

The FAT File System

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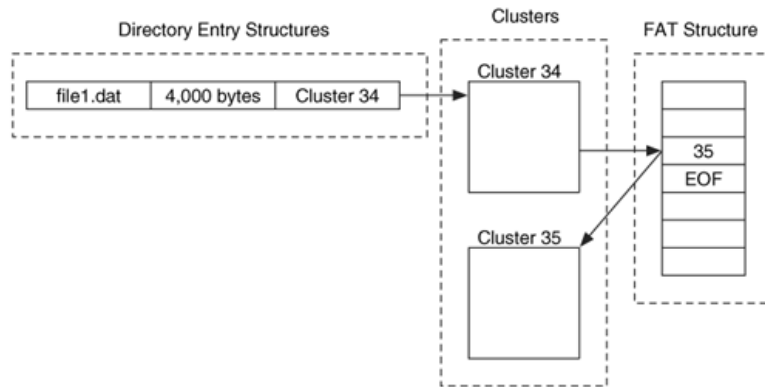
1. FAT Overview

- Simple - and common - file system
- Found on all Windows OS and many devices
 - **FAT12**: Developed 1977 (MS Disk BASIC)
 - **FAT16**: Developed 1987 (MS-DOS 3.31)
 - **FAT32**: Developed 1996 (Win95 OSR2)
- Few data structures supported:

- **Cluster**: Basic storage unit for files
- **Directory**: Lists file name, starting cluster, and length
- **File Allocation Table**: Contains cluster status and pointer to next cluster in chain

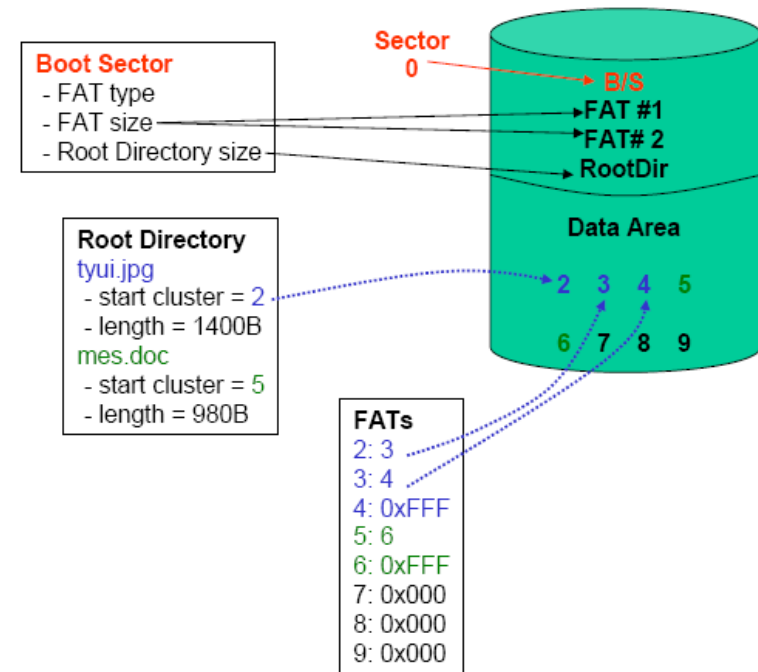
2. FAT Example

Relationship between the directory entry structures, clusters, and FAT structure:



3. Boot Sector, FAT, Root Directory, and Files

- File `tyui.jpg`:
 - occupies clusters 2, 3, and 4.
 - The file size is 1,400 bytes, it occupies 1,536 bytes (3 clusters) on the disk, and cluster 4 includes 136 bytes of slack space.
- File `mes.doc`:
 - occupies clusters 5 and 6.
 - The file size is 980 bytes, it occupies 1,024 bytes (2 clusters), and has 44 bytes of slack space in cluster 6.
- Clusters 7, 8, and 9 are unallocated.



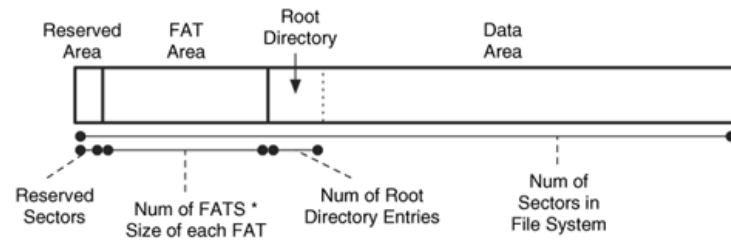
4. FAT File System Layout

Reserved
Area

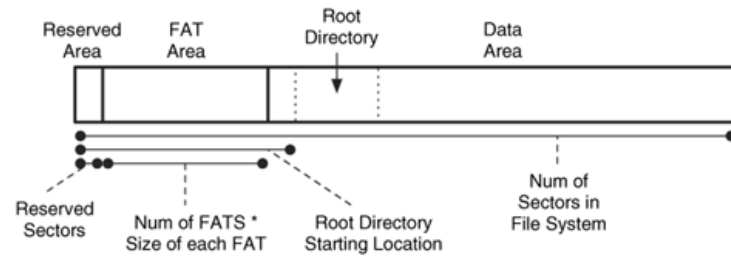
	FAT Area	Data Area
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5. FAT12 FAT16 FAT32 Layouts Compared

FAT12/16



FAT32



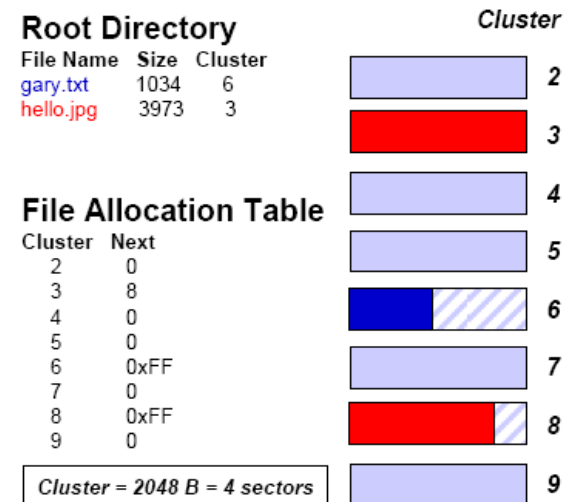
6. FAT Clusters and Sectors

- A cluster is a group of consecutive sectors
 - A sector is usually 512 B
 - A cluster is 1, 2, 4, 8, 16, 32, or 64 sectors (i.e., it can range from 512 B to 32 KB)
- Each cluster has an address
- The first cluster has an address of 2
 - I.e., there is no addressable cluster 0 or 1

7. FAT, Slack, and Unallocated Space

- Clusters 3, 6, and 8 are allocated; clusters 2, 4, 5, 7, and 9 are unallocated
- Clusters 6 and 8 are only partially filled; the unused portion is slack space

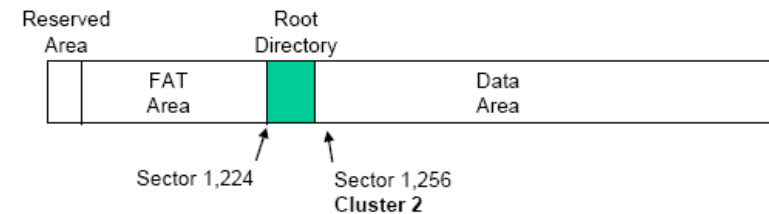
- File gary.txt:
 - logical size is 1,034 bytes
 - physical size is 2,048 bytes (slack = 1,014 B)
- File hello.jpg:
 - logical size is 3,973 bytes
 - physical size is 4,096 bytes (slack = 123 B)



8. Where is the First FAT Cluster?

- The first cluster is Cluster 2
- Actual location of cluster 2 is different in FAT12/16 and FAT32
- Assume cluster size = 2,048 B (4 sectors)
- Assume that data area starts at sector 1224
- First sectors of data area are reserved for the Root Directory
 - Size is established at boot time
- Cluster 2 starts after Root Directory
- Root directory is set at 32 sectors
 - Occupies sectors 1,224-1,255

FAT12/16 Cluster Example:



- Cluster 2 starts at sector 1,256
- Cluster 3 starts at sector 1,260
- Cluster 4 at 1,264...

9. Boot Sector

- First sector of a FAT system is the boot sector
 - Contains most of the information with which to determine
 - the file system type, and
 - size and location of data structures
- Boot sector format is different for FAT12/16 and FAT32

10. FAT Boot Sector, bytes 0-35 (FAT12/16 and FAT32)

Bytes	Purpose
0-2	Assembly code instructions to jump to boot code (mandatory in bootable partition)
3-10	OEM name in ASCII
11-12	Bytes per sector (512, 1024, 2048, or 4096)
13	Sectors per cluster (Must be a power of 2 and cluster size must be <=32 KB)
14-15	Size of reserved area, in sectors
16	Number of FATs (usually 2)
17-18	Maximum number of files in the root directory (FAT12/16; 0 for FAT32)
19-20	Number of sectors in the file system; if 2 B is not large enough, set to 0 and use 4 B value in bytes 32-35 below
21	Media type (0xf0=removable disk, 0xf8=fixed disk)
22-23	Size of each FAT, in sectors, for FAT12/16; 0 for FAT32
24-25	Sectors per track in storage device
26-27	Number of heads in storage device
28-31	Number of sectors before the start partition
32-35	Number of sectors in the file system; this field will be 0 if the 2B field above (bytes 19-20) is non-zero

11. FAT Boot Sector (FAT12/16)

--	--

Bytes	Purpose
0-35	(See previous table)
36	BIOS INT 13h (low level disk services) drive number
37	Not used
38	Extended boot signature to validate next three fields (0x29)
39-42	Volume serial number
43-53	Volume label, in ASCII
54-61	File system type level, in ASCII. (Generally "FAT", "FAT12", or "FAT16")
62-509	Not used
510-511	Signature value (0xaa55)

12. FAT12 Boot Sector

Offset	Hex	ASCII
00000000	EB 3C 90 4D 53 44 4F 53	e<<IMSDOS5.0....
00000010	02 E0 00 40 0B F0 09 00	.a.e.s.....
00000020	00 00 00 00 00 00 29 CF	.....)If+NO NA
00000030	4D 45 20 20 20 20 46 41	ME FAT12 3E
00000040	8E D1 BC F0 7B 8E D9 B8	INMS(10, . 1AuM.)
00000050	38 4E 24 7D 24 8B C1 99	8NS)S1Ate<.r.le:
00000060	66 A1 1C 7C 26 66 3B 07	f i .] & f ; & tWuu. iE
00000070	02 88 56 02 80 C3 10 73	. iV. iA. s&E f. i-
00000080	66 16 03 46 1C 13 56 1E	f..F..V..F..Niv.
00000090	60 89 46 FC 89 56 FE B8	' iFuVp. .s& i^..
000000A0	C3 4B F7 F3 01 46 FC 11	ÄH-ö.Fü.Npaö..öee
000000B0	00 72 39 26 38 2D 74 17	.r9Gö-t..t..Xijó|
000000C0	61 74 32 4E 74 09 83 C7	at2ht..iC ürw&ü
000000D0	FB 7D B4 7D 8B F0 AC 90	ä)' i6-1@t.Ht..'
000000E0	BB 07 00 CD 10 EB EF A0	>..i.ei y)ee u)e
000000F0	E1 CD 16 CD 19 26 8B 55	ä i . i. & iU. R'..>.ö
00000100	3B 00 72 E8 5B 8A 56 24	:.re[iV&M'. iüCF6
00000110	3C 7D C7 46 F4 29 7D 8C	=)CF6))iüiNoiN&E
00000120	06 96 7D CB EA 03 00 00	. i)Eö... .ME i fEö
00000130	86 03 46 1C 66 8B D0 66	i . F. f iB&Aö.e^..ME
00000140	4A 4A 8A 46 0D 32 EA F7	JJ i F. 2&-ä.Fü.Vp&
00000150	4A 52 50 06 53 6A 01 6A	JRP.Sj..j.. i F. i'3
00000160	D2 F7 F6 91 F7 F6 42 87	Ö-ö'-öB iE-v..iote
00000170	C0 CC 02 0A CC B8 01 02	Ä i . . i . i'..u..B
00000180	8B F4 8A 56 24 CD 13 61	iö iV& i .oar.@.B.
00000190	5E 0B 49 75 06 F8 C3 41	^..i.u.oM>.. f j.ö
000001A0	B0 4E 54 4C 44 52 20 20	*NILD R ..Re
000001B0	6D 6F 76 65 20 64 69 73	move disks or ot
000001C0	68 65 72 20 6D 65 64 69	her media.y..Dis
000001D0	6B 20 65 72 72 6F 72 FF	k errorry..Press
000001E0	61 6E 79 20 6B 65 79 20	any key to resta
000001F0	72 74 0D 0A 00 00 00 00	rt.....-E&ü&
00000200	00 00 00 00 00 00 00 00	A&ü

13. Boot Sector Interpretation

```
00-02: eb 3c 90      Instructions to jump to boot code
03-0a: 4d 53 44 4f 53 35 2e 30
                        Name string (MSDOS5.0)
0b-0c: 00 02        Bytes/sector (0x0200 = 512)
0d   : 01          Sectors/cluster (1)
0e-0f: 01 00        Size of reserved area (1 sector)
10   : 02          Number of FATs (2)
11-12: e0 00        Max. number of root directory entries (0x00e0 = 224)
13-14: 40 0b        Total number of sectors (0x0b40 = 2,880)
15   : f0          Media type (removable)
16-17: 09 00        FAT size (0x0009 = 9 sectors)
18-19: 12 00        Sectors/track (0x0012 = 18)
1a-1b: 02 00        Number of heads (0x0002 = 2)
1c-1f: 00 00 00 00  Number of sector before partition (0)
20-23: 00 00 00 00  Total number of sectors (0 because 2B value not equal 0)
24   : 00          Drive number (0)
25   : 00          Unused
26   : 29          Extended boot signature
27-2a: cf cd b1 c4   Volume serial number (C4B1-CDCF)
2b-35: 4e 4f 20 4e 41 4d 45 20 20 20 20
                        Volume label ("NO NAME ")
36-3d: 46 41 54 31 32 20 20 20
                        File system type label ("FAT12 ")
3e-1fd : [snip]     Not used
1fe-1ff: 55 aa      Signature value (0xaa55)
```

14. Capacity of this Medium

- FAT12 allocates 12 bits per FAT entry
 - Limits addressing to 4,096 (212) clusters
- This (removable) device is configured so that:
 - 1 cluster = 1 sector
 - 1 sector = 512 B
- This FAT12 table is limited in capacity to 2,097,152 bytes (2 MB)
 - I.e., 4K clusters of 512 B each
- This device has 2,880 sectors
 - 512 B clusters yields a device capacity of 1.44 MB
 - Corresponds to what we would expect for a floppy

15. Sector Assignments

Sector(s)	Address	Function
0	0x0000-0x01ff	Boot Sector
1-9	0x0200-0x13ff	File Allocation Table (primary)
10-18	0x1400-0x25ff	File Allocation Table (secondary)
19-32	0x2600-0x41ff	Root Directory
33-2879	0x4200-0x167fff	File storage space

NOTES:

- Boot Sector is 1 sector (0x200 bytes)
- There are two FATs, each 9 sectors (0x1200 bytes)
- The Root Directory can contain 224 entries, each 32 bytes (7168, or 0x1c00, bytes; 14 sectors)
- File storage starts at sector #33 (1+9+9+14), byte #0x4200 (0x200+0x1200+0x1200+0x1c00)

16. Root Directory

- Contains file names and metadata
 - Located immediately after FAT(s) in FAT12/16 or in a location specified in the FAT32 boot sector
 - Supports 8.3 names or long file names
 - New entries are added to the directory using a first-available or next-available strategy
 - First-available: Finds first unallocated entry in the directory (e.g., Win98)
 - Next-available: Finds next available entry from the last allocated entry; at end of directory chain, start again at beginning (e.g., WinXP)
-

17. Root Directory Entries

- The Root Directory is a series of entries describing files
- Each entry is 32 bytes and contains
 - single short (8.3) filename (SFN),
 - attributes,
 - MAC times,
 - start cluster,
 - size,
 - and other metadata.
 - Additional 32B entries contain the file's long filename (LFN)

18. Root Directory Entry Format (SFN)

Root Directory SFN Entry Data Structure	
Bytes	Purpose
0	First character of file name (ASCII) or allocation status (0x00=unallocated, 0xe5=deleted)
1-10	Characters 2-11 of the file name (ASCII); the "." is implied between bytes 7 and 8
11	File attributes (see File Attributes table)
12	Reserved
13	File creation time (in tenths of seconds)*
14-15	Creation time (hours, minutes, seconds)*
16-17	Creation date*
18-19	Access date*
20-21	High-order 2 bytes of address of first cluster (0 for FAT12/16)*
22-23	Modified time (hours, minutes, seconds)
24-25	Modified date
26-27	Low-order 2 bytes of address of first cluster
28-31	File size (0 for directories)

File Attributes	
Flag Value	Description
0000 0001 (0x01)	Read-only
0000 0010 (0x02)	Hidden file
0000 0100 (0x04)	System file
0000 1000 (0x08)	Volume label
0000 1111 (0x0f)	Long file name
0001 0000 (0x10)	Directory
0010 0000 (0x20)	Archive

* Bytes 13-22 are unused by DOS

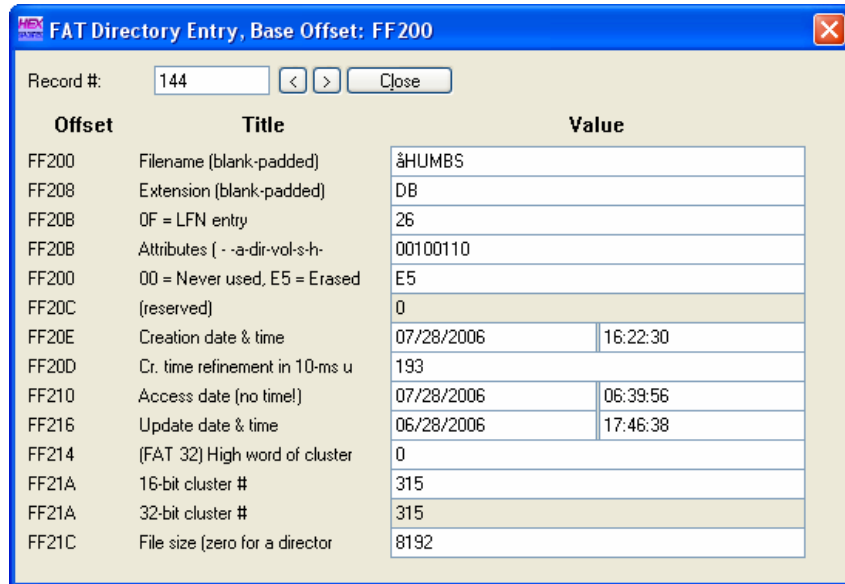
19. Root Directory Example

Offset	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	
000FF120	42	70	00	67	00	00	00	FF	FF	FF	FF	0F	00	D3	FF	FF	Bp g yyyý Öyy
000FF130	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	00	00	FF	FF	FF	FF	yyyyyyyyyy yyyý
000FF140	01	62	00	65	00	6C	00	69	00	6E	00	0F	00	D3	5F	00	b e l i n Ö
000FF150	67	00	61	00	79	00	6C	00	65	00	00	00	2E	00	6A	00	g a y l e . j
000FF160	42	45	4C	49	4E	5F	7E	31	4A	50	47	20	00	96	CF	82	BELIN~1JPG Ĩİ
000FF170	FC	34	FC	34	00	00	31	B0	B6	32	8D	00	B6	6A	05	00	ü4ü4 1*İ2İ İj
000FF180	42	6A	00	70	00	67	00	00	00	FF	FF	0F	00	56	FF	FF	Bj p g yy Vyy
000FF190	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	00	00	FF	FF	FF	FF	yyyyyyyyyy yyyý
000FF1A0	01	6B	00	65	00	73	00	73	00	6C	00	0F	00	56	65	00	k e s s l Ve
000FF1B0	72	00	5F	00	67	00	61	00	72	00	00	00	79	00	2E	00	r _ g a r y .
000FF1C0	4B	45	53	53	4C	45	7E	31	4A	50	47	20	00	AB	CF	82	KESSE~1JPG «İİ
000FF1D0	FC	34	FC	34	00	00	31	B0	B6	32	E4	00	29	6A	05	00	ü4ü4 1*İ2ä)j
000FF1E0	E5	54	00	68	00	75	00	6D	00	62	00	0F	00	A4	73	00	âT h u m b ðs
000FF1F0	2E	00	64	00	62	00	00	00	FF	FF	00	00	FF	FF	FF	FF	. d b yy yyyý
000FF200	E5	48	55	4D	42	53	20	20	44	42	20	26	00	C1	CF	82	âHUMBS DB & Áİİ
000FF210	FC	34	FC	34	00	00	D3	8D	DC	34	3B	01	00	20	00	00	ü4ü4 ÓİÜ4;

Three files shown here:

```
BELIN_~1.JPG @ offset 0xff160 (belin_gayle.jpg entry starts @ offset 0xff140)
KESSLER~1.JPG @ offset 0xff1c0 (kessler_gary.jpg entry starts @ offset 0xff1a0)
?HUMBS.DB @ offset 0xff200 (Thumbs.db; deleted)
```

20. Sample Root Directory Entry



The screenshot shows a window titled "FAT Directory Entry, Base Offset: FF200". It displays a table of directory entry fields for record 144. The fields are organized into three columns: Offset, Title, and Value. The values are as follows:

Offset	Title	Value
FF200	Filename (blank-padded)	âHUMBS
FF208	Extension (blank-padded)	DB
FF20B	OF = LFN entry	26
FF20B	Attributes (-a-dir-vol-s-h-	00100110
FF200	00 = Never used, E5 = Erased	E5
FF20C	(reserved)	0
FF20E	Creation date & time	07/28/2006 16:22:30
FF20D	Cr. time refinement in 10-ms u	193
FF210	Access date (no time!)	07/28/2006 06:39:56
FF216	Update date & time	06/28/2006 17:46:38
FF214	(FAT 32) High word of cluster	0
FF21A	16-bit cluster #	315
FF21A	32-bit cluster #	315
FF21C	File size (zero for a director	8192

21. Another Sample Root Directory Entry

FAT Directory Entry, Base Offset: FF1C0

Record #: 142 < > Close

Offset	Title	Value
FF1C0	Filename (blank-padded)	KESSE~1
FF1C8	Extension (blank-padded)	JPG
FF1CB	0F = LFN entry	20
FF1CB	Attributes (- a-dir-vol-s-h-	00100000
FF1C0	00 = Never used, E5 = Erased	4B
FF1CC	(reserved)	0
FF1CE	Creation date & time	07/28/2006 16:22:30
FF1CD	Cr. time refinement in 10-ms u	171
FF1D0	Access date (no time!)	07/28/2006 06:39:56
FF1D6	Update date & time	05/22/2005 22:01:34
FF1D4	(FAT 32) High word of cluster	0
FF1DA	16-bit cluster #	228
FF1DA	32-bit cluster #	228
FF1DC	File size (zero for a director	354857

22. FATs Compared

Attribute	FAT12	FAT16	FAT32
Used For	Floppies; small hard drives	Small to large hard drives	Large to very large hard drives
Size of Each FAT Entry	12 bits	16 bits	28 bits
Maximum Number of Clusters	~4,096	~65,536	~268,435,456
Supported Cluster Sizes	512 B to 4 KB	2 KB to 32 KB	4 KB to 32 KB
Maximum Volume Size	16,736,256 B (16 MB)	2,147,123,200 B (2 GB)	~2 ⁴¹ B (2 TB)

23. FAT12 File Allocation Table

- FAT table entries are *packed* so that two cluster entries occupy three bytes with the following general format:

yz Zx XY

where

- xyz is the one pointer entry and
 - XYZ is the second pointer entry.
- E.g., bytes 242-244:

2d e0 02

refer to clusters 0x02d (45) and 0x02e (46)

- Primary FAT starts at sector 1, byte 0x200 (shown here)
- The starting cluster in the directory is also a pointer into the FATs linking to the next cluster in the file

Primary FAT sector 1:

Offset	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	Access
00000200	ff	ff	ff	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000210	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000220	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000230	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000240	c0	02	20	e0	02	2f	00	03	31	20	03	33	40	03	35	60	A..h..1..38.5*
00000250	03	37	80	03	39	a0	03	38	c0	03	30	e0	03	3f	00	04	.71.9..!A..h.?.
00000260	41	20	04	43	40	04	45	60	04	47	80	04	ff	af	04	4b	A..C@.E\G..y.K
00000270	c0	04	4d	f0	ff	00	00	00	00	00	00	00	00	00	00	00	A.M8y.....
00000280	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000290	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000002a0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000002b0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000002c0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000002d0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000002e0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000002f0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000300	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000310	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000320	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000330	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000340	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000350	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000360	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000370	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000380	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000390	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000003a0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000003b0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000003c0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000003d0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000003e0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
000003f0	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....
00000400	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	.....

24. Interpreting FAT12

```
0260 41 20 04 43 40 04 45 60 04 47 80 04 ff af 04 4b A .C@.E\G..y.K
0270 c0 04 4d f0 ff 00 00 00 00 00 00 00 00 00 00 A.M8y.....
```

- The Primary FAT starts at Sector 1, byte #0x0200.
- Suppose a file has a starting cluster of 0x49 (73).
 - The file starts on the media at cluster #73
 - The FAT entry pointing to the next cluster is in the FAT at byte $\#(73 \times 1.5 + 1) = 110$ (0x6e)
 - Since the FAT starts at 0x0200, the FAT entry for this file is at 0x026e

- Example:

1st cluster is 0x49 (73). FAT entry starts at high-order nibble of 0x026e (110) = 0x04a (74)

2nd cluster is 0x4a (74). FAT entry starts at low-order nibble of 0x0270 (112) = 0x04b (75)

3rd cluster is 0x04b (75). FAT entry starts at high-order nibble of 0x0271 (113) = 0x04c (76)

4th cluster is 0x04c (76). FAT entry starts at low-order nibble of 0x0273 (115) = 0x04d (77)

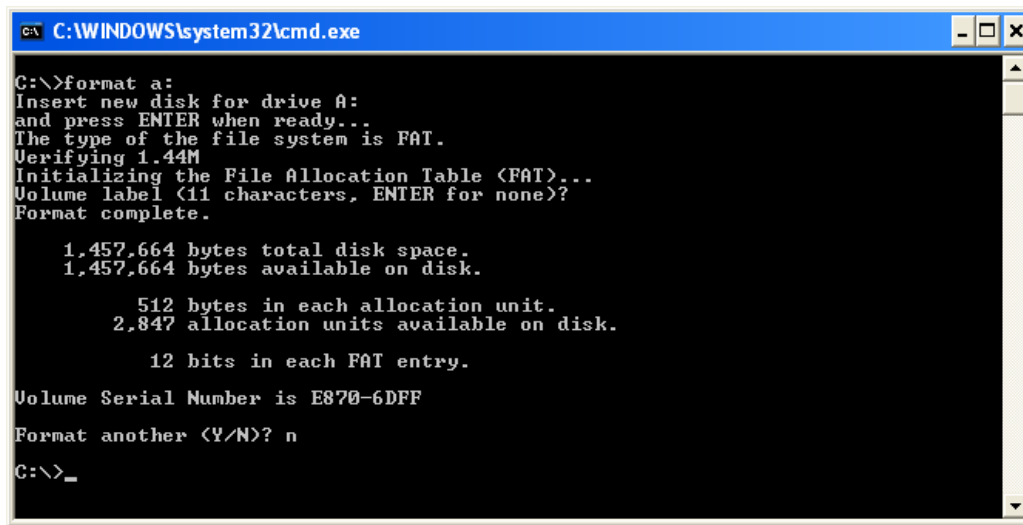
5th cluster is 0x04d (77). FAT entry starts at high-order nibble of 0x0274 (116) = 0xfff (end of list)

- The physical size of this file is five clusters (2560 bytes), and occupies clusters 73, 74, 75, 76, and 77 on the medium. (It is merely a coincidence that the clusters are contiguous.)

25. FAT12 Contents

Entry	Pointer		Entry	Pointer
2	0		71	72
3	0		72	0xfff
4	0	2nd cluster chain starts at cluster 73 (length 5)	73	74
:	:		74	75
40	0		75	76
41	0		76	77
42	43	1st cluster chain starts at cluster 42 (length 31)	77	0xfff
43	44		78	0
44	45		79	0
::	::		80	0
70	71		:	0

26. Formatting a Floppy



```
C:\WINDOWS\system32\cmd.exe
C:\>format a:
Insert new disk for drive A:
and press ENTER when ready...
The type of the file system is FAT.
Verifying 1.44M
Initializing the File Allocation Table (FAT)...
Volume label (11 characters, ENTER for none)?
Format complete.

  1,457,664 bytes total disk space.
  1,457,664 bytes available on disk.

    512 bytes in each allocation unit.
  2,847 allocation units available on disk.

    12 bits in each FAT entry.

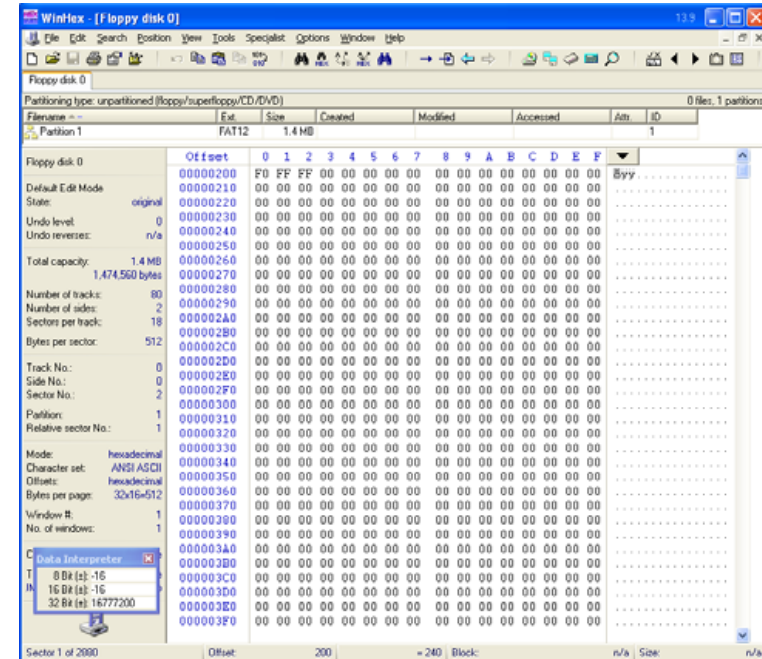
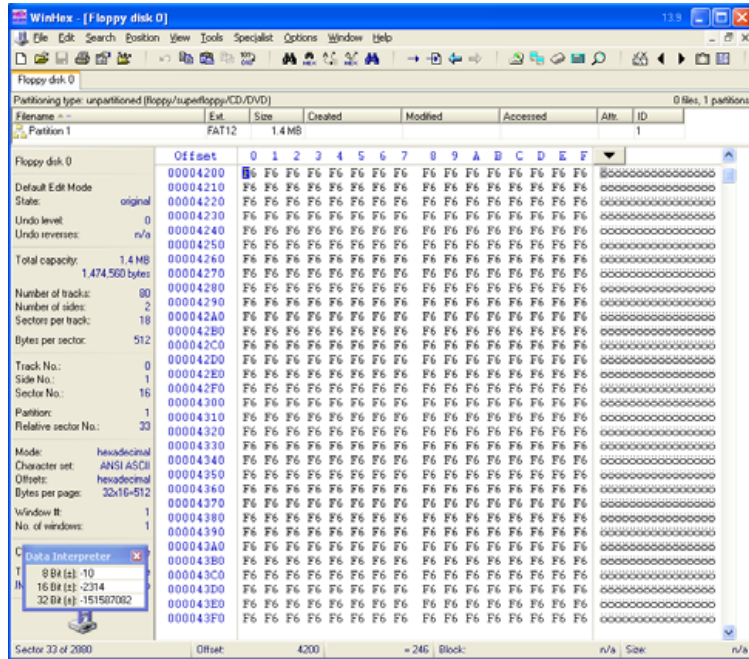
Volume Serial Number is E870-6DFF
Format another (Y/N)? n
C:\>_
```

- Formatting will initialize the FATs (0x00) and root directory (0xF6)
- On a floppy, format will overwrite the data area with 0xF6
- Data is NOT deleted when using Quick Format on a floppy or any format on a hard drive

27. Formatted Floppy Data Structures

Floppy Data Structures [before](#) formatting, uninitialized:

Floppy Data Structures [after](#) formatting, initialized root directory:



28. Allocating A New File

1. Find first free entry in directory and write file name
 2. Search FAT for unallocated cluster; set to EOF (0xFFFF)
 3. Write that cluster's address into directory entry
 4. If another cluster is needed,
 - find an unallocated FAT entry,
 - reset that value to EOF, and
 - reset previous FAT pointer to this new cluster
- (Repeat this step as necessary.)

29. Deleting A File

-
1. Find directory entry for file to delete
 2. Using starting cluster value in the root directory, set all FAT entries in file's cluster chain to zero
 3. Deallocate directory entry by overwriting first byte of the entry with 0xE5 (å)

30. For More Information...

- FAT: General Overview of On-Disk Format, v1.03 (12/6/2000), Microsoft:

<http://www.microsoft.com/whdc/system/platform/firmware/fatgen.mspx>

http://digitalforensics.champlain.edu/download/FAT_general_overview-LFN.pdf

- File Allocation Table, Wikipedia:

http://en.wikipedia.org/wiki/File_Allocation_Table