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File Allocation Table

File Allocation Table (**FAT**) is a file system developed for personal computers and was the default file system for the MS-DOS and Windows 9x operating systems. Originally developed in 1977 for use on floppy disks, it was adapted for use on hard disks and other devices. The increase in disk drive capacity over time drove modifications to the design that resulted in versions: FAT12, FAT16, FAT32, and exFAT. FAT was replaced with NTFS as the default file system on Microsoft operating systems starting with Windows XP.[3] Nevertheless, FAT continues to be commonly used on relatively small capacity solid-state storage technologies such as SD card, MultiMediaCard (MMC) and eMMC because of its compatibility and ease of implementation.[4]

Uses

Historical

FAT was used on hard disks throughout the DOS and Windows 9x eras. Microsoft introduced NTFS with the Windows NT platform in 1993, but FAT remained the standard for the home user until the introduction of Windows XP in 2001. Windows Me was the final version of Windows to use FAT as its default file system.

For floppy disks, FAT has been standardized as ECMA-107[5] and ISO/IEC 9293:1994[6] (superseding ISO 9293:1987[7]). These standards cover FAT12 and FAT16 with only short 8.3 filename support; long filenames with VFAT were partially patented.[8] While FAT12 is used on floppy disks, FAT16 and FAT32 are typically found on the larger media.

Modern

FAT is used internally for the EFI system partition in the boot stage of EFI-compliant computers.[9]

FAT is still used in drives expected to be used by multiple operating systems, such as in shared Windows, Linux and DOS environments. Microsoft Windows additionally comes with a pre-installed tool to convert a FAT file system into NTFS directly without the need to rewrite all files, though this cannot be reversed easily.[10] The FAT file system is used in removable media such as floppy disks, super-floppies, memory and flash memory cards or USB flash drives. FAT is supported by portable devices such as PDAs, digital cameras, camcorders, media players, and mobile phones.

The DCF file system adopted by almost all digital cameras since 1998 defines a logical file system with 8.3 filenames and makes the use of either FAT12, FAT16, FAT32 or exFAT mandatory for its physical layer for compatibility.[11]

Technical details

The file system uses an index table stored on the device to identify chains of data storage areas associated with a file, the *File Allocation Table* (*FAT*). The FAT is statically allocated at the time of formatting. The table is a linked list of entries for each *cluster*, a contiguous area of disk storage. Each entry contains either the number of the next cluster in the file, or else a marker indicating the end of the file, unused disk space, or special reserved areas of the disk. The *root directory* of the disk contains the number of the first cluster of each file in that directory. The operating system can then traverse the FAT, looking up the cluster number of each successive part of the disk file as a *cluster chain* until the end of the file is reached. *Sub-directories* are implemented as special files containing the *directory entries* of their respective files.

Each entry in the FAT linked list is a fixed number of bits: 12, 16 or 32. The maximum size of a file or a disk drive that can be accessed is the product of the largest number that can be stored in the entries (less a few values reserved to indicate unallocated space or the end of a list) and the size of the disk cluster. Even if only one byte of storage is needed to extend a file, an entire cluster must be allocated to it. As a result, large numbers of small files can result in clusters being allocated that may contain mostly "empty" data to meet the minimum cluster size.

Originally designed as an 8-bit file system, the maximum number of clusters must increase as disk drive capacity increases, and so the number of bits used to identify each cluster has grown. The successive major variants of the FAT format are named after the number of table element bits: 12 (FAT12), 16 (FAT16), and 32 (FAT32).

Variants

There are several variants of the FAT file system (e.g. FAT12, FAT16 and FAT32). FAT16 refers to both the original group of FAT file systems with 16-bit wide cluster entries and also to later variants. "VFAT" is an optional extension for long file names, which can work on top of any FAT file system. Volumes using VFAT long-filenames can be read also by operating systems not supporting the VFAT extension.

Original 8-bit FAT

The original FAT file system (or *FAT structure*, as it was called initially) was designed and implemented by Marc McDonald,[14] based on a series of discussions between McDonald and Bill Gates.[14] It was introduced with 8-bit table elements[12][13][14] (and valid data cluster numbers up to `0xBF`[12][13]) in a precursor to Microsoft's *Standalone Disk BASIC-80* for an 8080-based successor[nb 2] of the NCR 7200 model VI data-entry terminal,

FAT

Developer(s)	Microsoft, NCR, SCP, IBM, Compaq, Digital Research, Novell, Caldera
Full name	File Allocation Table
Variants	8-bit FAT, FAT12, FAT16, FAT16B, FAT32, exFAT, FATX, FAT+
Introduced	
Partition ID	
Directory co	
File allocati	
Bad blocks	
Max volume	FAT32: 2 TB (16 TB for 4 KB sectors)
Max file size	4,294,967,295 bytes (4 GB − 1) with FAT16B and FAT32[1]
Max no. of files	FAT12: 4,068 for 8 KB clusters FAT16: 65,460 for 32 KB clusters FAT32: 268,173,300 for 32 KB clusters
Max filename length	8.3 filename, or 255 UCS-2 characters when using LFN[nb 1]
	Features
Dates recorded	Modified date/time, creation date/time (DOS 7.0 and higher only), access date (only available with ACCDATE enabled),[2] deletion date/time (only with DELWATCH 2)
Date range	1980-01-01 to 2099-12-31 (2107-12-31)
Date resolution	2 seconds for last modified time, 10 ms for creation time, 1 day for access date, 2 seconds for deletion time
Forks	Not natively
Attributes	Read-only, hidden, system, volume, directory, archive
File system permissions	FAT12/FAT16: File, directory and volume access rights for read, write, execute, delete only with DR-DOS, PalmDOS, Novell DOS, OpenDOS, FlexOS, 4680 OS, 4690 OS, Concurrent DOS, Multiuser DOS, System Manager, REAL/32: execute with only FlexOS, 4680 OS, 4690 OS; individual file / directory passwords not with FlexOS, 4680 OS, 4690 OS; world/group/owner permission classes only with multiuser security loaded FAT32: Partial, only with DR-DOS,

Microsoft Corporation is an American multinational technology conglomerate headquartered in Redmond, Washington. Founded in 1975, the company became highly influential in the rise of personal computers through software like

equipped with 8-inch (200 mm) floppy disks, in 1977[15] or 1978.[nb 2] In 1978, *Standalone Disk BASIC-80* was ported to the 8086 using an emulator on a DEC PDP-10,[16] since no real 8086 systems were available at this time. The FAT file system was also used in Microsoft's MDOS/MIDAS,[14] an operating system for 8080/Z80 platforms written by McDonald since 1979. The *Standalone Disk BASIC* version supported three FATs,[12][13][17] whereas this was a parameter for MIDAS. Reportedly, MIDAS was also prepared to support 10-bit, 12-bit and 16-bit FAT variants. While the size of directory entries was 16 bytes in *Standalone Disk BASIC*,[12][13] MIDAS instead occupied 32 bytes per entry.

Tim Paterson of Seattle Computer Products (SCP) was first introduced to Microsoft's FAT structure when he helped Bob O'Rear adapting the *Standalone Disk BASIC-86* emulator port onto SCP's S-100 bus 8086 CPU board prototype during a guest week at Microsoft in May 1979.[16] The final product was shown at Lifeboat Associates' booth stand at the National Computer Conference in New York[16] on June 4–7, 1979, where Paterson learned about the more sophisticated FAT implementation in MDOS/MIDAS[14] and McDonald talked to him about the design of the file system.[15]

FAT12

Between April and August 1980, while borrowing the FAT concept for SCP's own 8086 operating system QDOS 0.10,[16] Tim Paterson extended the table elements to **12 bits**,[18] reduced the number of FATs to two, redefined the semantics of some of the reserved cluster values, and modified the disk layout, so that the root directory was now located between the FAT and the data area for his implementation of **FAT12**. Paterson also increased the nine-character (6.3) filename[12][13] length limit to eleven characters to support CP/M-style 8.3 filenames and File Control Blocks. The format used in Microsoft *Standalone Disk BASIC's* 8-bit file system precursor was not supported by QDOS. By August 1980, QDOS had been renamed to 86-DOS.[19] Starting with 86-DOS 0.42, the size and layout of directory entries was changed from 16 bytes to 32 bytes[20] in order to add a file date stamp[20] and increase the theoretical file size limit beyond the previous limit of 16 MB.[20] 86-DOS 1.00 became available in early 1981. Later in 1981, 86-DOS evolved into Microsoft's MS-DOS and IBM PC DOS.[14][18][21] The capability to read previously formatted volumes with 16-byte directory entries[20] was dropped with MS-DOS 1.20.

FAT12 used 12-bit entries for the cluster addresses; some values were reserved to mark the end of a chain of clusters, to mark unusable areas of the disk, or for other purposes, so the maximum number of clusters was limited to 4078.[22][23] To conserve disk space, two 12-bit FAT entries used three consecutive 8-bit bytes on disk, requiring manipulation to unpack the 12-bit values. This was sufficient for the original floppy disk drives, and small hard disks up to 32 megabytes. The FAT16B version available with DOS 3.31 supported 32-bit sector numbers, and so increased the volume size limit.

All the control structures fit inside the first track, to avoid head movement during read and write operations. Any bad sector in the control structures area would make the disk unusable. The DOS formatting tool rejected such disks completely. Bad sectors were allowed only in the file data area. Clusters containing bad sectors were marked unusable with the reserved value `0xFF7` in the FAT.

While 86-DOS supported three disk formats (250.25 KB, 616 KB and 1232 KB, with FAT IDs `0xFF` and `0xFE`) on 8-inch (200 mm) floppy drives, IBM PC DOS 1.0, released with the original IBM Personal Computer in 1981, supported only an 8-sector floppy format with a formatted capacity of 160 KB (FAT ID `0xFE`) for single-sided 5.25-inch floppy drives, and PC DOS 1.1 added support for a double-sided format with 320 KB (FAT ID `0xFF`). PC DOS 2.0 introduced support for 9-sector floppy formats with 180 KB (FAT ID `0xFC`) and 360 KB (FAT ID `0xFD`).

86-DOS 1.00 and PC DOS 1.0 directory entries included only one date, the last modified date. PC DOS 1.1 added the last modified time. PC DOS 1.x file attributes included a hidden bit and system bit, with the remaining six bits undefined. At this time, DOS did not support sub-directories, but typically there were only a few dozen files on a diskette.

The PC XT was the first PC with an IBM-supplied hard drive, and PC DOS 2.0 supported that hard drive with FAT12 (FAT ID `0xF8`). The fixed assumption of 8 sectors per clusters on hard disks practically limited the maximum partition size to 16 MB for 512 byte sectors and 4 KB clusters.

The *BIOS Parameter Block* (*BPB*) was introduced with PC DOS 2.0 as well, and this version also added read-only, archive, volume label, and directory attribute bits for hierarchical sub-directories.[24]

MS-DOS 3.0 introduced support for high-density 1.2 MB 5.25-inch diskettes (media descriptor `0xF9`), which notably had 15 sectors per track, hence more space for the FATs.

FAT12 remains in use on all common floppy disks, including 1.44 MB and later 2.88 MB disks (media descriptor byte `0xF0`).

Initial FAT16

In 1984, IBM released the PC AT, which required PC DOS 3.0 to access its 20 MB hard disk.[25][26] Microsoft introduced MS-DOS 3.0 in parallel. Cluster addresses were increased to 16-bit, allowing for up to 65,526 clusters per volume. However, the maximum possible number of sectors and the maximum partition size of 32 MB did not change. Although cluster addresses were 16 bits, this format was not what today is commonly understood as **FAT16**. A partition type `0x04` indicates this form of FAT16 with less than 65,536 sectors (less than 32 MB for sector size 512). The benefit of FAT16 was the use of smaller clusters, making disk usage more efficient, particularly for large numbers of files only a few hundred bytes in size.

As MS-DOS 3.0 formatted all 16 MB-32 MB partitions in the FAT16 format, a 20 MB hard disk formatted under MS-DOS 3.0 was not accessible by MS-DOS 2.0.[27] MS-DOS 3.0 to MS-DOS 3.30 could still access FAT12 partitions under 15 MB, but required all 16 MB-32 MB partitions to be FAT16, and so could not access MS-DOS 2.0 partitions in this size range. MS-DOS 3.31 and higher could access 16 MB-32 MB FAT12 partitions again.

Logical sectored FAT

MS-DOS and PC DOS implementations of FAT12 and FAT16 could not access disk partitions larger than 32 megabytes. Several manufacturers developed their own FAT variants within their OEM versions of MS-DOS.[28]

Some vendors (AST and NEC[28]) supported eight, instead of the standard four, primary partition entries in their

	REAL/32 and 4690 OS
Transparent compression	FAT12/FAT16: Per-volume, SuperStor, Stacker, DoubleSpace, DriveSpace
	FAT32: No
Transparent encryption	FAT12/FAT16: Per-volume only with DR-DOS
	FAT32: No

8-bit FAT

Developer(s)	Microsoft, NCR, SCP
Full name	8-bit File Allocation Table
Introduced	1977/1978: NCR Basic +6 for NCR
	1978: Standalone Disk BASIC-80 (16-byte directory entries)[12][13]
	(1978: Standalone Disk BASIC-86 internal only)
	1979-06-04: Standalone Disk BASIC-86 for SCP (16-byte directory entries)
	1979: MIDAS (32-byte directory entries)
Limits	
Max file size	8 MB
File size granularity	record-granularity (128 bytes)[12][13]
Max filename length	6.3 filename (binary files), 9 characters (ASCII files)[12][13]
Max directory depth	No sub-directories
Allowed filename characters	ASCII (`0x00` and `0xFF` not allowed in first character)[12][13]
Features	
Dates recorded	No
Attributes	Write protected, EBCDIC conversion, read after write, binary (random rather than sequential file)[12][13]

FAT12

Developer(s)	SCP, Microsoft, IBM, Digital Research, Novell
Full name	12-bit File Allocation Table
Introduced	1980-07 (QDOS 0.10, 16-byte directory entries)
	1981-02-25 (86-DOS 0.42, 32-byte directory entries, several reserved sectors)
	c. 1981–08/10 (PC DOS 1.0, 32-byte directory entries, 1 reserved sector)
	1982-03-03 (MS-DOS 1.25, 32-byte directory entries, 1 reserved sector)
Partition IDs	MBR/EBR:
	FAT12: `0x01` e.a.
	BDP: `EBD0A0A2-B9E5-4433-87C0-68B6B72699C7`
Limits	
Max volume size	16 MB (with 4 KB clusters)
	32 MB (with 8 KB clusters)
Max file size	Limited by volume size
File size granularity	1 byte