On-disk filesystem structures

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Filesystem on-disk structures for FAT, HPFS, NTFS and JFS

FSYS - Software

DFSee

Presentation contents

- Generic filesystem architecture
- FAT, File Allocation Table
- HPFS, High Performance FileSystem
- NTFS, New Technology FileSystem
- Examples using DFSee ...

Who am I ?

Jan van Wijk

- Software Engineer, C, Rexx, Assembly
- Founded FSYS Software in 2001
- First OS/2 experience in 1987, developing parts of OS/2 1.0 EE (Query Manager, later DB2)
- Used to be a systems-integration architect at a large bank, 500 servers and 7500 workstations

- Home page: http://www.dfsee.com

Information in a filesystem

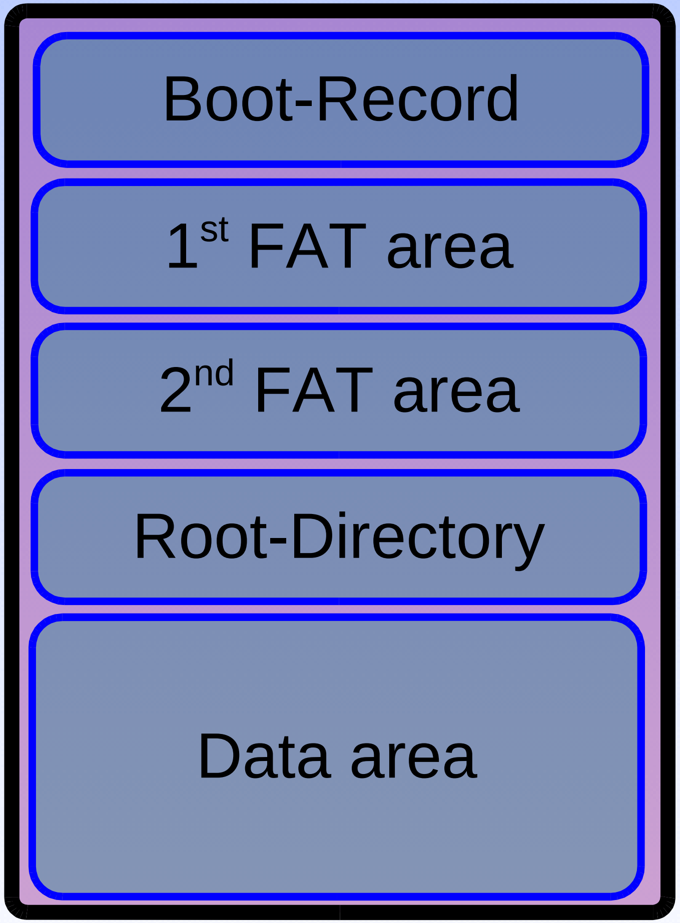
- Generic volume information
  - Bootsector, superblocks, special files ...
- File and directory descriptive info
  - Directories, FNODEs, INODEs, MFT
  - Hierachy of files/directories
- Freespace versus used areas
  - Allocation-table, bitmap
- Used areas for each file/directory
  - Allocation-table, run-list, bitmap

File Allocation Table

- The FAT filesystem was derived from older CPM filesystems for the first (IBM) PC
- Designed for diskettes and small harddisks
- Later expanded with sub-directory support to allow larger hierarchical filesystems

- Supported natively by the OS/2 kernel
- Enhancements in installable filessystems like FAT32.IFS and VFAT.IFS

FAT(16) Volume layout



- Bootsector, bootcode, labels and geometry/size info (BPB)
- File Allocation table, 12/16 bits for every cluster in the volume
- Exact duplicate of 1st FAT

- Fixed size, fixed position

- First data located at cluster 2
- Has clusters of filedata as well as clusters with sub-directories

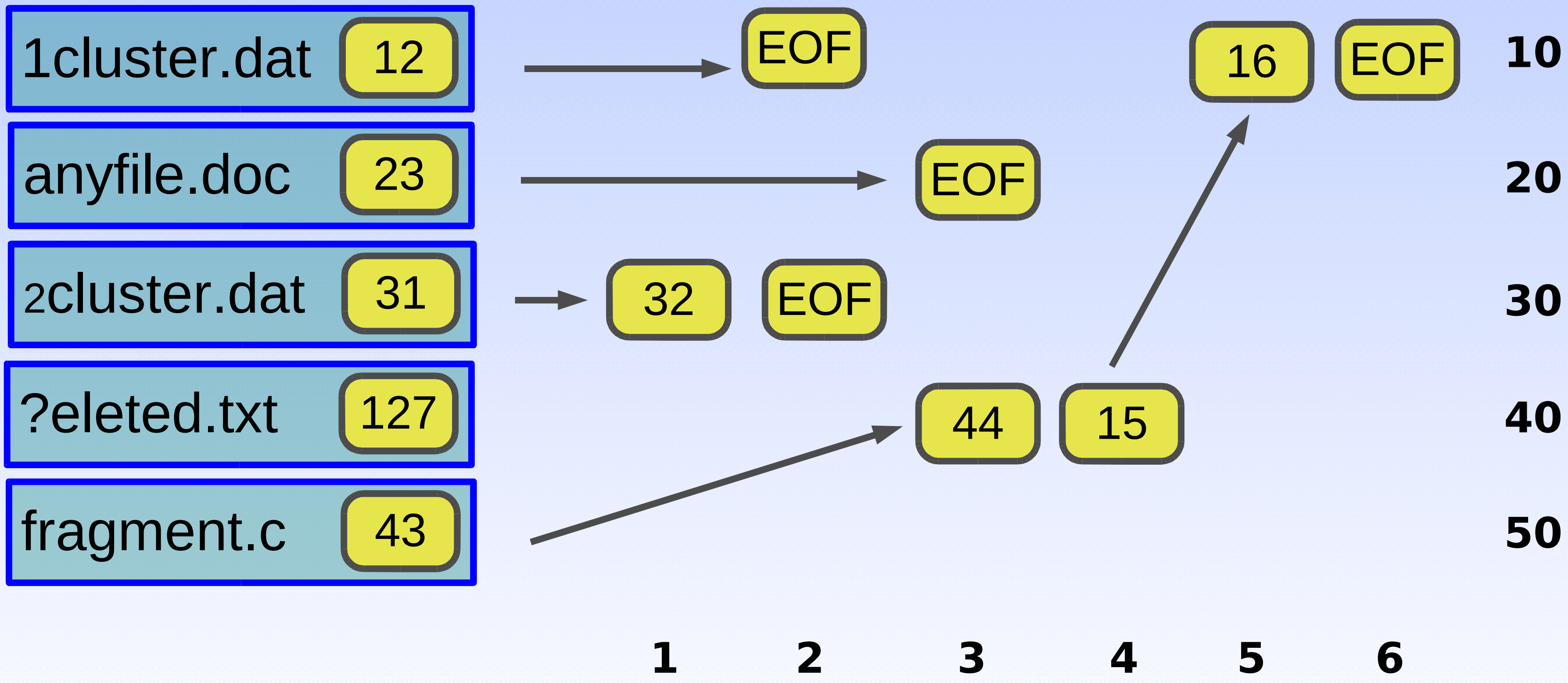
The Allocation Table

- The actual File Allocation Table has ONE value for every allocation unit (cluster):
  - Free, the cluster is NOT in use, value is 0 (zero)
  - 2 .. max, location of the NEXT cluster in the chain
  - EOF, end of file, this is the last cluster in the chain
  - BAD, the cluster is unusable due to bad sectors
- Each value can be 12 bits, 16 bits or 32 bits depending on volume and cluster size.
- A directory entry points to the FIRST cluster of an 'allocation chain'

FAT Allocation Chain

Directory entries

Part of the FAT area



1cluster.dat	12
anyfile.doc	23
2cluster.dat	31
?eleted.txt	127
fragment.c	43

	1	2	3	4	5	6
10		EOF			16	EOF
20			EOF			
30	32	EOF				
40			44	15		
50						

FAT directory entries

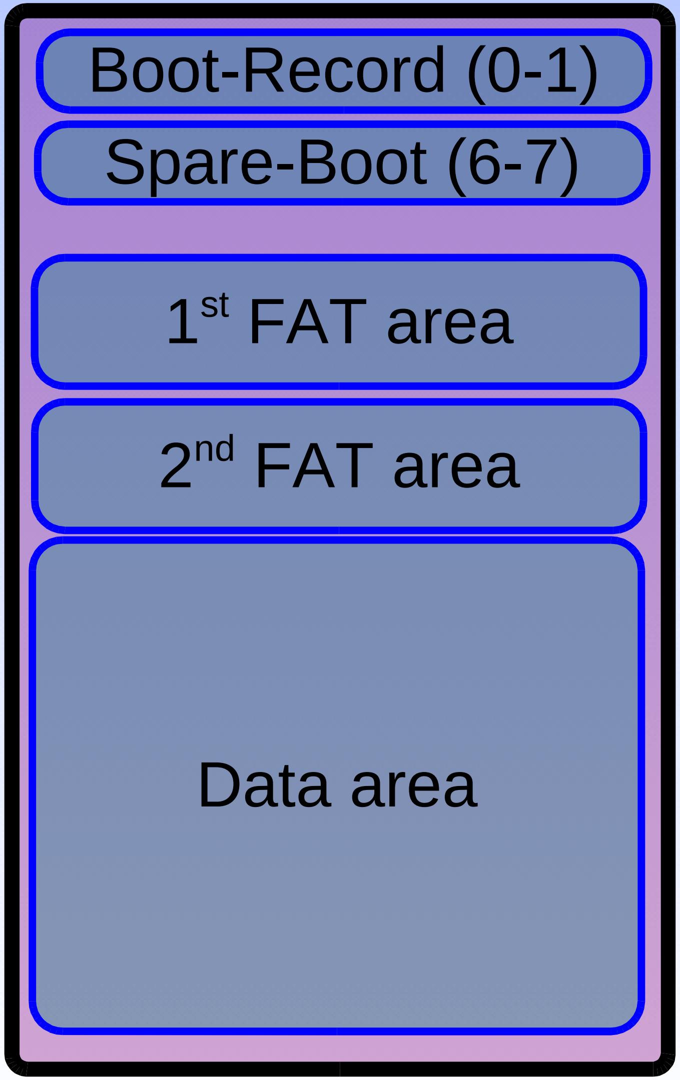
- A basic FAT directory entry contains:
  - 8 character BASE filename
  - 3 character file extension
  - 1 byte attribute with RO, System, Hidden etc
  - 4 byte date and time information
  - 2 bytes (16-bit) cluster-number for FIRST cluster
  - 4 bytes (32-bit) filesize, maximum value 2 Gb
- OS/2, FAT32 and VFAT may add:
  - 2 bytes index value to OS2 extended-attributes
  - 2 bytes extra cluster number, making it 32-bit
  - Extra create/access date and time fields (VFAT)

Common problems with FAT

- Combined file-allocation and freespace administration (no redundancy) may cause:
  - Lost clusters, allocated but no directory link
  - Cross-links, clusters that are in more than 1 chain
  - Undelete will be UNRELIABLE for fragmented files because the cluster allocation is unknown after the file is erased. (clusters marked FREE)

- OS/2 specific EA related problems:
  - stored in one huge file “EA DATA . SF”
  - Linked from an index in the FAT directory entry, can be damaged by other OS's or defragmenters

FAT32 Volume layout



Boot-Record (0-1)

Spare-Boot (6-7)

1st FAT area

2nd FAT area

Data area

- Bootsector, bootcode, label, geo and size info (BPB). Location of Root directory, freespace size
- File Allocation table, 32 bits for every cluster in the volume
- Exact duplicate of 1st FAT
- First data located at cluster 2 (usually the Root directory)
- Has clusters of filedata as well as clusters with directories

High Performance File System

- Designed by MS and IBM to overcome the shortcommings of the FAT filesystem
- Based on UNIX-like Fnodes and B-trees
- Designed for larger harddisks (> 100 MiB)
- More redundancy, less sensitive to crashes
- B-trees, fragmentation is less of a problem
- Implemented as Installable Filesystem with dedicated caching (HPFS.IFS, HPFS386.IFS)

HPFS Features and limits

- FS-size upto 2 terabyte (2048 GiB) by design
- OS/2 implementation limit of 64 GiB due to shared cache design (5 bits of 32 for cache use)

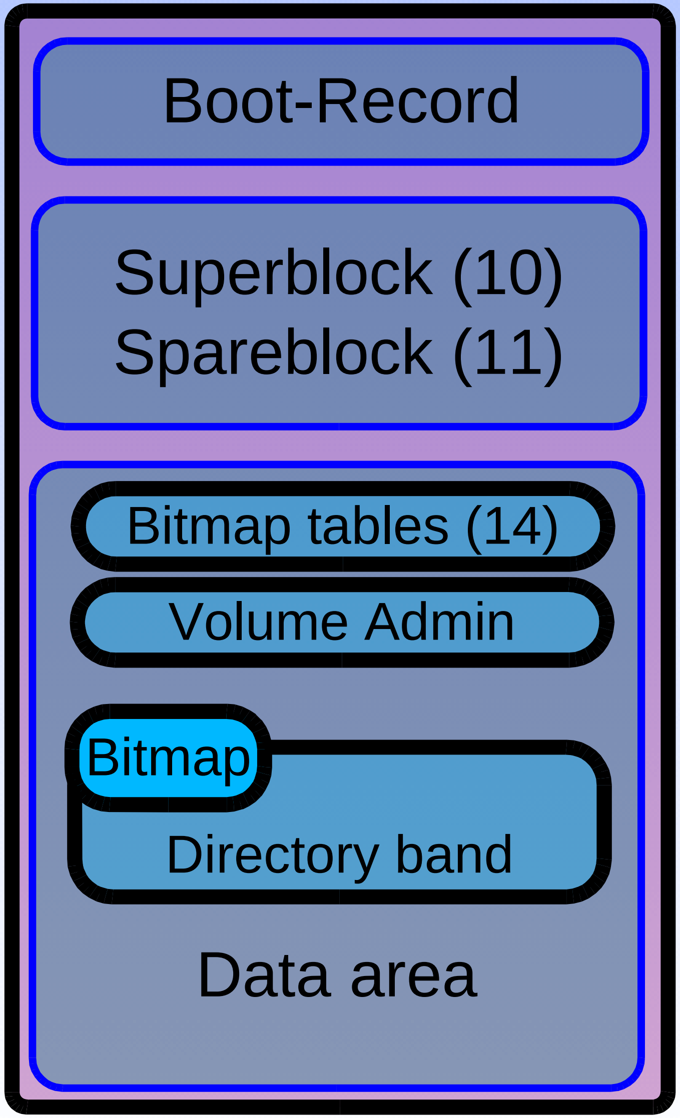
- Allocation in single 512-byte sectors

- Filename maximum length of 254 characters
- Support for multiple codepages for filenames

- B-trees used for allocation and directories

- Multi-level cache: Paths, Directories and Data

HPFS Volume layout



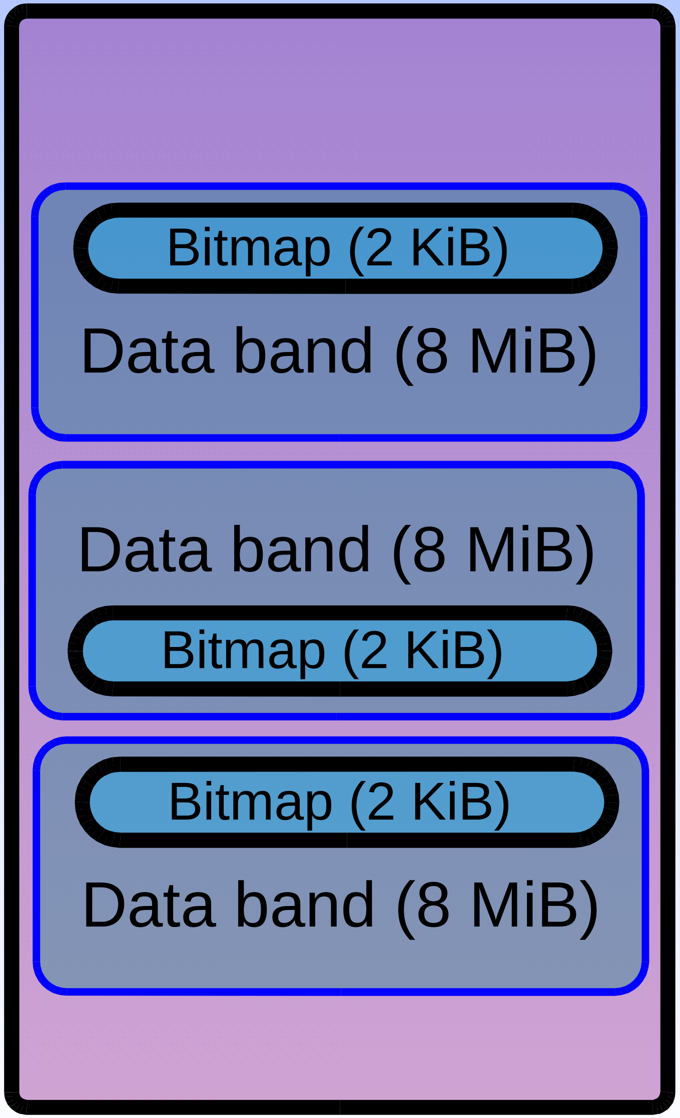
- Bootsector with HPFS bootcode
- Fixed volume-information
  pointer to Root-directory
- Variable volume-information

- Division in 8 MiB data bands
- Codepage, Hotfix, Spare etc

- Pre-allocated DIR-blocks, 1% in middle of volume (max 800 Mb)
- Separate Directory-BITMAP

- Filedata + extra allocation and directory blocks when needed

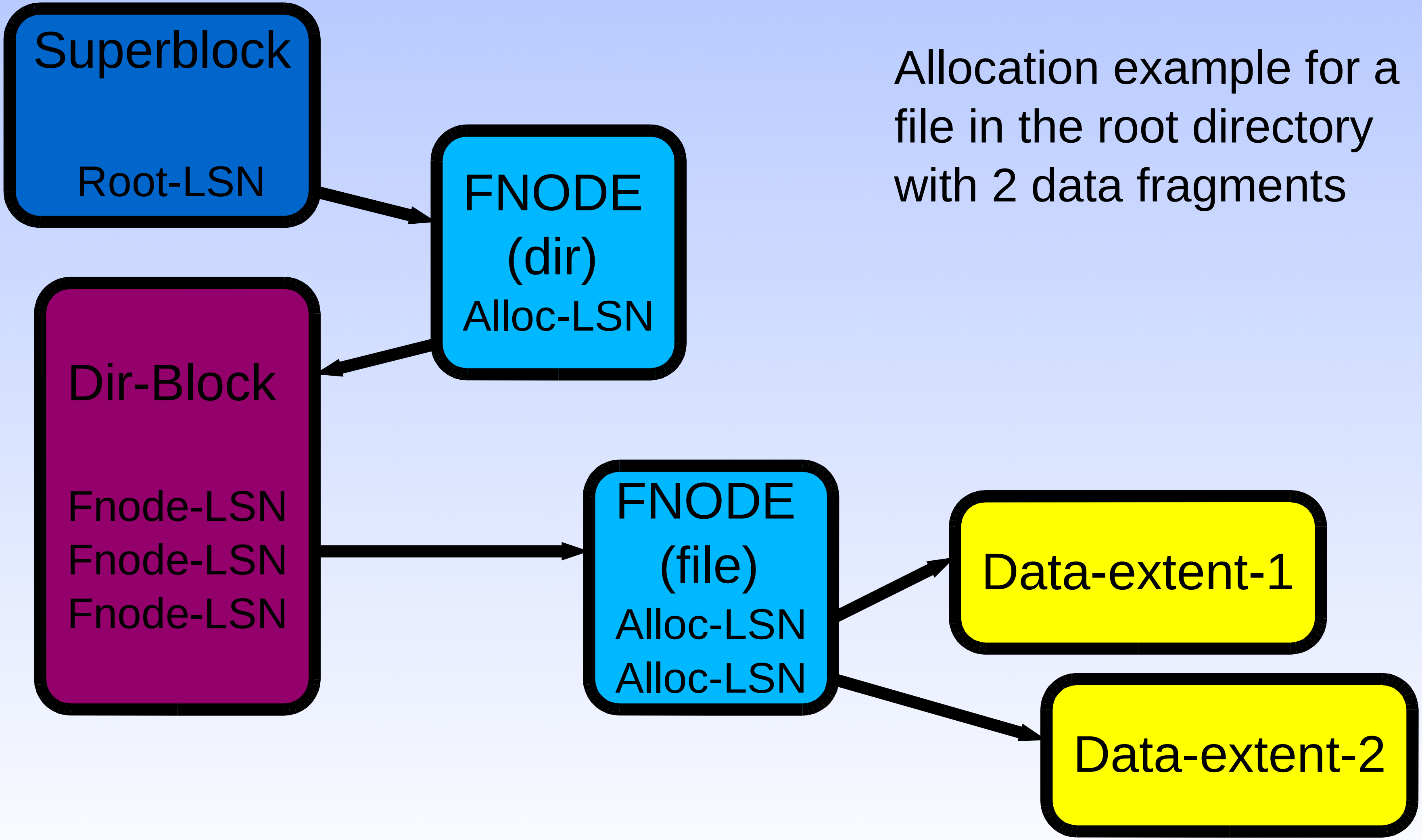
HPFS data-bands layout



- Data Bands:
  - Are of a FIXED size of 8 MiB (128 per gigabyte partition size)
  - Each have a freespace BITMAP that are located at the start or at the end (alternating) so they are back-to-back
  - Maximum UNFRAGEMENTED filesize is almost 16 MiB

HPFS File allocation

Allocation example for a file in the root directory with 2 data fragments



Superblock

Root-LSN

FNODE (dir)

Alloc-LSN

Dir-Block

Fnode-LSN

Fnode-LSN

Fnode-LSN

FNODE (file)

Alloc-LSN

Alloc-LSN

Data-extent-1

Data-extent-2

HPFS Fnode layout

- An Fnode is 512 bytes with fixed size info:
  - Unique binary signature string 'ae 0a e4 f7'
  - Sectornumber (LSN) for Parent directory
  - First 15 characters of the filename (short name)
  - Length of filename, and length of the filedata
  - Type of the Fnode, either File or Directory
  - Allocation information, max of 8 LSN+size pairs
  - DASD limits (user quota, HPFS386 only)

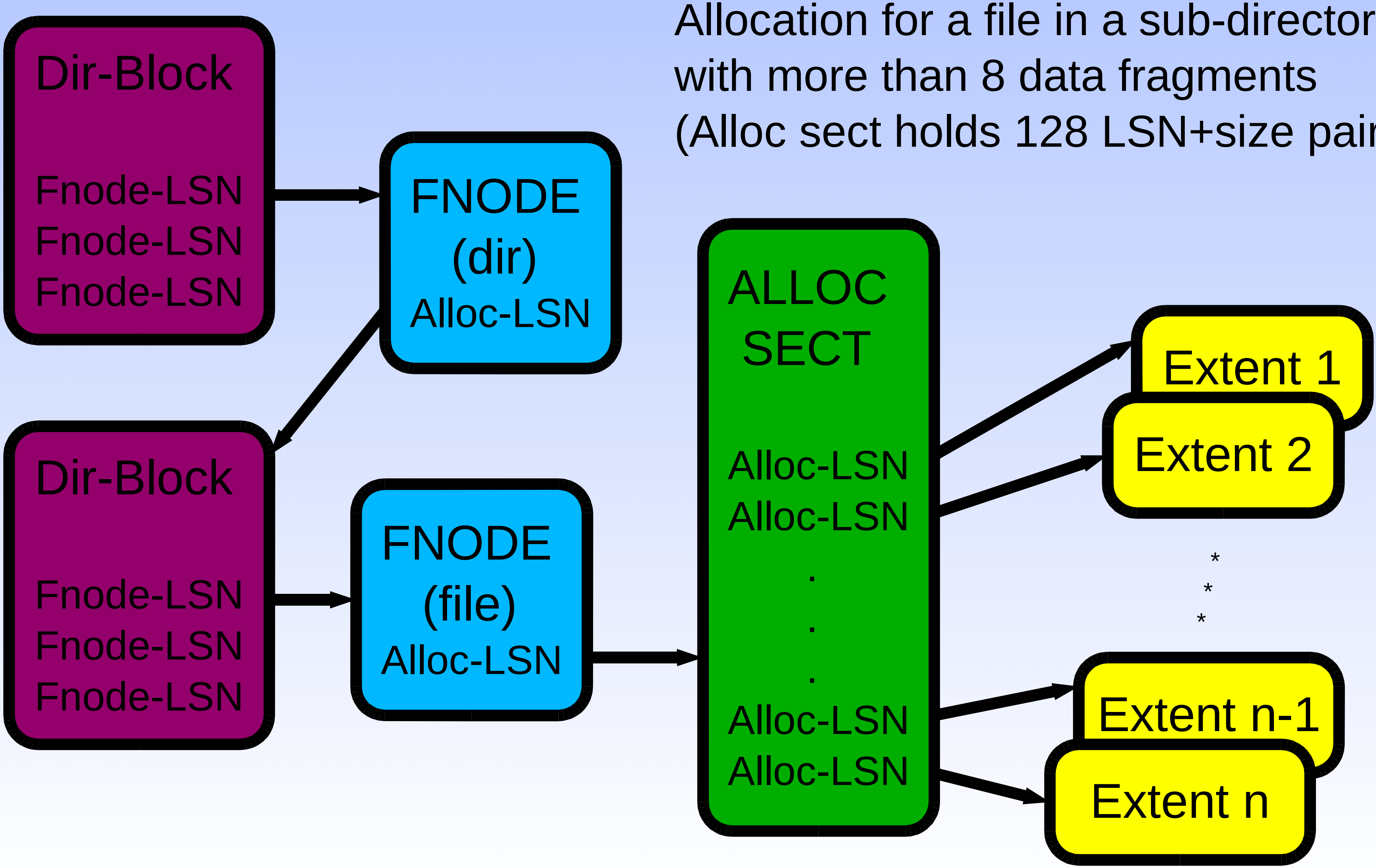
- Then, variable sized info may be present, either in the Fnode itself or externally:
  - Extended-attribute data (.longname, .icon etc)
  - Access Control Lists (HPFS386 only)

HPFS DirBlock layout

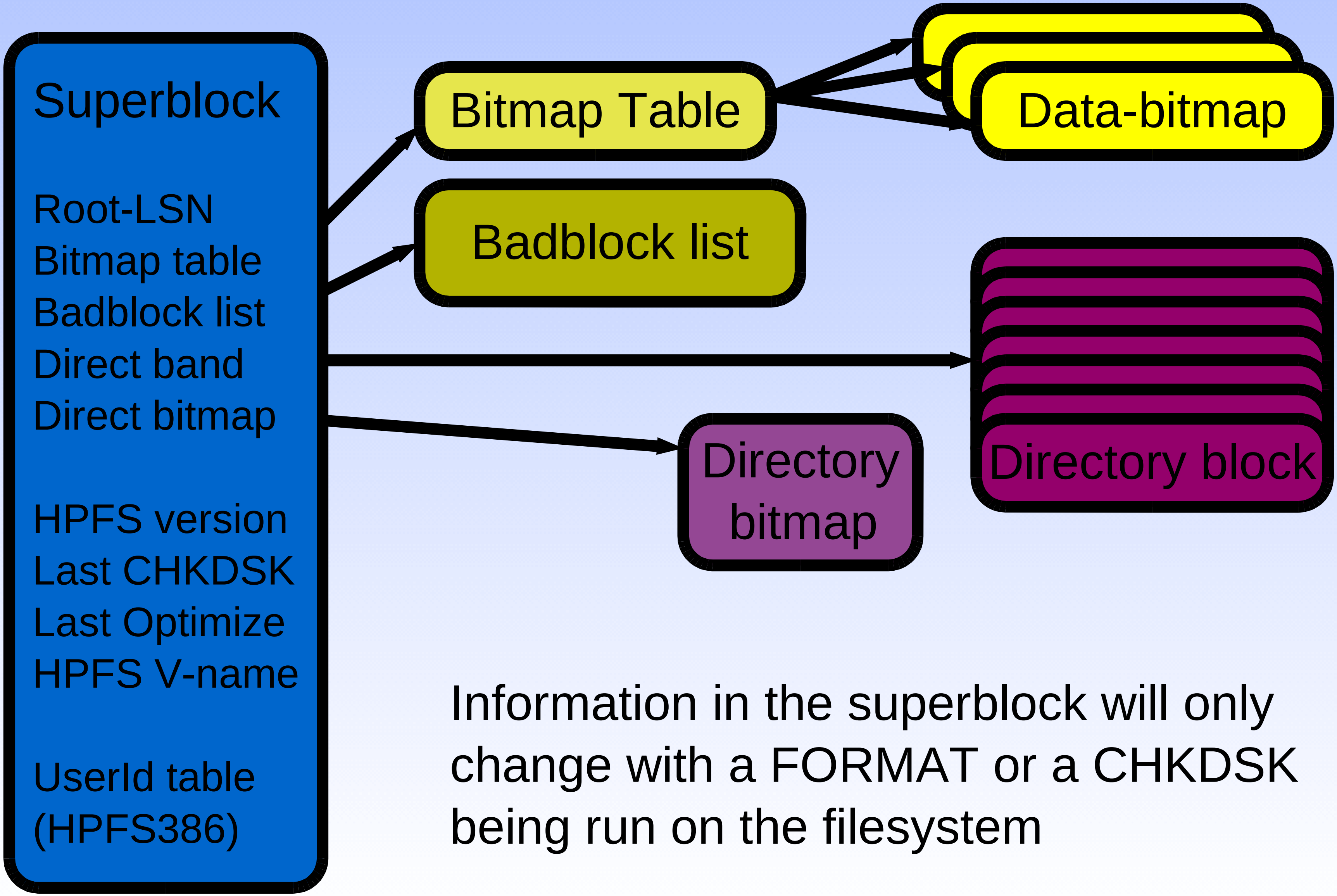
- A DirBlock is 2048 bytes with fixed size info:
  - Unique binary signature string 'ae 0a e4 77'
  - LSN for Parent and type Fnode or DirBlock (B-tree)
  - Sectornumber for THIS Directory-Block
  - Number of changes since creation of the block
- Then, variable sized Directory info with:
  - A B-tree 'down' pointer (DirBlock LSN),   OR
  - Three date/time fields creation, modify, last access
  - The standard (FAT, SHRA) attributes
  - File data length and extended-attribute length
  - Codepage number to use with the filename
  - Variable sized filename, max 254 characters

HPFS Fragmented File

Allocation for a file in a sub-directory
with more than 8 data fragments
(Alloc sect holds 128 LSN+size pairs)



HPFS Superblock info



Superblock

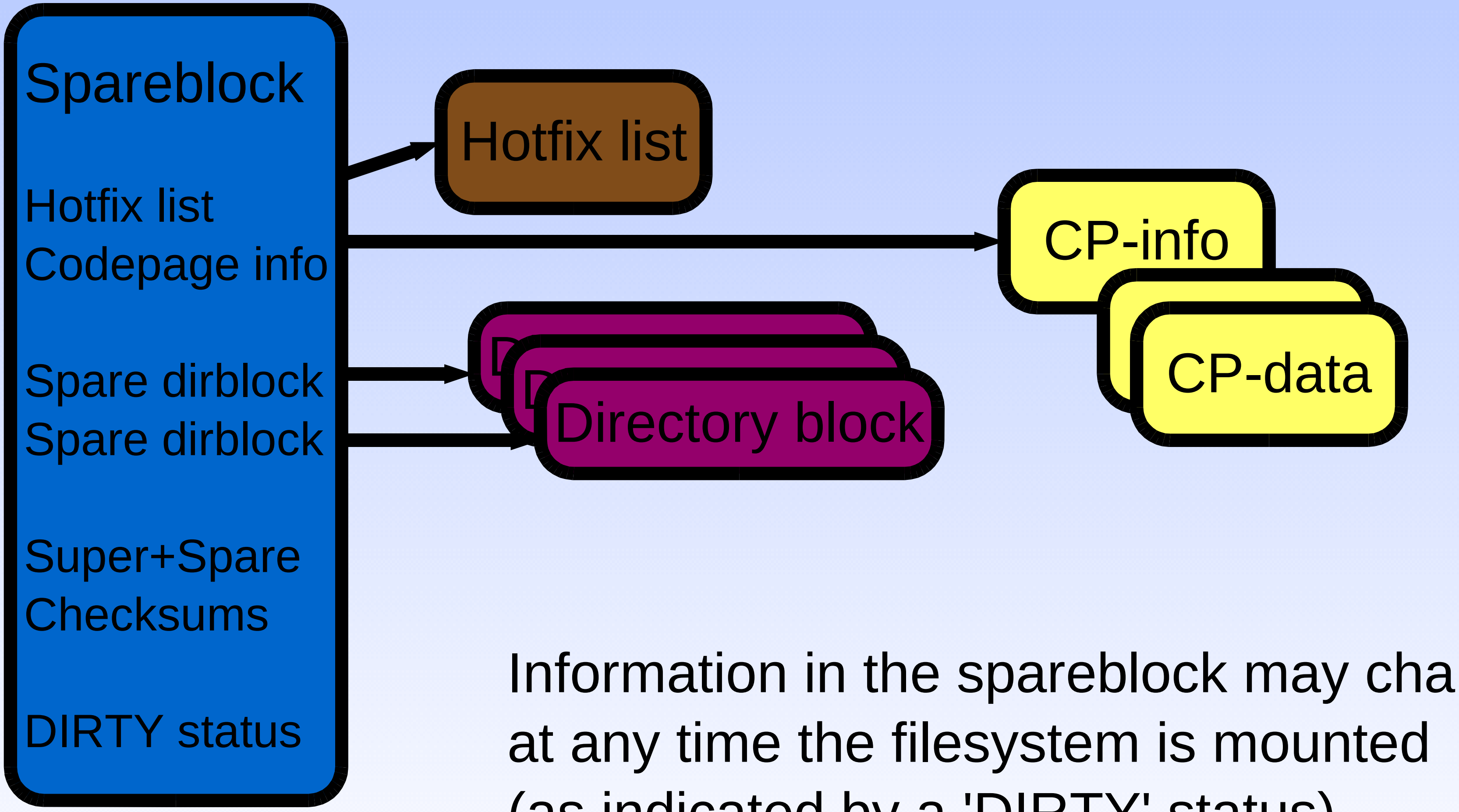
Root-LSN
Bitmap table
Badblock list
Direct band
Direct bitmap

HPFS version
Last CHKDSK
Last Optimize
HPFS V-name

UserId table
(HPFS386)

Information in the superblock will only change with a FORMAT or a CHKDSK being run on the filesystem

HPFS Spareblock info



Spareblock

Hotfix list
Codepage info

Spare dirblock
Spare dirblock

Super+Spare
Checksums

DIRTY status

Hotfix list

CP-info

CP-data

Directory block

Information in the spareblock may change
at any time the filesystem is mounted
(as indicated by a 'DIRTY' status)

New Technology File System

- Design started as new FS for OS/3 (32-bit OS/2) before that was renamed to Windows NT
- Organisation like a database, everything, including the FS administration itself is a FILE represented by an entry in the Master File table (MFT)
- Can handle extreme sizes due to 64 bit values used
- All data represented by attribute values, with the data being the 'default data attribute'. Supports multiple data-streams for a single file.
- Has native support for OS/2 EA's (as MFT attribute)

NTFS limits

- FS-size upto 2^64 clusters by design
  - Some tools limited to 2048 GiB due to use of 32 bits for sector or cluster numbers

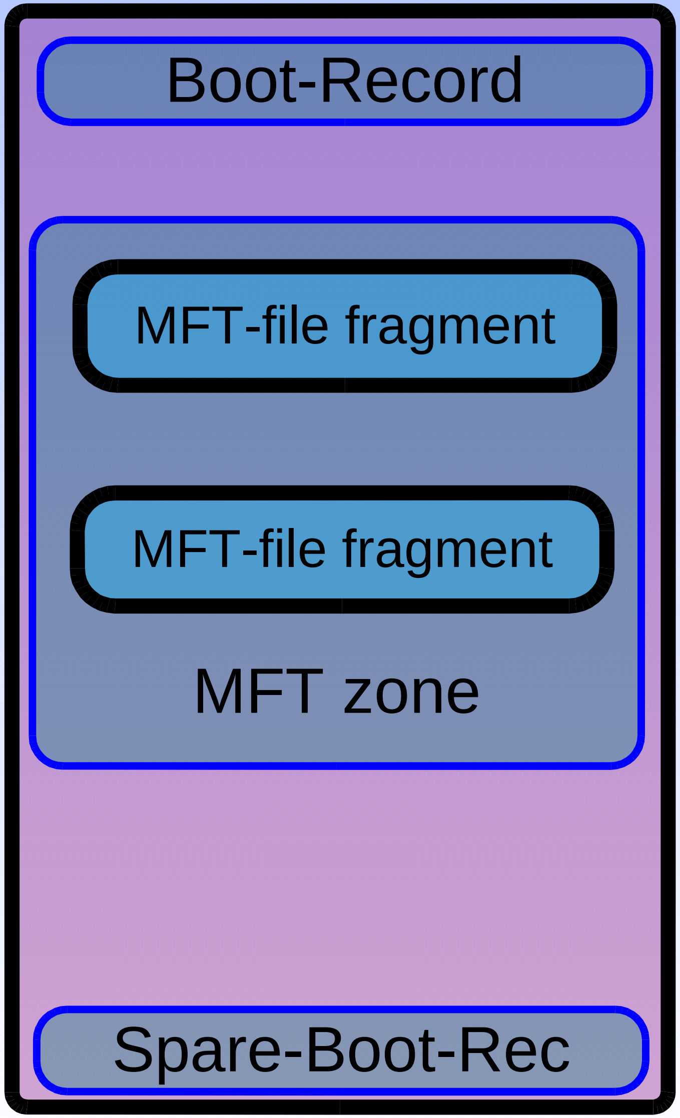
- Allocation in clusters of typically 8 sectors
- MFT record typical size is 2 KiB
  - May hold all data for small files. Larger attributes are stored externally, using runlists for the allocated space

- Filename of unlimited length, limited by the OS itself to a length of 254 characters

NTFS Features

- Uses UNICODE for filenames to allow for any character set (like codepages in HPFS)
- The FS keeps a transaction-LOG of all changes to the FS-structures to allow quick recovery and guarantee a consistent filesystem.
  - This makes it a ***journalling*** filesystem
  - File data itself is NOT part of the journal, so may get lost/damaged after a crash!

NTFS Volume layout



- Bootsector with NTFS bootcode
- Some fixed volume-information, pointer to MFT and MFT-spare

- MFT zone is reserved to reduce fragmentation of the MFT, but will be used for data if FS gets full

- MFT itself is a regular file, so CAN and WILL get fragmented

- Rest of space is for all external attributes, not stored in the MFT records themselves ...

NTFS special files

0 = $MFT	Main MFT file, all files/dirs
1 = $MFTmirr	Mirror MFT file, 1st 4 entries
2 = $LogFile	Journalling logfile
3 = $Volume	Global volume information
4 = $AttrDef	Definitions for attribute values
5 = \	Root directory
6 = $Bitmap	Allocation bitmap
7 = $Boot	Bootrecord (8 KiB at sect 0)
8 = $BadClus	Bad cluster administration
9 = $Secure	Global Security information
A = $Upcase	Collating and uppercase info
B = $Extend	Extended info (NTFS 5, XP)

MFT special file remarks

- Special files upto MFT-A are fixed, and standard
- MFT B represents a directory with (for XP):

$ObjId	Object identification data
$Quota	User space restriction data
$Reparse	Reparse points, aliases in the filesystem, much like Unix/Linux soft-links (or WPS shadows)

- MFT numbers upto arround 1A are reserved for system file use by the FS itself, after that the first user files will appear

MFT record layout

- The MFT record is of a fixed size (1 KiB) that starts with a fixed header containing:
  - Unique signature string 'FILE'
  - Sequence, generation and 'fixup' information
  - Offset to first dynamic attribute in the record (0x38)
  - Type of the MFT-record, either File or Directory
- After this a dynamic list of variable sized attributes follows, these can be either:
  - Internal (Self contained) when small
  - External, using an allocation run-list pointing to one or more clusters being used for the data

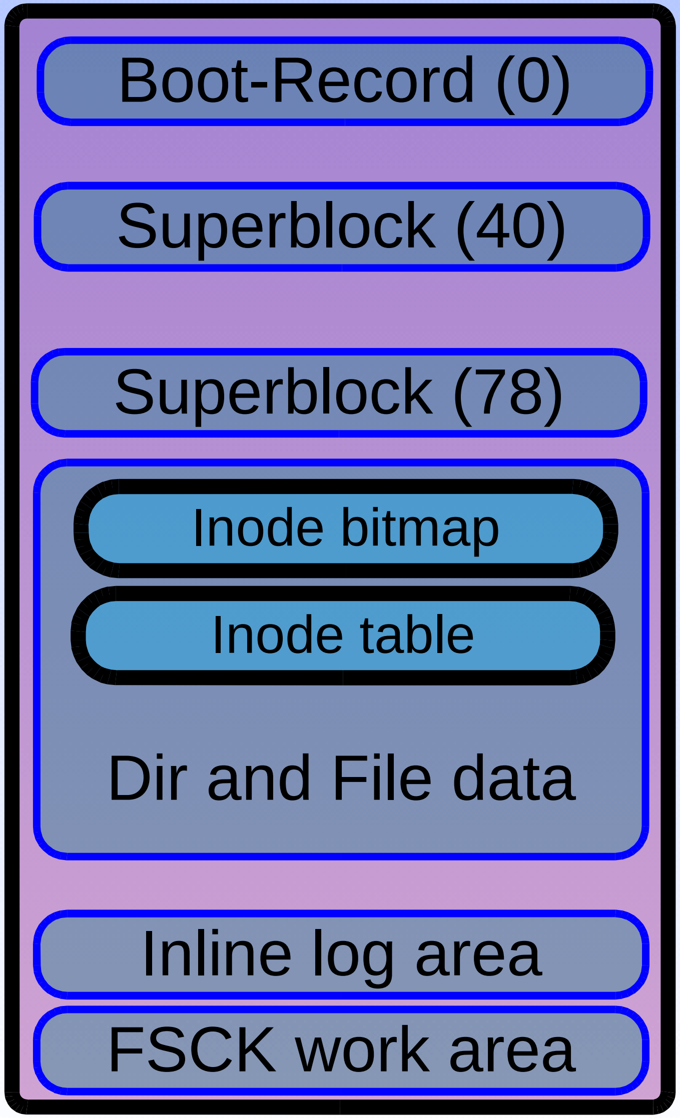
MFT attributes (from $AttrDef)

- 10 = $STANDARD_INFORMATION
- 20 = $ATTRIBUTE_LIST (group of attributes)
- 30 = $FILE_NAME
- 40 = $OBJECT_ID
- 50 = $SECURITY_DESCRIPTOR
- 60 = $VOLUME_NAME
- 70 = $VOLUME_INFORMATION
- 80 = $DATA (default or named data stream)
- 90 = $INDEX_ROOT (B-tree root, directories)
- A0 = $INDEX_LOCATION
- B0 = $BITMAP
- C0 = $REPARSE_POINT
- D0 = EA_INFORMATION
- E0 = EA (actual OS/2 extended attribute data)
- 100 = LOGGED_UTILITY_STREAM

Journalled File System

- Designed by IBM for its AIX operating system
- Based on UNIX-like structure with journalling and multiple storage area capabilities
- Ported to an OS/2 IFS by IBM to allow huge expandable filesystems with good performance and journalling (fast crash recovery)
- Port released as 'open source' for Linux too
- Relies on LVM for some of its functionality

JFS Volume layout



Boot-Record (0)

Superblock (40)

Superblock (78)

Inode bitmap

Inode table

Dir and File data

Inline log area

FSCK work area

- Bootsector, standard (label etc)
- JFS specific volume data with pointers to lots of info :-)
- Duplicate of main superblock
- Actual contents is grouped in 'aggregates' of fixed size
  Layout of that to be refined
- The 'journal' file area
- Temporary space for CHKDSK

On-disk filesystem structures

Questions ?