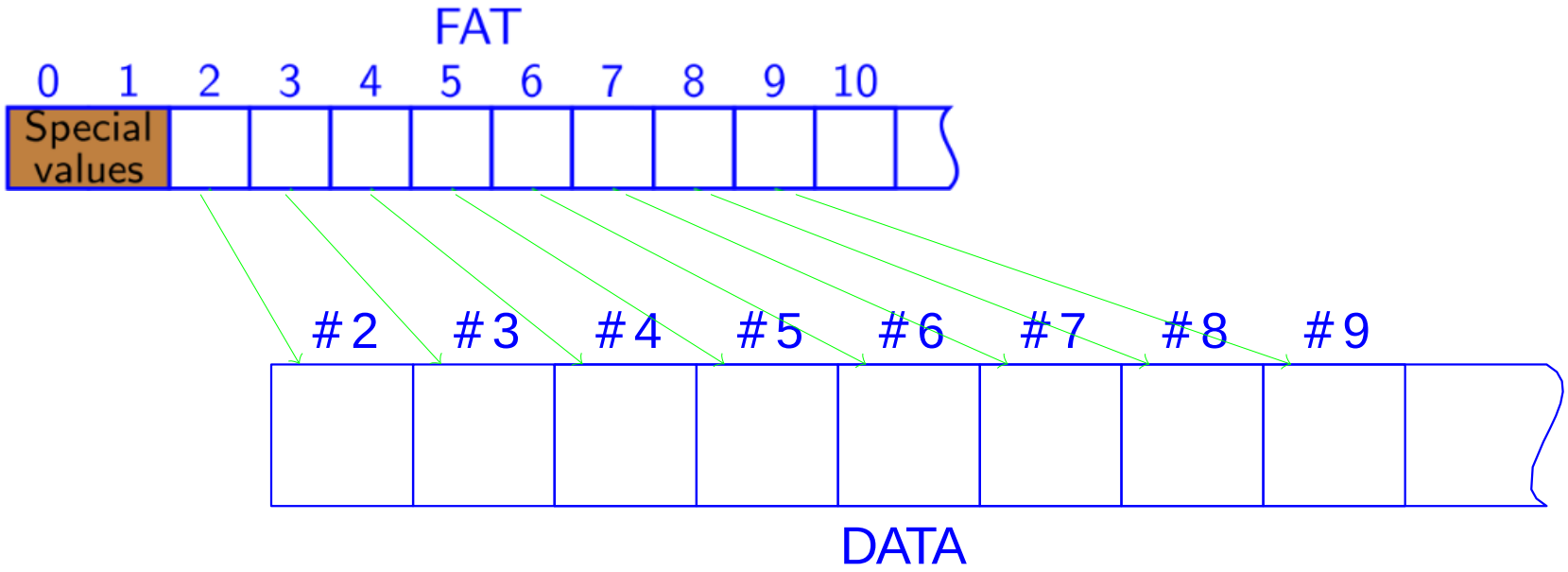
FAT utilized to manage memory blocks/clusters in the data area of storage memory

- Using block
  - Allocated to each file/directory
- Free block
- Error block

Method

FAT include many elements

- Each element can be 12bit, 16bit, 32bit
- Each element corresponding to 1 block (cluster) on the data area
  - First 2 elements (0,1) has special meaning
    - Disk format, Bit shutdown, Bit diskerrror
  - Element # 2 corresponding to first cluster of the Data



Implementation

Each element of FAT contain a value represents the property of corresponding cluster

FAT[(32)16]12	Meaning
[(0000)0]000h	Cluster is free
[(0000)0]001h	Unused value
[(0000)0]002h →[(0FFF)F]FEFh	Cluster being used. Value is a pointer, point to next cluster of file
[(0FFF)F]FF0h →[(0FFF)F]FF6h	Reserved value, unused
[(0FFF)F]FF7h	Mark corresponding cluster is broken
[(0FFF)F]FF8h→ →[(0FFF)F]FFFh	Cluster is being used and it's the last cluster of file (*EOC:End Of Cluster chain*). Usually value: [(0FFF)F]FFFh

Cluster linking

Root entry

ABC	TXT	A		Time	Date	008	Size

FAT	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Special values	03	04	05	FFF	00	00	09	10	12	FF7	15	00	00	16	FFF	00	21	FFF

DATA

#2	#3	#4	#5	#6	#7	#8	#9	#10	#11

#12	#13	#14	#15	#16	#17	#18	#19	#20	#21

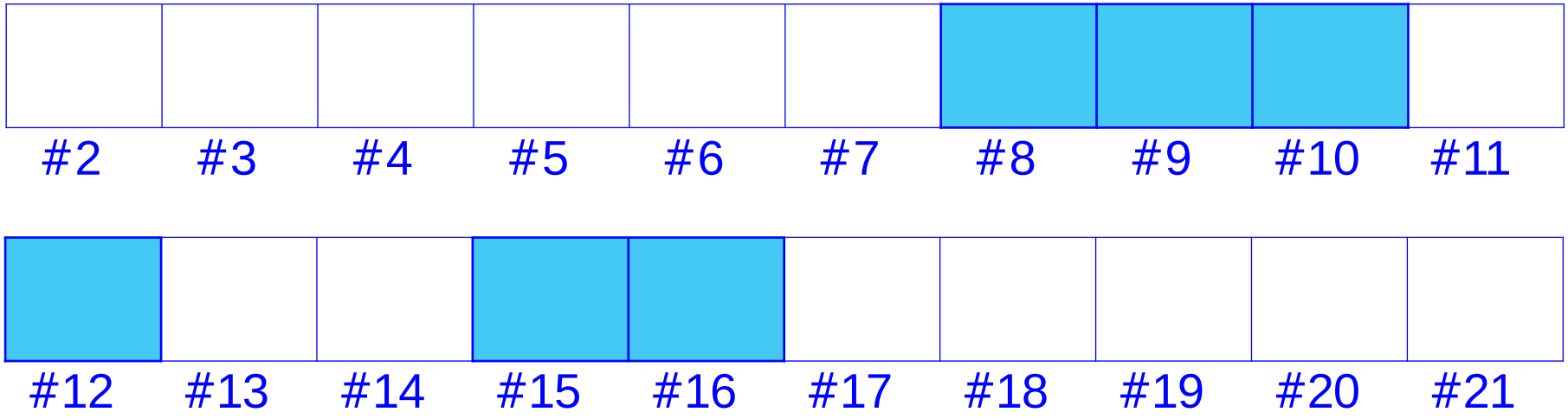
Cluster linking

Root entry

ABC	TXT	A		Time	Date	008	Size

FAT	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Special values	03	04	05	FFF	00	00	09	10	12	FF7	15	00	00	16	FFF	00	21	FFF

DATA



Cluster linking

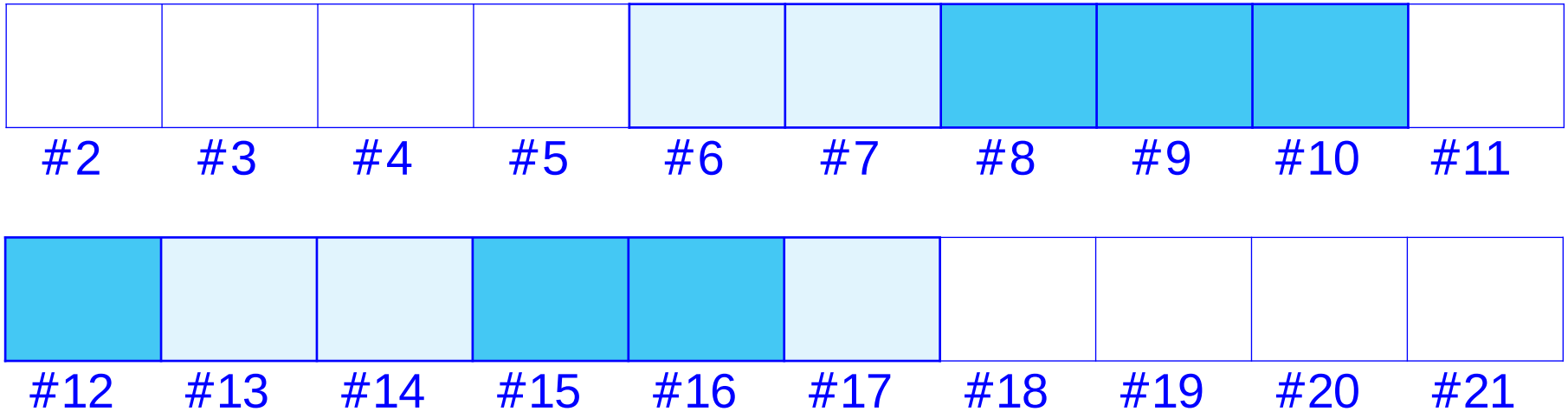
Root entry

ABC	TXT	A		Time	Date	008	Size

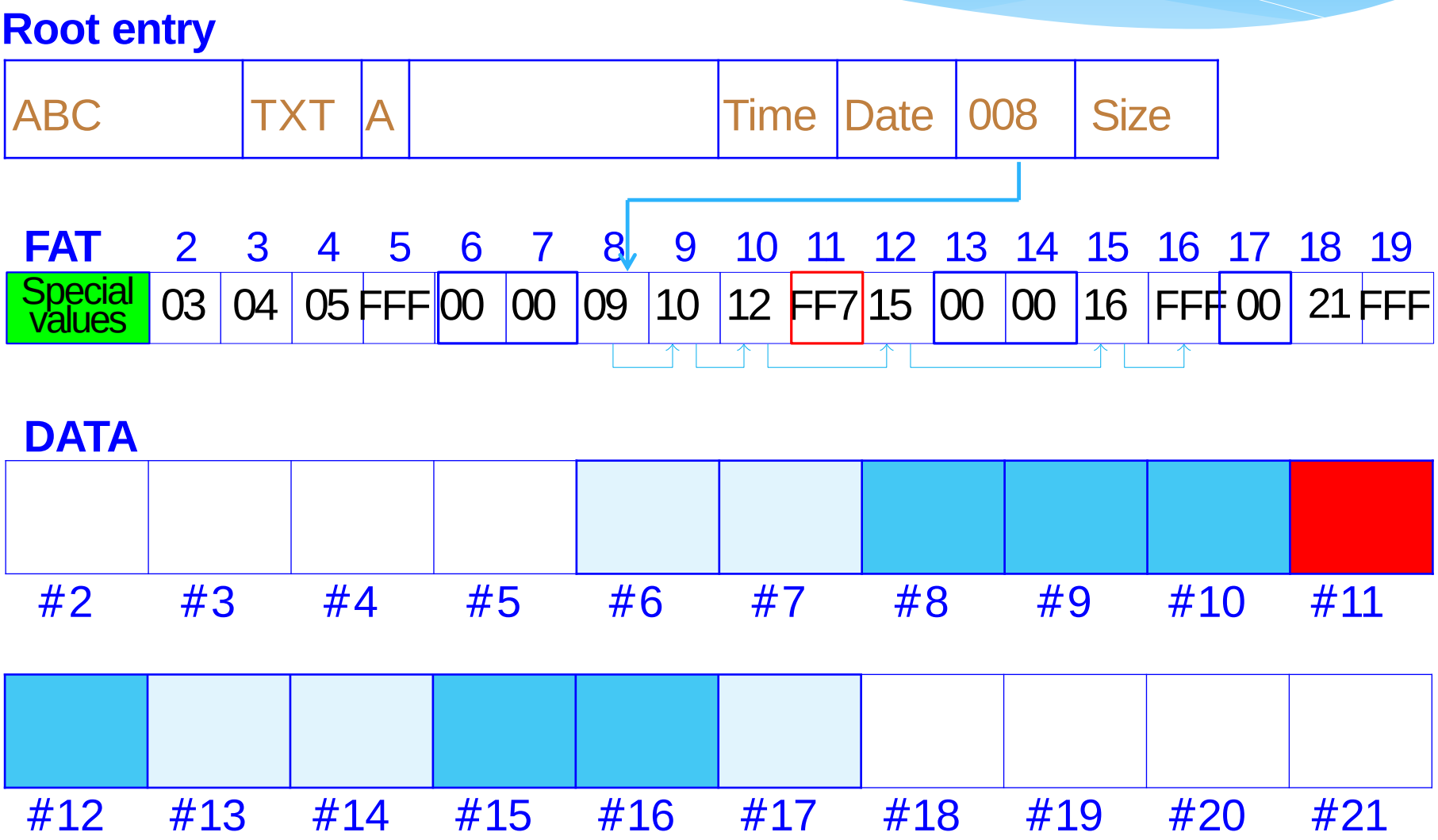
FAT

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Special values	03	04	05	FFF	00	00	09	10	12	FF7	15	00	00	16	FFF	00	21	FFF

DATA



Cluster linking



Cluster linking

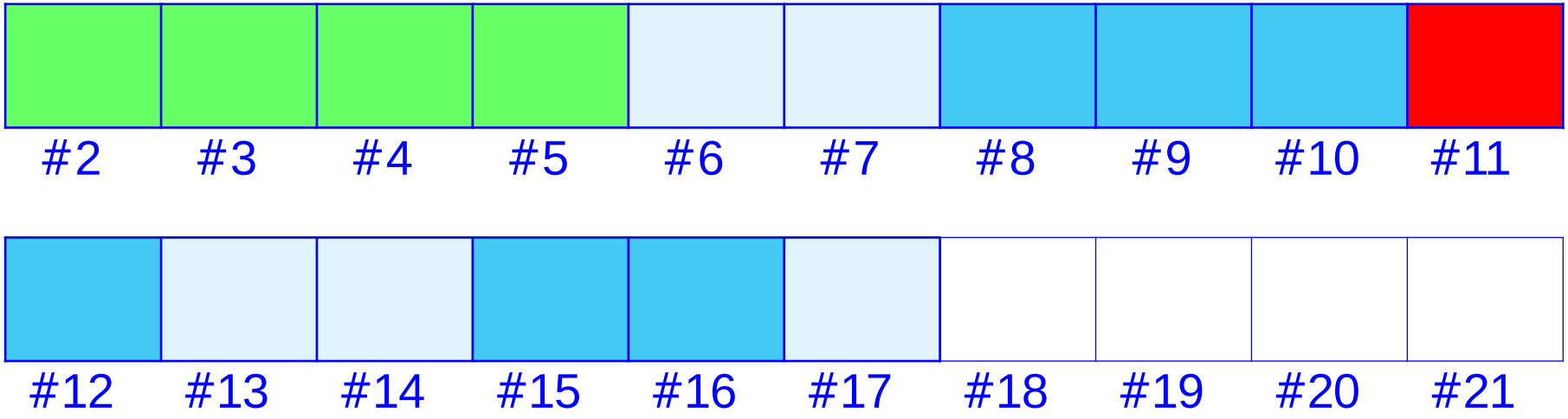
Root entry

ABC	TXT	A		Time	Date	008	Size

FAT

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Special values	03	04	05	FFF	00	00	09	10	12	FF7	15	00	00	16	FFF	00	21	FFF

DATA



Example: Read one sector of FAT32

```
#include <windows.h>
#include <stdio.h>
 int main(int argc, char *argv[]){
        HANDLE hDisk;
        BYTE Buf[512]; DWORD FAT[128];
        WORD FATAddr; DWORD byteread, i;
        hDisk = CreateFile("\\\\.\\F:", GENERIC_READ,
                                FILE_SHARE_READ|FILE_SHARE_WRITE, NULL,
                                OPEN_EXISTING,0,NULL);
        ReadFile(hDisk,Buf,512,&byteread,NULL);
        memcpy(&FATAddr,&Buf[14],2);//Offset 14 Sector truoc FAT
        SetFilePointer(hDisk,FATAddr * 512, NULL,FILE_BEGIN);
        ReadFile(hDisk,FAT,512,&byteread,NULL);
        for(i=0;i<128;i++) printf(" %08X ",FAT[i]);
        CloseHandle(hDisk);
        return 0;
}
```

Example: First Sector of a FAT32

A Root entry

52	45	41	44	4D	42	52	20	43	20	20	20	00	5E	B9	5A
A8	3E	A8	3E	00	00	CE	79	A4	3E	03	00	BD	0A	00	00

FAT

0FFFFFF8	FFFFFFFF	0FFFFFFF	00000004	00000005	00000006	00000007	00000008
0FFFFFFF	0000000A	0000000B	0000000C	0000000D	0FFFFFFF	0FFFFFFF	00000000
00000000	00000000	00000000	00000000	00000015	00000016	00000017	00000018
00000019	0000001A	0000001B	0000001C	0000001D	0000001E	0000001F	00000020
0FFFFFFF	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000
00000000	00000000	00000000	00000000	00000000	00000000	00000000	00000000

- Boot sector
- FAT (File Allocation Table)
- Root directory

Structure of root directory

- Table consists of file record
  - Each record size is 32 bytes
    - Contain information involve one file/directory/ volume label
- FAT12/FAT16
  - Root directory lie right behind FAT
  - Size = Number of maximum elements in root directory * 32
- FAT32
  - Location is defined based on BPB
    - Filed #18: Number of ROOT's first cluster
  - Undefined size
  - Support long file name (LFN: Long File Name)
    - One file may use more than 1 element

Structure of one element

Stt	Ofs	Size	Meaning
1	0	8B	File name
2	8	3B	Extension
3	11	1B	File's attribute
4	12	10B	Not used in FAT12/FAT16. Used in FAT32
4.1	12	1B	Reserved
4.2	13	1B	File created time, unit 10ms
4.3	14	1W	File created time (*hour - minute - second*)
4.4	16	1W	File created date
4.5	18	1W	Last access date
4.6	20	1W	Number of starting cluster of file(*FAT32: High part*)
5	22	1W	Last update time
6	24	1W	Last update date
7	26	1W	Number of starting cluster of file (*FAT32: Low part*)
8	28	1DW	Size in byte

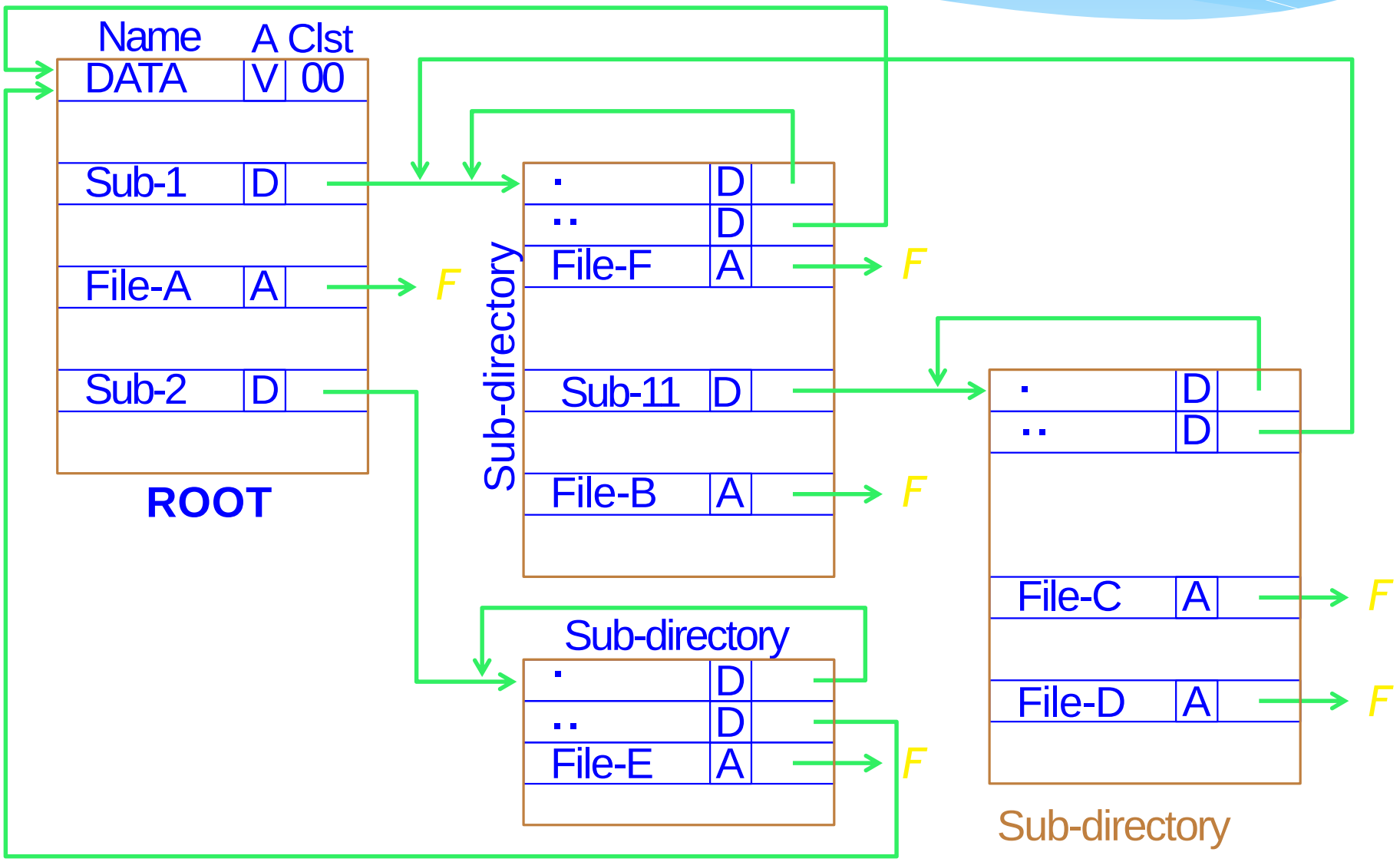
Structure of an element : file name

- Sequence of ASCII contain file name
- Not accept space in file name
  - Command copy, del,... do not recognize name contains space
- If smaller than 8 character, insert space character for sufficient 8 character
- First character may contain special meaning
  - 00h: First character of not used part
  - E5h (character "δ"): File corresponding to this element was deleted
  - 2Eh (character "."): Sub directory
    - cluster number field point to itself
    - Structure of sub directory is similar to root directory: contain 32bytes elements

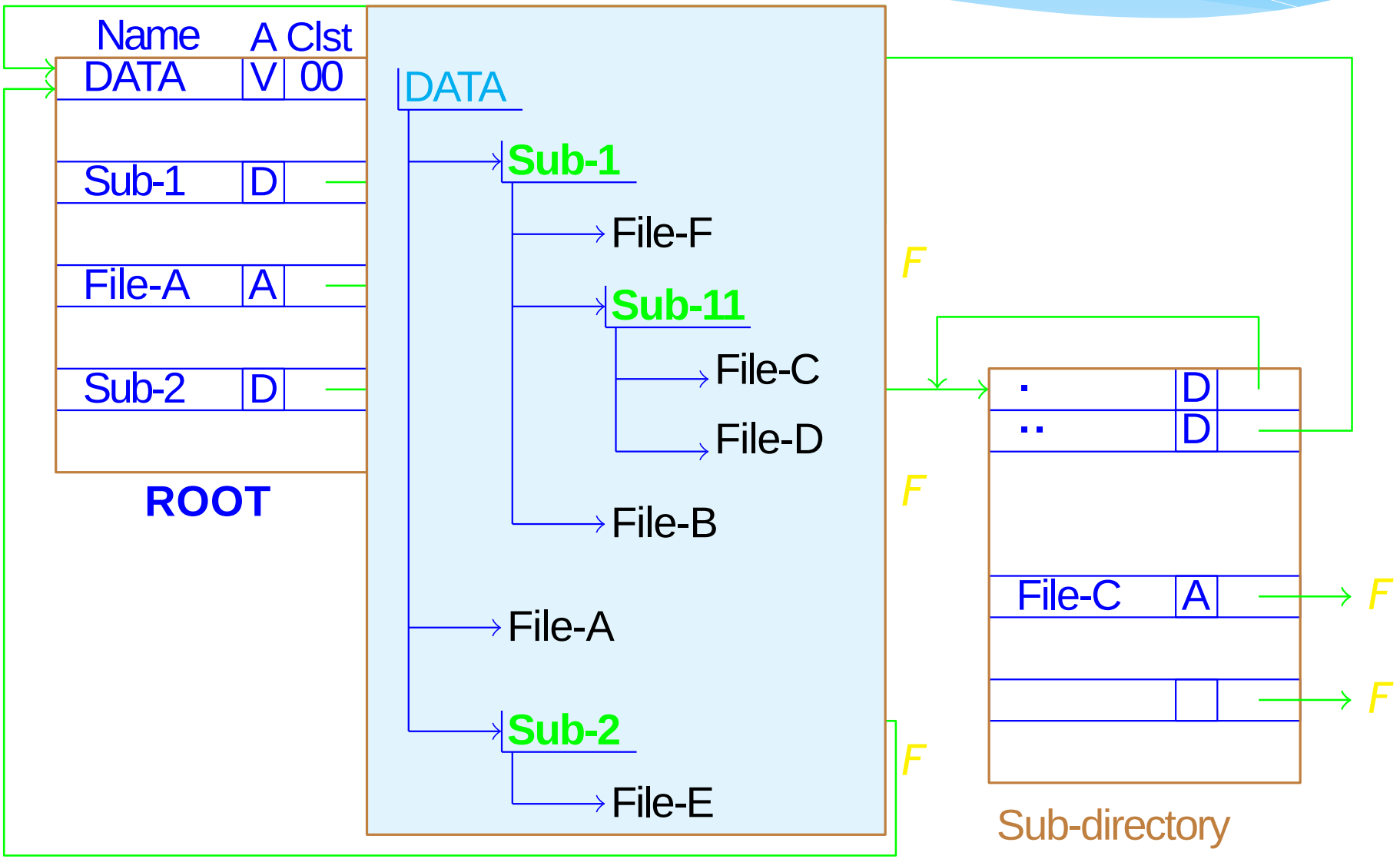
Structure of an element : file name

- First character may contain special meaning (continues)
  - 2Eh2Eh (character ".."): Parent directory of current directory
    - Cluster number field point to parent directory
    - If parent is root, #cluster start by zero (FAT12/16)
    - Sub directory lie in Data area, manage similar to a file ⇒ File of file record
    - FAT12/16: Root directory is at a defined position; FAT32: Root directory lies in Data area

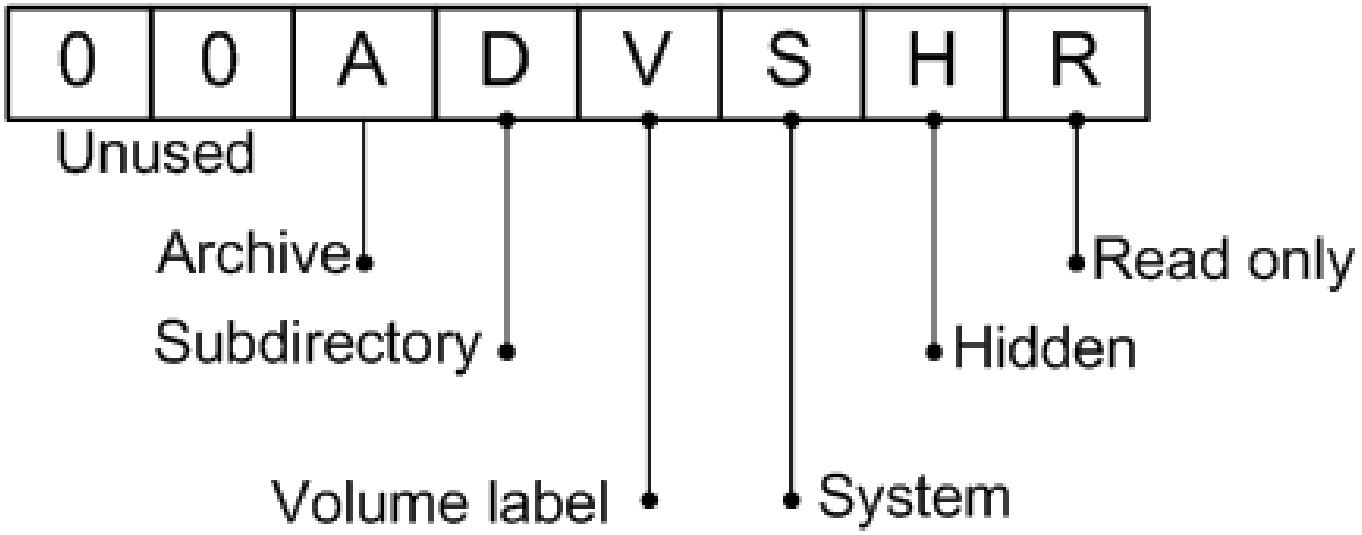
Sub directory



Sub directory



Structure of an element : Attribute field



Example: Byte attribute **0Fh**:

0	0	0	0	1	1	1	1

⇒ File has attribute Volume label+System+Hidden+Read only

Note: Attribute byte 's value **0x0F** is not used in *MS-DOS* ⇒ For marking the *Long File Name element*

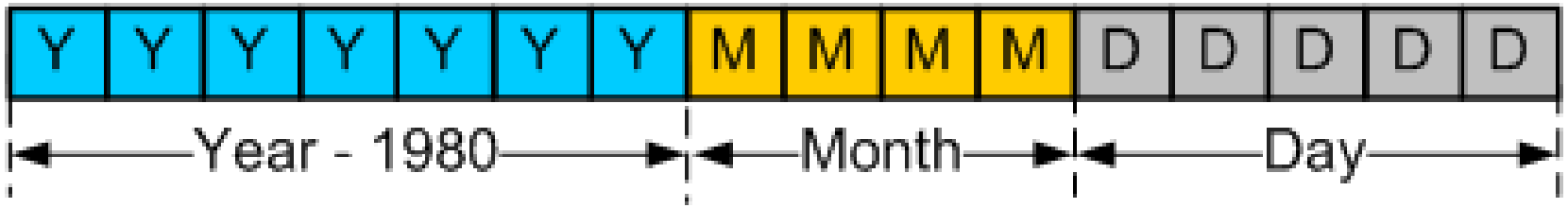
Structure of an element

Example: 15 hour 34 minute 45 second

0	1	1	1	1	1	0	0	0	1	0	1	0	1	1	0

Value: **7C56**

Structure of an element : Date



Example: Day 17 month 5 Year 2011

0	0	1	1	1	1	1	0	1	0	1	1	0	0	0	1

Value : **3EB1**

Long File Name (LFN) system

Ofs	Size	Meaning
0	1B	Element Order
1	5W	First 5 unicode characters
11	1B	Attribute. Mark *LFN element* Always value 0Fh
12	1B	Reserved (00)
13	1B	Checksum: Allow check if long file name is corresponding to 8.3 name?
14	6W	unicode character 6,7,8,9,10,11
26	1W	Cluster number. Not used (0000)
28	1W	unicode character 12
30	1W	unicode character 13

Long File Name (LFN) system: Ordering field

- Show the order of LFN element
  - Each LFN element contain 13 Unicode characters
- First element has value of ordering field: 1
- Last element use bit number 6 to mark
  - Only use maximum 20 elements
  - After last character is 0x00 0x00.
  - Unused character has values 0xFF 0xFF
- Bit number 7 (0x80) show corresponding element is deleted
- Example: file "This is a very long file name.docx"

Entry	Ord	Attr	Data
LFN 3	0x43	0x0F	ame.docx
LFN 2	0x02	0x0F	y long file n
LFN 1	0x01	0x0F	This is a ver
8.3 Name	THISIS~1.DOC		

Example: A sector of ROOT

```
44 41 54 41 20 20 20 20 20 20 20 08 00 00 00 00
00 00 00 00 00 00 64 25 A5 3E 00 00 00 00 00 00
E5 44 48 20 20 20 20 20 50 44 46 20 18 0A 93 34
A5 3E A5 3E 00 00 6F 34 A5 3E 03 00 38 25 29 00
41 45 00 78 00 65 00 6D 00 70 00 0F 00 EF 6C 00
65 00 73 00 00 00 FF FF FF FF 00 00 FF FF FF FF
45 58 45 4D 50 4C 45 53 20 20 20 10 00 C4 9B 34
A5 3E A5 3E 00 00 9C 34 A5 3E 96 14 00 00 00 00
42 72 00 2E 00 63 00 00 00 FF FF 0F 00 43 FF FF
FF FF FF FF FF FF FF FF FF FF 00 00 FF FF FF FF
01 52 00 65 00 61 00 64 00 42 00 0F 00 43 69 00
6F 00 73 00 53 00 65 00 63 00 00 00 74 00 6F 00
52 45 41 44 42 49 7E 31 43 20 20 20 00 A6 B2 4B
A5 3E A5 3E 00 00 76 5C 9A 3E 3F 2E D1 01 00 00
52 45 41 44 4D 42 52 20 43 20 20 20 00 3C 86 5B
A5 3E A5 3E 00 00 CF 79 A4 3E 40 2E BD 0A 00 00
41 54 00 65 00 6D 00 70 00 73 00 0F 00 F0 00 00
FF FF FF FF FF FF FF FF FF FF 00 00 FF FF FF FF
54 45 4D 50 53 20 20 20 20 20 20 10 00 11 9A 96
A5 3E A5 3E 00 00 9B 96 A5 3E 46 2E 00 00 00 00
42 A1 01 6E 00 67 00 20 00 34 00 0F 00 12 2E 00
70 00 64 00 66 00 00 00 FF FF 00 00 FF FF FF FF
01 42 00 E0 00 69 00 20 00 67 00 0F 00 12 69 00
A3 1E 6E 00 67 00 20 00 63 00 00 00 68 00 B0 01
42 41 49 47 49 4E 7E 31 50 44 46 20 00 0A 93 34
A5 3E A5 3E 00 00 6F 34 A5 3E 03 00 38 25 29 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 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 00 00 00 00 00
```

Example: Content of ROOT

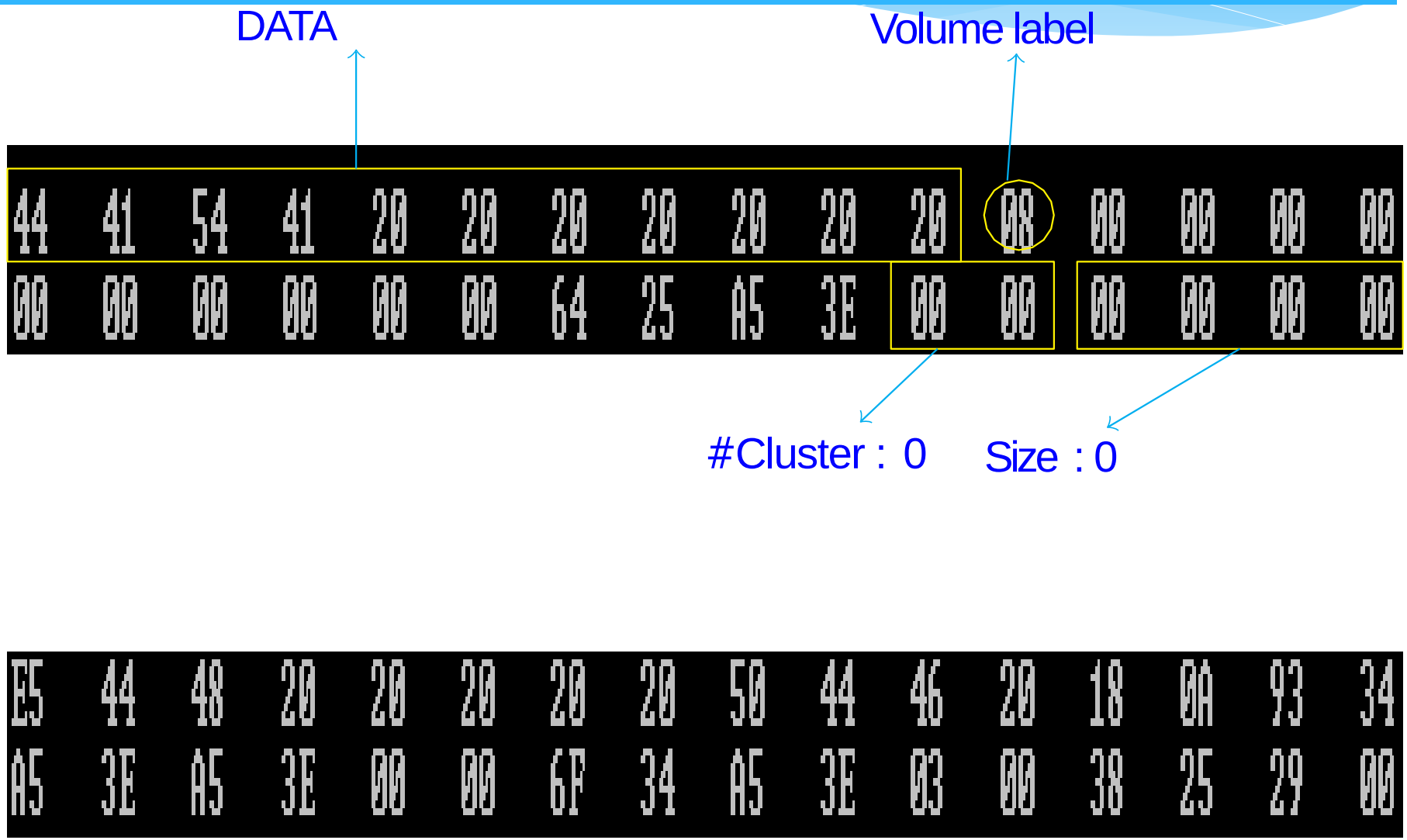
```
F:\>DIR
 Volume in drive F is DATA
 Volume Serial Number is DC27-F353

 Directory of F:\

05/05/2011  06:36 AM    <DIR>          Exemples
04/26/2011  11:35 AM               465 ReadBiosSector.c
05/04/2011  03:14 PM             2,749 READMBR.C
05/05/2011  06:52 PM    <DIR>          Temps
05/05/2011  06:35 AM         2,696,504 Bài gi?ng chuong 4.pdf
               3 File(s)      2,699,718 bytes
               2 Dir(s)      14,247,424 bytes free

F:\>_
```

Decode ROOT

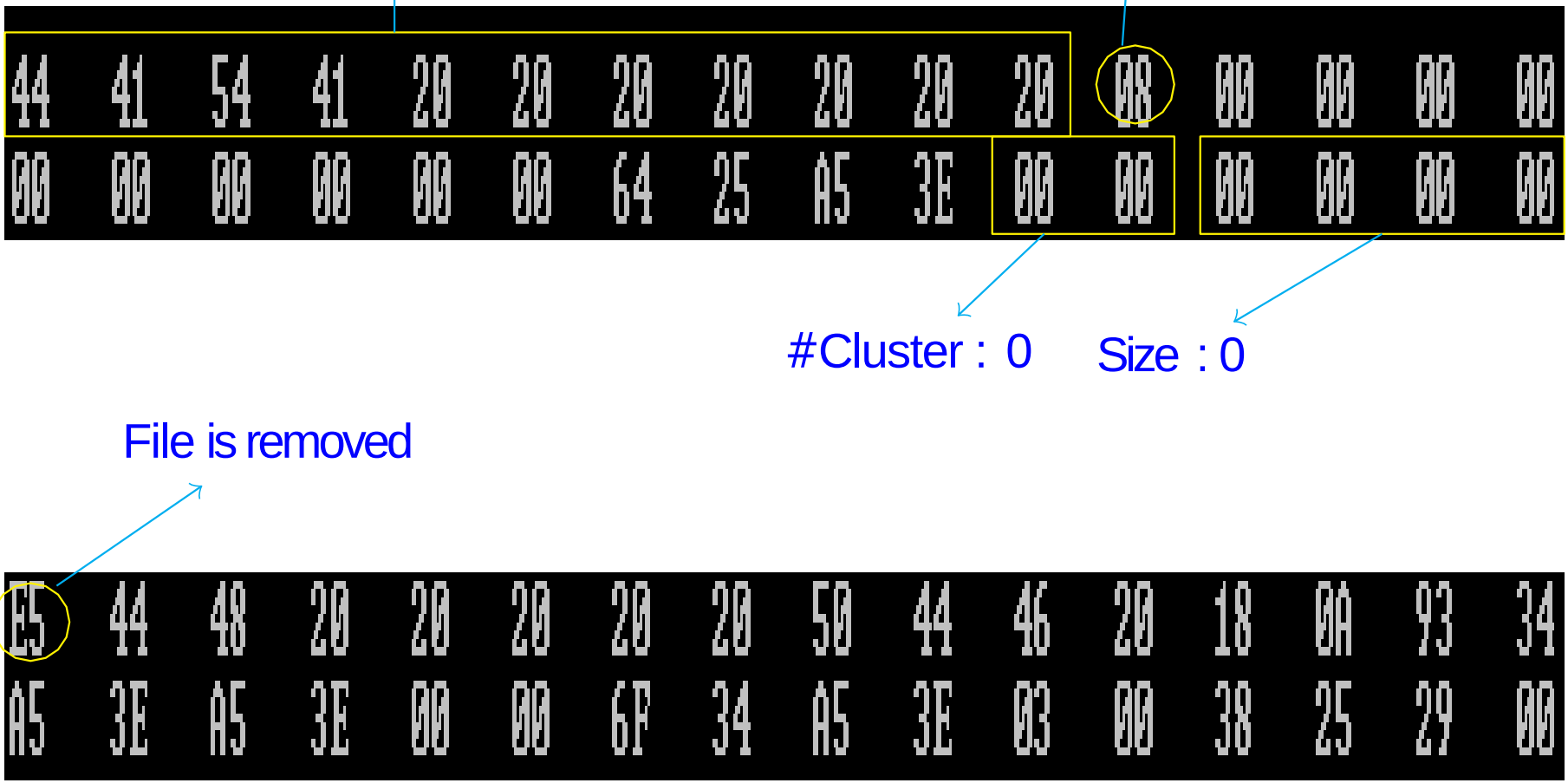
```
44 41 54 41 20 20 20 20 20 20 20 00 00 00 00 00
00 00 00 00 00 00 64 25 A5 3E 00 00 00 00 00 00
```

```
E5 44 48 20 20 20 20 20 50 44 46 20 18 0A 93 34
A5 3E A5 3E 00 00 6F 34 A5 3E 03 00 38 25 29 00
```

Decode ROOT 1

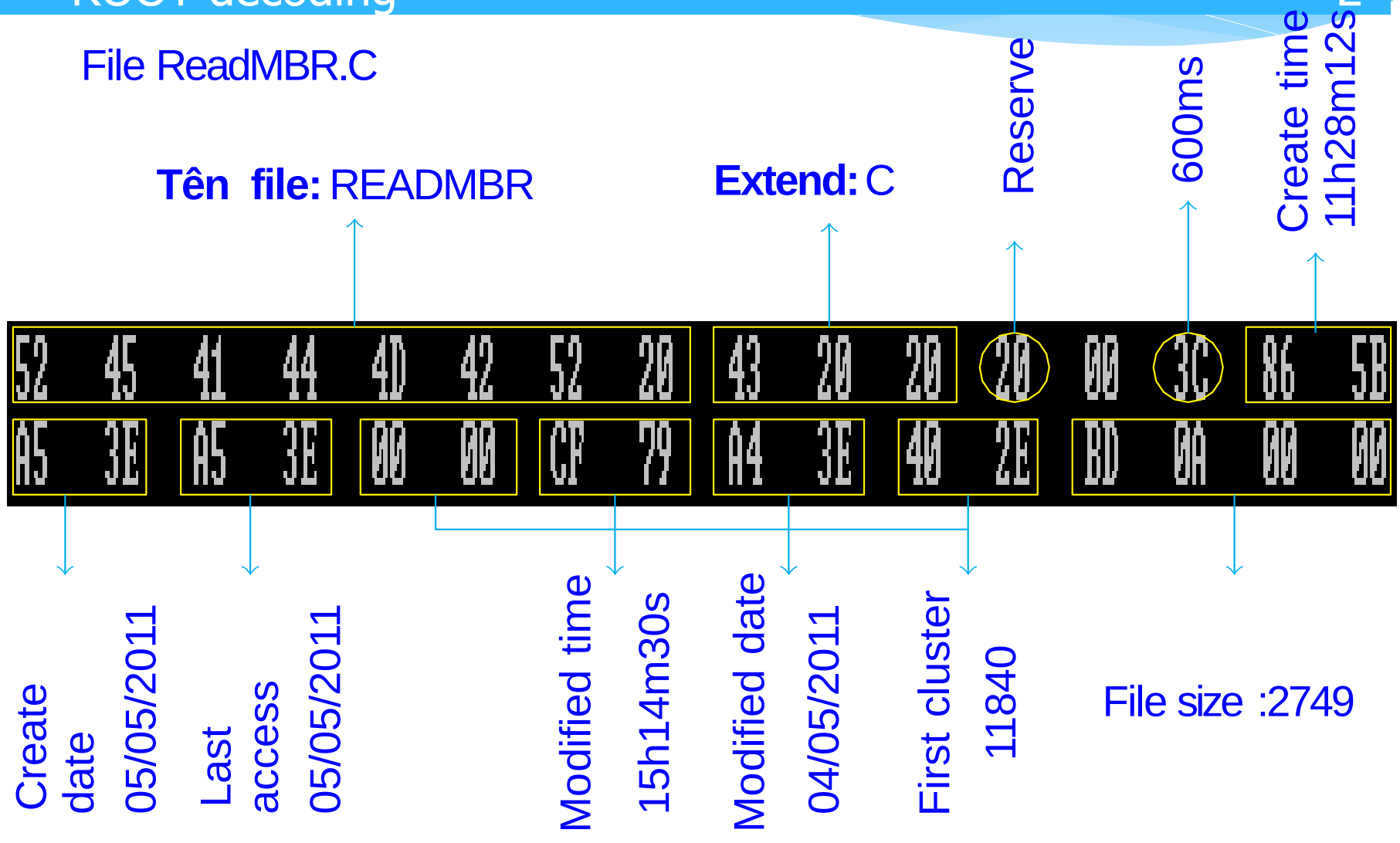


ROOT decoding 1



ROOT decoding 2

File ReadMBR.C



ROOT decoding

42	72	00	2E	00	63	00	00	00	FF	FF	0F	00	43	FF	FF
FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	00	00	FF	FF	FF	FF
01	52	00	65	00	61	00	64	00	42	00	0F	00	43	69	00
6F	00	73	00	53	00	65	00	63	00	00	00	74	00	6F	00
52	45	41	44	42	49	7E	31	43	20	20	20	00	A6	B2	4B
A5	3E	A5	3E	00	00	76	5C	9A	3E	3F	2E	D1	01	00	00

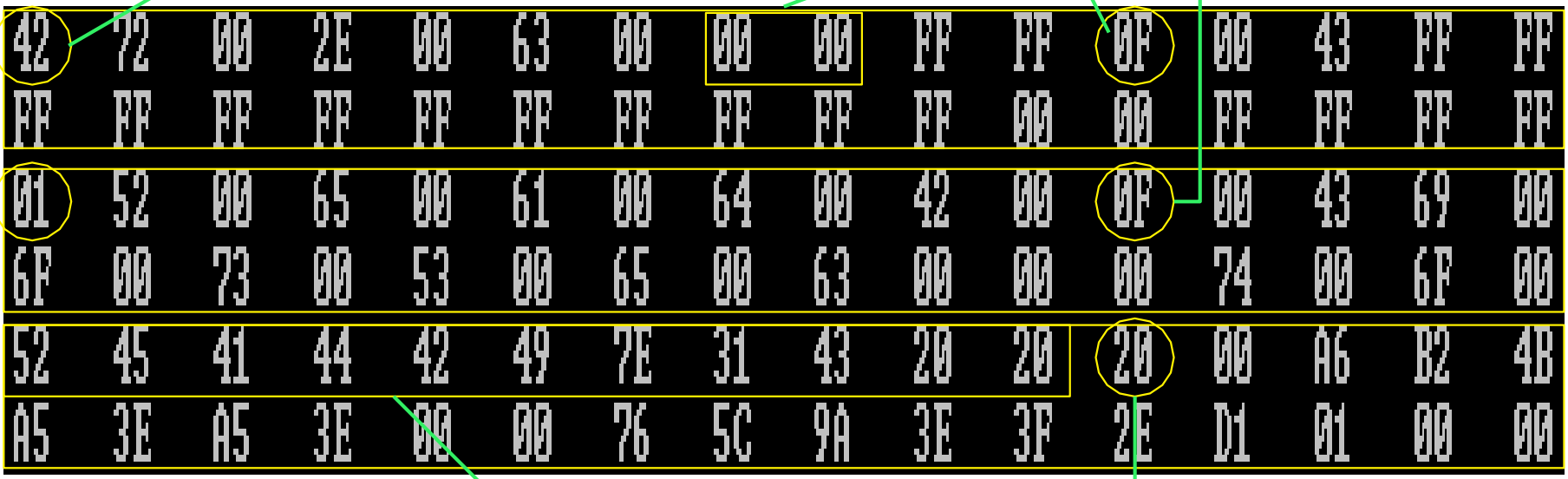
ROOT decoding

File: **ReadBiosSector.c**

LFN# 1(*ReadBiosSecto*)

LFN#2 – last LFN (*r.c*)

Character after last character(0x00 00)



READBI~1.C

Normal 8.3 element

Conclusion