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Algorithms and Methods for Distributed Storage Networks

7 File Systems

Christian Schindelhauer

Albert-Ludwigs-Universität Freiburg
Institut für Informatik
Rechnernetze und Telematik

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Literature

- Storage Virtualization, Technologies for Simplifying Data Storage and Management, Tom Clark, Addison-Wesley, 2005
- Numerous File System Manuals
- Wikipedia

Measuring Memory

- 1 Byte = 1 B = 8 Bit = 8b

1 kilobyte	= 1 kB =	1000 Bytes	
1 megabyte	= 1 MB =	1000 kB =	10^6 Bytes
1 gigabyte	= 1 GB =	1000 MB=	10^9 Bytes
1 terabyte	= 1 TB =	1000 GB =	10^{12} Bytes
1 petabyte	= 1 PB =	1000 TB =	10^{15} Bytes
1 exabyte	= 1 EB =	1000 PB =	10^{18} Bytes
1 zettabyte	= 1 ZB =	1000 EB =	10^{21} Bytes
1 yottabyte	= 1 YB =	1000 ZB =	10^{24} Bytes

- 1 Byte = 1 B = 8 Bit = 8b

1 kibibyte	= 1 kB =	1024 Bytes	
1 mebibyte	= 1 MiB =	1024 kiB =	1.04 10^6 Byte
1 gibibyte	= 1 GiB =	1024 MiB=	1.07 10^9 Bytes
1 tebibyte	= 1 TiB =	1024 GiB =	1.10 10^{12} Bytes
1 pebibyte	= 1 PiB =	1024 TiB =	1.12 10^{15} Bytes
1 exbibyte	= 1 EiB =	1024 PiB =	1.15 10^{18} Bytes
1 zebibyte	= 1 ZiB =	1024 EiB =	1.18 10^{21} Bytes
1 yobibyte	= 1 YiB =	1024 ZiB =	1.21 10^{24} Bytes

Important File Systems

- **Unix File Systems**
  - ext2 (Linux)
  - ZFS (Solaris)
- **Windows**
  - FAT (File Allocation Table)
    - DOS, Windows 3, Windows 2000
  - NTFS (New Technology File System)
    - Windows 2000, Windows XP, Windows Vista
- **Mac OS X**
  - HFS+ (Hierarchical File System)

File Metadata

- **Data of applications combined with *metadata***
- **Unix File System (Unix inode)**
  - File type and access permission
  - Number of links to this file
  - Owner ID number
  - Group ID number
  - Number of bytes in file
  - Time stamp for last file access
  - Time stamp for last file modification
  - Time stamp for last inode modification
  - Generation number
  - Number of Extents (disk blocks with data)
  - Version of inode
  - List of disk blocks
  - Disk device containing blocks
- **Windows (NTFS File Attributes)**
  - Time stamp and link count
  - Location of extended attributes beyond the current record
  - File name (≤ 255 characters)
  - Security descriptor for ownership/access rights
  - File data
  - Object ID for distributed link tracking
  - Index root
  - Index allocation
  - Volume information
  - Volume name
- **HFS+**
  - Color (3 Bits)
  - locked, custom icon, bundle, invisible, alias, system, stationery, inited, no INIT resources, shared, desktop
  - Access control list
  - plus Unix meta-data

File Naming

- **Unix File System (or HFS+)**
  - Discourage use of special characters like:
    `* & % $ | ^ / \ ~`
  - Files should not start with „`-`“
- **Windows (NTFS File Attributes)**
  - Forbidden special characters:
    `/ \ : * ? " < > |`
  - File extensions crucial for usage: **`.exe`**, **`.com`**, **`.bat`**
- **Problematic for file transfer**

File Ownership, Rights, Locking

- **Security feature to manage access**
- **Unix File System**
  - user, group, all rights
  - read, write, execute
- **Windows (NTFS File Attributes)**
  - access restricted to a user or to a group
- **File locking for concurrent write operations**

File Size

- **Depends of File System**
  - 2 GiB (FAT16)
  - 4 TiB (ext2)
  - 16 TiB (NTFS)
  - 8 EiByte (HFS+)
  - 16 EiByte (ZFS)
- **Maximums size of file systems**
  - Fat16: 2^{16} entries and 2^{16} clusters @ 512 Byte
  - ext2: 10^{18} files, max. 16 TebiBytes (TiB)
  - NTFS: 2^{32} files, 256 TiB
  - HFS+ or ZFS: max 16 EiB

File System Hierarchy

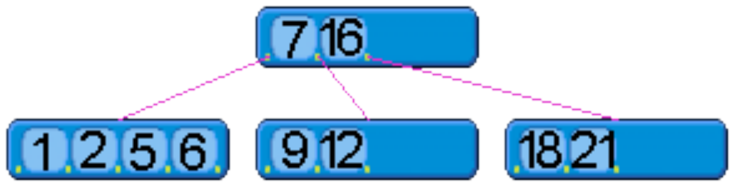
- **Starting from the root directory**
- **Tree with**
  - directories as inner nodes
  - files as leafs
- **In addition**
  - hard links
  - symbolic links
  - devices within the structures

Tree Structures

- Files (and often directories) are organized with one or multiple
  - B-Trees or
  - B*-Trees
- Often multiple trees, e.g. HFS+ (all B*-trees)
  - Extent Overflow File (extra extents with allocation block allocated to which file)
  - Catalog File (records for all files and directories)
    - indexed by ID (Catalog Node ID)
  - Attributes Files (for file attributes and metadata {forks})

B-Trees

- **Height-balanced trees**
- **(m/2,m)-B-Tree**
  - Every node has at most m children.
  - Every node (except root and leaves) has at least m/2 children.
  - The root has at least 2 children if it is not a leaf node.
  - All leaves appear in the same level, and carry no information.
  - A non-leaf node with k children contains k – 1 keys
- **If a node**
  - is full it will be split at the next insertion
  - is too empty it will be filled or merged with a neighbor node
- **If the root node is full a new level will be inserted**

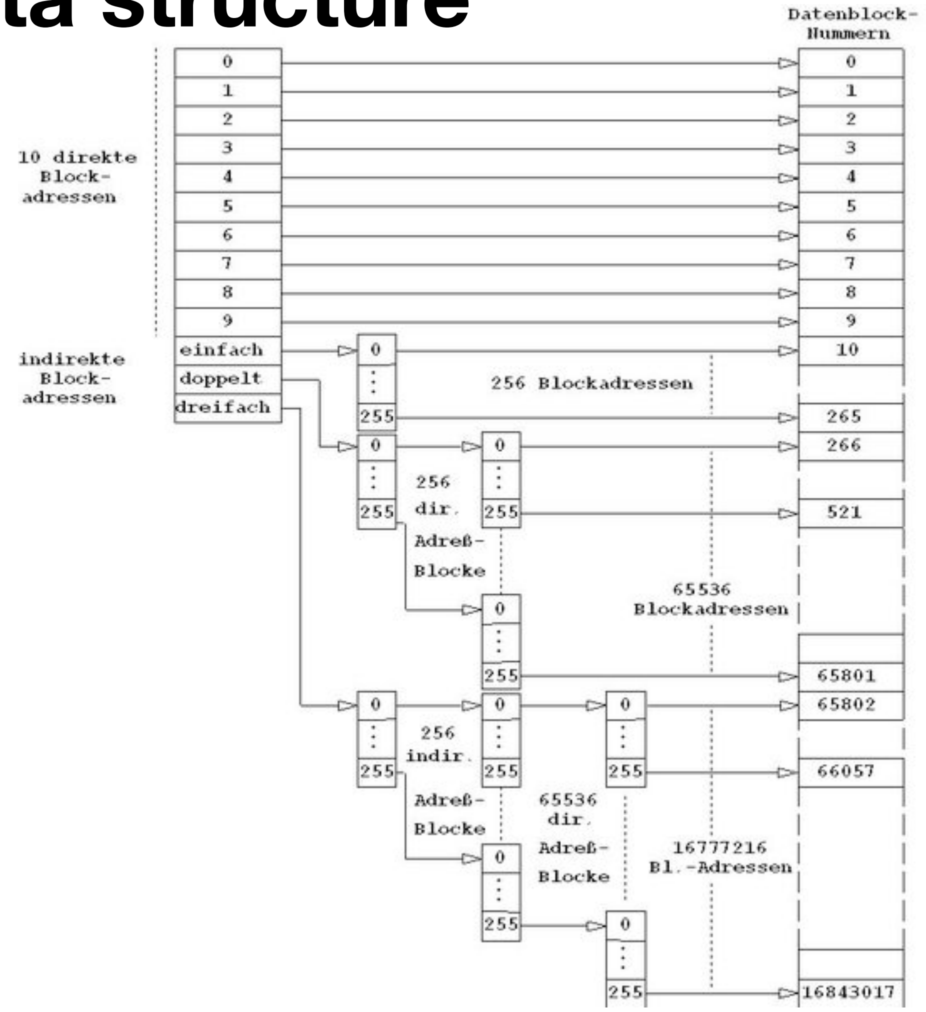


B*-Trees

- **Height-balanced trees**
- **Like B-Trees**
  - but information is stored in the leafs
  - inner nodes carry only keys
- **(k,k*)-B*-Tree**
  - root has at most 2 k entries
  - inner nodes have [4/3 k,2 k] entries
  - leaf nodes have [4/3 k*,2 k*] entries

ext2 data structure

- **Disk space is divided into blocks**
- **Block groups form super-block**
    - like cylinder groups in UFS
    - superblock
    - blockgroup bitmap
    - inode bitmap
    - data blocks
- **Each file has an inode**
- **Inode**
    - metadata (no file name)
- **Tree structure with**
    - direct links to blocks depth up to 3
    - indirect depth 2 links
    - triple indirect depth 3 links



http://de.wikipedia.org/wiki/Inode

File System Consistency

- **Special operation can validate and repair the file system consistency**
  - e.g. chkdsk in Windows, fsck in Unix
  - risky and prone to data loss
- **Journalling**
  - journal logs all operations before they take place such they can be reversed
  - after some time the journal is closed and a new journal is opened
  - File system can be easily recovered after crashed
    - available in ext3, HFSJ ,...

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