

## Windows NT File System

„Ausgewählte Betriebssysteme“  
Institut Betriebssysteme  
Fakultät Informatik

## Outline

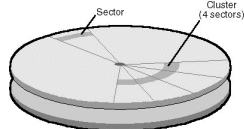
- NTFS
  - File System Formats
  - File System Driver Architecture
  - Advanced Features
  - NTFS Driver
  - On-Disk Structure (MFT, ...)
  - Compression
  - Recovery Support
  - Encryption Support

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## Hardware Basics

- Sector:
  - addressable block on storage medium
  - usually 512 bytes (x86 disks)
- Cluster:
  - addressable block of file system format
  - multiple of sector size



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## Win2K File System Formats

- CDFS: ISO 9660 (old CD-ROM FS)
- UDF (Universal Disk Format):
  - ISO 13346 compliant (for optical disk/DVD)
  - Replaces CDFS
  - Filenames can be 255 character long
  - Max path length is 1023 character
  - Filenames can be upper and lower case
- FAT12, FAT16, FAT32
  - FAT12 for anything smaller 16MB
  - FAT16 if explicitly specified (format command)
  - FAT32 anything bigger than 4GB
- NTFS

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## NTFS

- For volumes larger than 2GB default cluster size of 4KB is used
- Can (theoretically) address up to 16 exabytes using 64-bit cluster indices
- Limited to address using 32-bit indices  
→ up to 128 TB (using 64KB clusters)

## NTFS Cluster Sizes

Volume Size	Default Cluster Size
512 MB or less	512 bytes
513 MB-1024 MB (1 GB)	1 KB
1025 MB-2048 MB (2 GB)	2 KB
Greater than 2048 MB	4 KB

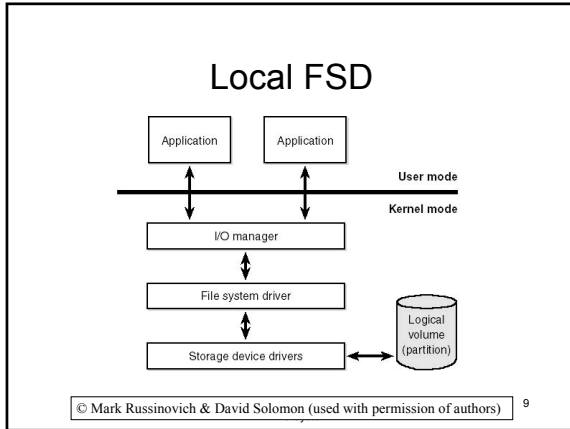
- Default value can be overridden

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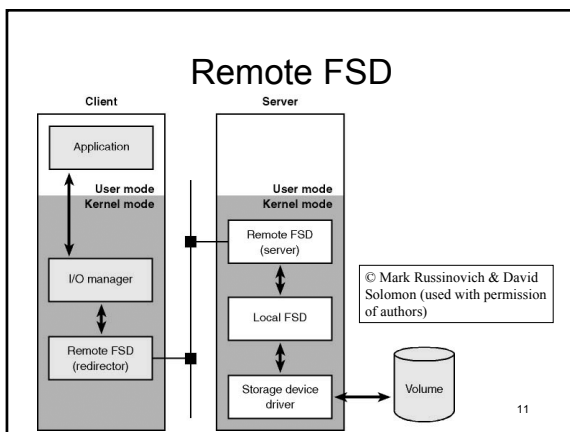
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## FS Driver Architecture

- Local FSDs:
  - Manage volumes directly connected to computer
  - Responsible for registering with I/O manager
  - First sector on volume identifies volume, its format and location of metadata
- Remote FSDs:
  - Allow access to volumes connected to remote computers
  - Consists of two components (client & sever)



- ### Local FSD (2)
- Device object is created for volume by FSD representing FS format
  - I/O Manager connects FSD's device object to volume's device object
  - Use cache manager to cache FS data (including metadata)
  - Cooperate with memory manager:
    - Mapped file cannot be truncated or deleted
  - Volume can be dismounted (for raw access)
    - First "normal" access remounts volume
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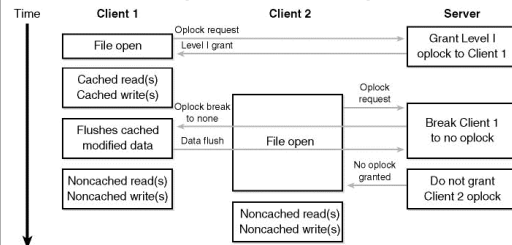


- ### Remote FSD (2)
- Win2K uses Common Internet File System (CIFS) protocol (enhanced version of SMB)
  - Client side FSD caches data (to synchronize *oplock protocol* is used)
  - File and printer sharing built on it
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## Oplock Protocol

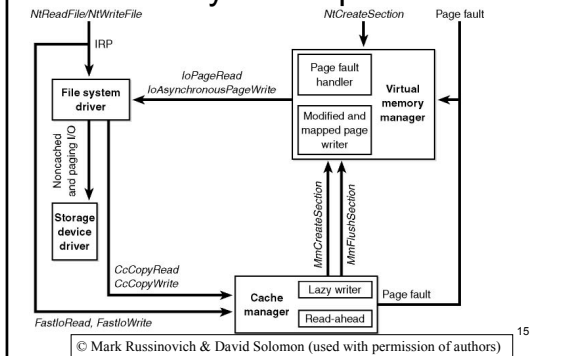
- „Opportunistic lock“
- Level I oplock granted for exclusive access (cached read and write)
- Level II oplock granted for shared access (cached read)
- Batch lock is Level I for multiple accesses with close operation in between (no additional oplock when reopening file)

## Oplock Example



- If Client 1 only reads → both get Level II oplock

## File System Operation



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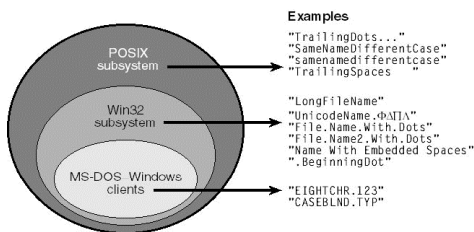
## Advanced Features

- Multiple data streams
- Unicode-based names
- General indexing facility
- Dynamic bad-cluster remapping
- Hard links and junctions (soft-links)
- Link tracking
- Per-user volume quotas
- De-fragmentation
- Compression and sparse files (see later section)
- Change logging (see later section)
- Encryption (see later section)

## Multiple Data Streams

- A file consists of streams
- One unnamed, default stream
- Stream name added to file name with colon (`stream.txt:longer`)
- Each stream has separate allocation size
- Each stream has separate file lock

## Unicode Filenames



## Hard Links and Junctions

- Hard links can be created with *CreateHardLink* and *In*
  - Different names link to same file on disk
  - One file contains multiple \$FILE\_NAME attributes
- Junctions are soft links, based on reparse points
  - Reparse point has reparse tag, which allows to identify owner, and reparse data
  - Owner can alter pathname and reissue I/O or
  - Owner can remove reparse point, alter file and reissue I/O (archive and restore file automatically)

## Link Tracking

- Links (e.g. shell shortcuts or OLE links) are another mechanism to “soft-link” files
- Link points to unique Object ID, which is stored in \$OBJECT\_ID attribute of file
- Target file can be allocated by querying for the Object ID
- Link tracking service implements the „link following“
- Mapping of Object IDs to filenames stored in file „\$Extend:\$O“ (see slide 29/30)

## Quotas

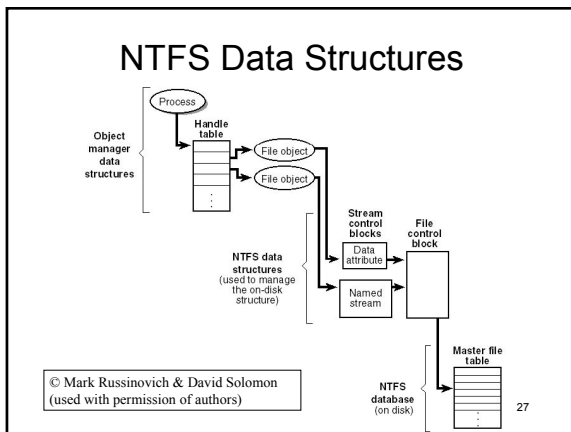
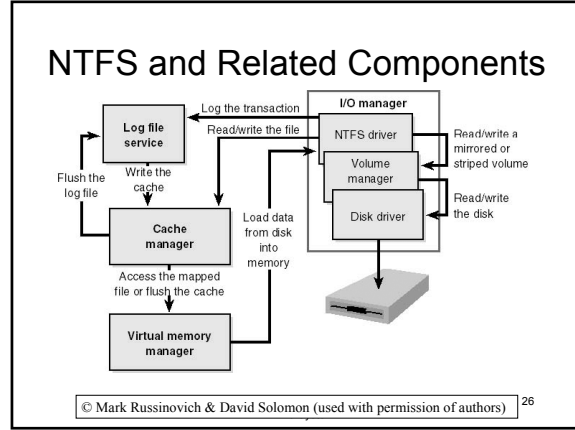
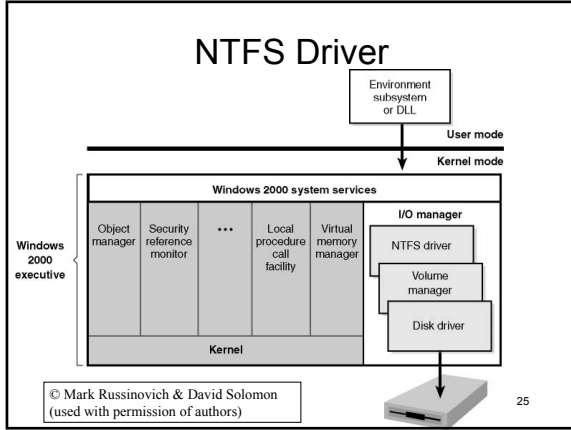
- Files are tagged with security ID (SID) of user
- Logical size of files counts against quota (not compressed size)
- Attempted violations and reached warning thresholds are logged in event log (and administrator can be notified)

## Defragmentation

- NTFS does not automatically de-fragment disks
- NTFS provides de-fragmentation API
- Can be used to move file data, and obtain cluster information of file
- Win2K includes de-fragmentation tool

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## NTFS On-Disk Structure

- Volumes: logical partitions (can span multiple partitions)
- Cluster: multiple of sector (always power of 2, e.g. 1,2,4,8 sectors)
- NTFS refers to physical locations on disk by logical cluster numbers (LCNs)
- NTFS refers to the data within a file by virtual cluster numbers (VCNs)

## Master File Table

- All data stored on volume is contained in files:
  - MFT, bootstrap data, allocation bitmap
  - Can relocate metadata
- MFT is array of file records
- File record has fixed size of 1KB
- MFT contains one record for each file on volume
- Metadata files have name starting with \$
- On boot, volume is mounted by reading MFT and constructing internal data structures

## MFT (2)

File	Description
0	\$Mft - MFT
1	\$MftMirr - MFT mirror
2	\$LogFile - Log file
3	\$Volume - Volume file
4	\$AttrDef - Attribute definition table
5	\ - Root directory
6	\$Bitmap - Volume cluster allocation file
7	\$Boot - Boot sector
8	\$BadClus - Bad-cluster file
9	\$Secure - Security settings file
10	\$UpCase - Uppercase character mapping
11	\$Extend - Extended metadata directory
12	Unused
15	Unused
16	User files and directories

Reserved for NTFS metadata files

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## MFT (3)

- \$Mft and \$MftMirr contain information about MFT (which blocks it occupies, ...)
- \$LogFile contains recovery information
- NTFS starts searching for a file in Root directory
- \$Bitmap shows free clusters
- \$Secure volume wide security descriptor database
- \$Boot – bootstrap code must be allocated at specific position on volume, but a file table entry is created, so inform can be read like file
- \$Volume contains volume name, NTFS version, disk-corruption bit
- \$Extend contains metadata, like quota, object ID file, ...



## File Reference Number

- A file is identified by 64-bit value, called file reference
- Consists of file number and sequence number
- File number corresponds to index in MFT
- Sequence number is incremented if file record in MFT is reused



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## File Record

- Strictly speaking: consists of attribute streams
- Each attribute:
  - Is identified by its attribute code
  - Has a value
  - Has an optional name (used to distinguish attributes of same type)
- E.g.:
  - \$FILE\_NAME attribute stores file name
  - \$DATA attribute stores content of file

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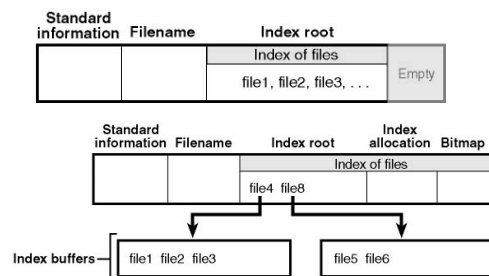
## File Record (2)

- Small files fit into record
- Attributes with values stored in record are called resident attribute (standard information is always resident)
- Attribute header contains information if it is resident
- For big attributes clusters are allocated (so-called runs) and referenced from record
- These attributes are called non-resident

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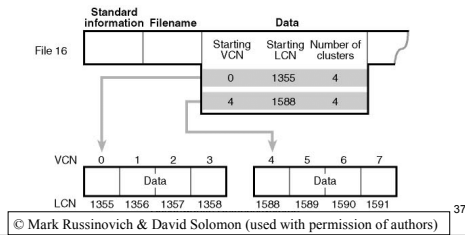
## Resident/Non-Resident Attributes



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## Non-Resident Attributes

- If multiple runs are needed to store an attribute, a mapping table of VCN is needed
- VCN (location in file), LCN (location on disk and size)



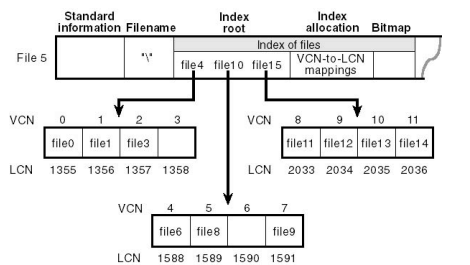
## Directory Lookup

- For fast directory lookup an index tree is maintained
- Tree is B+ tree
- Each entry in tree contains information on file name, size, time stamp → directory information can be displayed without touching the file
- Requires this information to be updated in two places
- Each 4KB index buffer can contain 20-30 filenames

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## Directory Lookup (2)



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## Compression

- Compress sparse files (with holes), by not allocating runs for the holes (zeros)

Standard information	Filename	Data		
		Starting VCN	Starting LCN	Number of clusters
		0	133	16
		32	193	16
		48	96	16
		128	324	16

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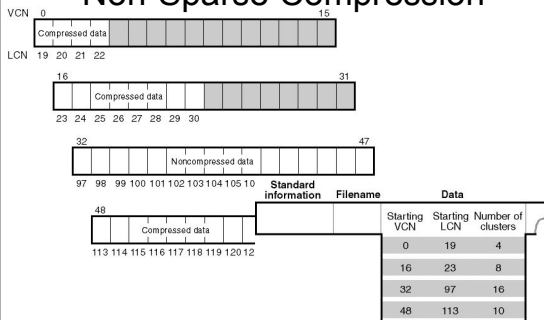
## Compression (2)

- Non-Sparse Data compressed by combining 16 consecutive clusters to *compression units*
- Compress unit and if at least one cluster is saved, store compressed data.
- Distinguish compressed from uncompressed by length of run (number of clusters < 16)
- (runs with less than 16 clusters can be compressed too, but mapping becomes complicated and when stored again, stored in consecutive 16 cluster run)

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## Non-Sparse Compression



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## Recovery Support

- NTFS uses transaction-processing scheme to implement recoverability
- Recovery Procedures limited to file system data – user data never guaranteed to be fully updated after crash
- Sub-operation of transactions that alter file system data are logged before being carried through on disk
- Logging done by Log File Service (LFS)

## Log File Service (LFS)

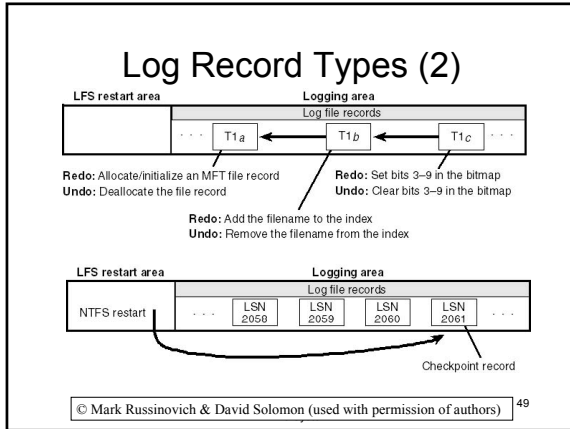
- Log file divided into *restart area*:
  - 2 copies
  - Contains context information, such as location of start of recovery
- And *logging area*:
  - Treated as infinite (logs are written looping through area)
- Logical Sequence Numbers (LSN) used to identify records (64bit)
- Provides services to NTFS to open/close log file, read/write records

## Transaction sequence

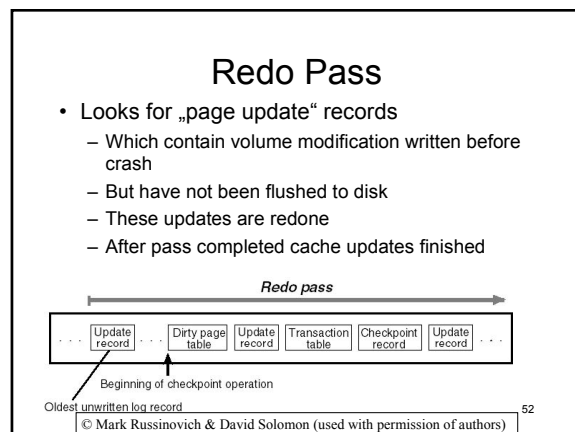
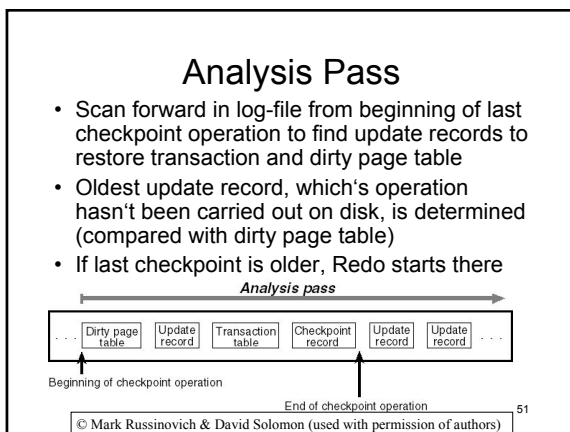
- Steps to ensure recoverability:
  1. NTFS calls LFS to record modification
  2. NTFS modifies volume
  3. Cache manager prompts LFS to flush Log to disk
  4. Cache manager flushes the volume changes
- Log file is also cached

## Log Record Types

- Update Records
  - Redo information: how to reapply one sub-operation
  - Undo information: how to reverse one sub-operation
  - Contain physical state of data
- Checkpoint record
  - Written, when data has been updated in file as well

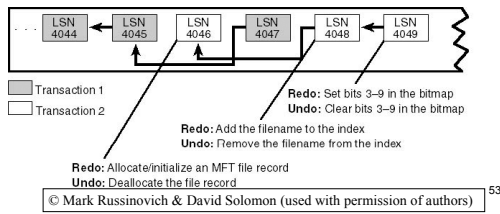


- ### Recovery
- Depends on two tables
    - Transaction table: keeps track of unfinished transactions
    - Dirty page table: contains modified pages, which contain file system structures
  - Once every 5 seconds:
    - Transaction table and dirty page table written to log
    - Checkpoint written to log
  - On recovery log-file is scanned three times
    - Analysis
    - Redo transactions
    - Undo transactions
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## Undo Pass

- Roll back any transactions that weren't committed
- Undo operations are logged (in case of another power down)
- After Undo Pass is complete an „empty“ LFS restart area is written



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## Encryption

- User is assigned a private/public key pair (when he/she first encrypts a file)
- When file is encrypted:
  - content is encrypted using random number called file encryption key (FEK) and DESX (stronger version of DES)
  - FEK is encrypted using public key of user and RSA and attached to file
  - For each user FEK is encrypted respectively

## Encryption (2)

- Private Key is stored in Registry (on disk “in a safe place”) or smart card
- EFK is also encrypted for each Recovery Agent if recovery policy is defined
- Usage of private key:
  - CryptGetUserKey to tell crypto provider to subsequently use this user's key
  - CryptDecrypt is called to decrypt EFK

