

# Windows NT File System

„Ausgewählte Betriebssysteme“  
Institut Betriebssysteme  
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## Outline

- Storage Management
  - Partitioning
  - Multi-disk Volumes
- Cache Manager
- NTFS
  - Next class

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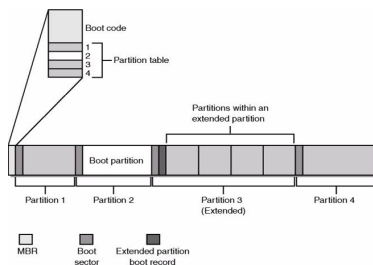
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## Disk Partitioning



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## Boot Process

- BIOS read MBR and executes code
- Code uses partition table to allocate active partition
- Reads 1. sector from it and executes it

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## Partition Table

- 4 partitions defined in MBR
- Primary or extended partitions
- Extended partition contains MBR, which allows further partitions
- Partition table entry contains:
  - Type of partition (FAT, NTFS, Linux swap, ...)
  - Start of partition
- „Basic partitions“

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## „Dynamic Partitioning“

- Logical Disk Manager (LDM) ported to Windows
- Define partition of type „LDM“
- LDM database in reserved last 1 MB of partition
- Provides „old style“ partition table for legacy applications (Ntldr, ...)
- Not used for laptops, disks on IEEE 1394 and USB buses as well as shared cluster servers

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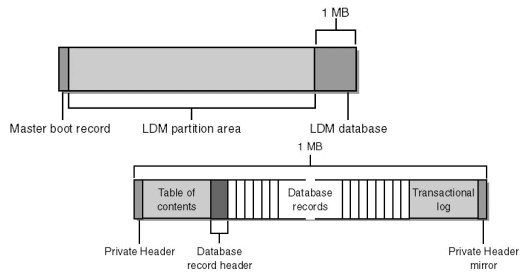
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## „Dynamic Partitioning“ (2)



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## LDM Database

- Private header contains
  - GUID of disk
  - Name of disk group (default Win2K has only one)
  - Pointer to begin of database table of contents
- Table of contents:
  - Size: 16 sectors
  - Contains information about layout of database
- Database record header:
  - Number of records
  - Name and GUID of disk group
  - Next free entry
- Transactional log

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## LDM Database Entry

- 128 byte fixed-size record
- Four types:
  - Partition = contiguous region on disk
  - Component = connector between one or more partitions and volume
  - Volume stores GUID, total size, state, drive-letter hint
  - Disk represents dynamic disk
- Entry may span multiple records

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## Sample Output

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----- Dynamic Disk Information -----
DiskGroup: Btsdelin2Dg0
Group-ID: e81dE72b-f373-41d2-9a5a-351fbc4928ca

Subdisk  Rel Sec  Tot Sec  Tot Size  Plex  Vol Type  Co1/Ord  DevName  State
=====  =====  =====  =====  ====  =====  =====  =====  =====
LDM-DATA  0            0            0            0      Simple  1/1      MISSING

Disk2-01  0            4096512     0            Volume1-01 Simple  1/1      MISSING
Disk2-02  4096575     4096512     0            Volume2-01 Simple  1/1      MISSING
Disk2-03  8193150     4096512     0            Volume3-01 Simple  1/1      MISSING
Disk2-04  12289725   4096512     0            Volume4-01 Simple  1/1      MISSING
Disk2-05  16386300   4096000     0            Volume8-01 Simple  1/1      MISSING
LDM-DATA  0            0            0            0      Simple  1/1      MISSING

Disk3-01  63          4096512   17771136   Volume5-01 Simple  1/1      Harddisk9 ONLINE
Disk3-02  4096638     4096512   17771136   Volume6-01 Simple  1/1      Harddisk9 ONLINE
Disk3-03  8193213     4096512   17771136   Volume7-01 Simple  1/1      Harddisk9 ONLINE
Disk3-04  12289788   4096000   17771136   Volume9-01 Simple  1/1      Harddisk9 ONLINE
LDM-DATA  17769088   2048      17771136   Volume9-01 Simple  1/1      Harddisk9 ONLINE

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## Dynamic Storage Terms

- **Volume:** storage unit made from free space on one or more disks
- **Simple volume:** uses free space from a single disk (can be a single region or consist of multiple, concatenated regions)
- **Spanned volume:**
  - Linked together from multiple disks (up 32 disks)
  - Can be extended onto additional disks
  - Cannot be mirrored
- **Mirrored volume:**
  - Fault-tolerant
  - Data duplicated on two physical disks (RAID-1)

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## Dynamic Storage Terms (2)

- **Striped volume:** data is interleaved across two or more physical disks. (RAID-0)
- **RAID-5 volume:**
  - Fault-tolerant
  - Data is striped across an array of three or more disks
  - Parity is also striped across the disk array.
- **System volume:** contains hardware-specific files needed to load Win2K (Ntldr, Boot.ini, Nt detect.com)
- **Boot volume:** contains Win2K operating system files (%Systemroot%)

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## Sample Output (2)

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----- LVM Volume Information -----
Volume  Volume  Mtnt  Subdisk  Plex  Physical  Size  Total  Col  Rel  Vol
Name     Type     Name  Name      Name    Sectors  Size  Ord  Sectors  State
-----
Stripel  Stripe  E     Disk1-01  Stripel-01  Harddisk0  12288000  4096000  1/3  63  ACTIVE
Stripel  Stripe  E     Disk2-01  Stripel-01  Harddisk1  12288000  4096000  2/3  63  ACTIVE
Stripel  Stripe  E     Disk4-01  Stripel-01  Harddisk3  12288000  4096000  3/3  63  ACTIVE

Volume1  Simple  F     Disk1-02  Volume1-01  Harddisk0  4096000  4096000  1/1  4096063  ACTIVE
Volume2  Simple  G     Disk4-02  Volume2-01  Harddisk3  4096000  4096000  1/1  4096063  ACTIVE
Volume3  Mirror  H     Disk1-03  Volume3-01  Harddisk0  9350917  9350917  1/1  8192063  SYNC
Volume3  Mirror  H     Disk4-03  Volume3-02  Harddisk3  9350917  9350917  1/1  8192063  SYNC
Raid1   RAID5  I     Disk3-01  Raid1-01  Harddisk2  35084288  17542144  1/3  63  SYNC
Raid1   RAID5  I     Disk5-01  Raid1-01  Harddisk4  35084288  17542144  2/3  63  SYNC
Raid1   RAID5  I     Disk6-01  Raid1-01  Harddisk5  35084288  17542144  3/3  63  SYNC

Volume4  Simple  J     Disk2-02  Volume4-01  Harddisk1  13446917  13446917  1/1

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## GUID Partition Table (GPT)

- Part of Extensible Firmware Interface Specification (EFI)
- EFI targets IA-64 (Itanium)
- Sector address 64 bit wide
- Uses CRC to ensure integrity of partition table
- Maintains backup copy of partition table
- Assigns each partition GUID

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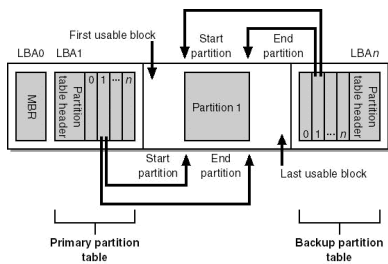
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## GPT



Note: LBA = Logical Block Address  
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## Storage Drivers

- Follow class/port/miniport architecture
  - Class driver: e.g. disk.sys (common functionality for disks)
  - Port driver: e.g. scsiport.sys
  - Miniport driver: e.g. aha154x.sys
- Class and Port driver mostly provided by Microsoft
- Miniport driver provided by manufacturer

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## Storage Drivers

- Disk driver creates device objects for disks (`\Device\HarddiskX\DRX`)
- Calls function *IoReadPartitionTable* to enumerate partitions of disks
- Disk driver creates device objects for partitions (`\Device\Harddisk0\DP(1)0x7e00-0x14...+1`)
- Disk driver creates symbolic links for legacy drivers (`\Device\Harddisk0\Partition0`)

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## Multipartition Volume Management

- Disc I/O for simple partition adds start of volume to volume-relative offset
- For multi-partition volumes „complicated“:
  - Need to check if I/O over multiple volumes (initiate additional IRPs)
  - Calculate which of the volumes has to be used
  - Perform parity checks (RAID-5)

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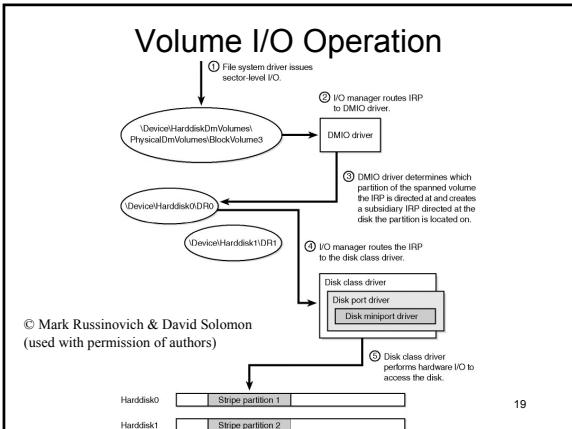
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- ### Volume Namespace
- Volumes are mounted (mountvol.exe)
  - Can mount volumes to directories:
    - Directory entry is reparse point (see later)
    - Reparse point redirects I/O to other driver
    - E.g. D:\Test\Test.txt and D:\Test is mounted to CD
      - D: is translated to \\?\D:, which links to partition
      - Driver of partition is asked to open „\Test\Test.txt“, which parses until „\Test“ and finds reparse point
      - Driver for reparse point (CD driver) is asked to parse „\Test.txt“
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- ### Outline
- Storage Management
    - Partitioning
    - Multi-Disk Volumes
  - Cache Manager
  - NTFS
    - Structure
    - FS drivers
    - MFT
    - Logging
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## Cache Manager

- Set of kernel-mode functions
- Cooperates with memory manager
- Provides caching for all file system types (local and network)
- Caches on virtual block basis (offset within file)
- Supports „hints“ passed by application at file open time
- Supports recoverable file systems

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## Cache Manager (2)

- Single, centralized system cache
- Use file mapping object
  - Map view of file into memory
  - Guarantees same data for all open views (guaranteed by memory manager)
- Map 256KB views

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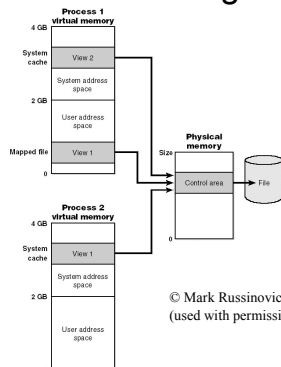
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## Coherent Caching Scheme



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## Recoverable File System Support

- Changes to FS structure are logged before intended update
- Disk writes are cached → Cache and FS work together:
  1. FS writes log file record of intended update
  2. FS calls Cache to flush this record
  3. FS updates metadata in cache
  4. Cache flushes altered metadata

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## Recoverable File System Support

- When FS writes data to cache, it can provide LSN (*logical sequence number*: identifies log entry corresponding to change)
- Pages with corresponding log entry are marked „no write“
- When cache manager intends to flush pages:
  - It determines highest LSN
  - Reports this LSN to FS
  - FS instructs Cache to flush log up to LSN
  - *After that*, cache flushes pages

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## Cache Structure

- Cache manager divides system cache memory region in 256KB slots (views)
- At file I/O cache manager maps 256KB aligned and sized region from file into free slot
- Slots are used on round robin basis
- Only „active“ views are mapped into address space
  - View becomes inactive depending on I/O (sequential/random access)
  - Inactive view is placed at end or front of memory manager's standby or modified list

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## Cache Size

- Cache Virtual Size
  - < 16MB physical memory: cache = 64 MB
  - > 16MB :  $128\text{MB} + (\text{phys.} - 16\text{MB})/4\text{MB} * 64\text{MB}$   
 = 128MB + 64MB for every 4MB above 16MB
  - E.g. For 64MB phys. Mem. = 896MB cache
- Cache Physical Size
  - Determined by memory manager's working set policy for „system working set“

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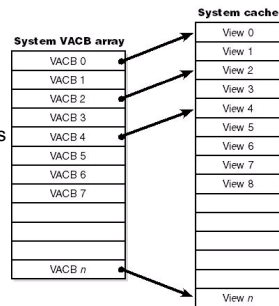
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## System Wide Cache Data Structures

- For every view a virtual address control block (VACB)
- VACB array stored in non-paged pool
- VACB contains address of view, cached file, start of view in file, reference count



Virtual address of data in system cache
Pointer to shared cache map
File offset
Active count

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## Per-File Cache Data Structures

- Each shared file object has pointer to section object (which describes mapped view of file)
- Section object points to shared cache map
- Shared cache map points to VACB index array, which contains references to VACBs used by file
- Shared cache map contains VACB index array with 4 entries (= 1MB file)
- Additional VACB index arrays contained in tree for larger files

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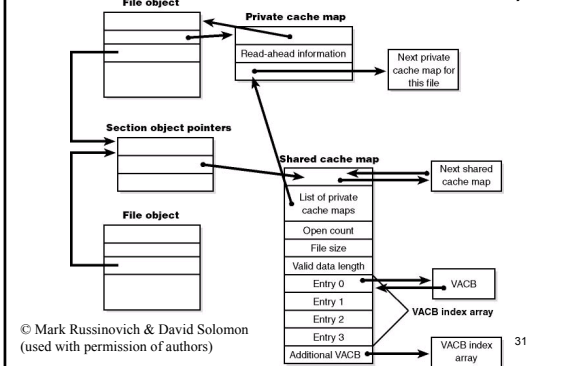
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## File Cache Data Structures (2)




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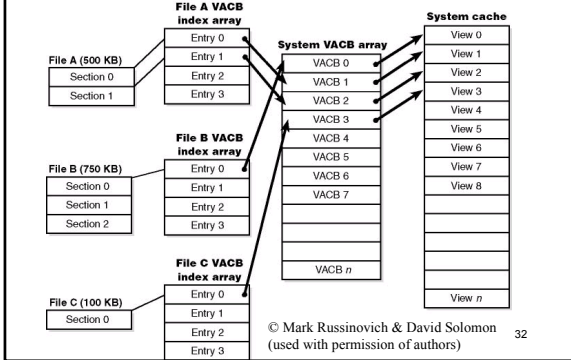
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## VACB Index Arrays




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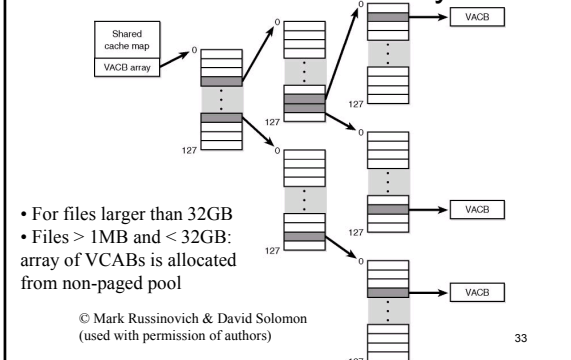
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## Multilevel VACB arrays




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## Cache Operation

- Writes into cache are buffered
- Lazy writer:
  - Wakes once per second
  - Writes one eighth of dirty pages
  - Wakes only if dirty page threshold (~3/8 phys. mem.) has been reached
  - If more dirty pages are generated than written, the number of written pages is adapted
  - Can be disabled (FILE\_ATTRIBUTE\_TEMPORARY) except if memory shortage
- Writes can go through cache (FILE\_FLAG\_WRITE\_THROUGH)
- Buffer can be flushed explicitly

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## Cache Operation (2)

- Read-Ahead
  - Cache stores last two read addresses and calculates next address for read-ahead
  - If sequential file access specified: no history, but sequential read-ahead (if read is past a view, this view is freed)
  - For random access files: no read-ahead
- When application reads:
  - Read is satisfied from cache and next I/O is initiated
  - Background thread reads while app. executes

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## System Threads

- Get work from worker queue
- Cache manager organizes work in two lists:
  - *express queue* for read-ahead
  - *regular queue* for lazy-write scans, write behinds, and lazy closes
  - items in per-processor look-aside list
  - number of items depends on system size

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## Fast I/O

- I/O manager calls file system driver's fast I/O to check whether cache can satisfy request
- No need to set up IRP
- If page is in cache, FS driver can read from memory
- Sometimes not fast I/O even if page is in memory
  - File is locked,
  - Asynchronous I/O, ...

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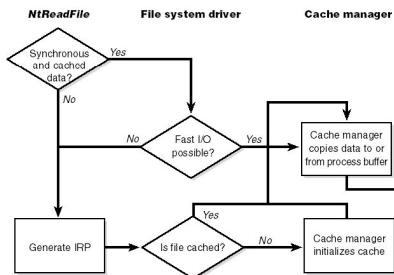
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## Fast I/O




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## Fast I/O

- After copy:
  - For reads: read-ahead information is updated
  - For writes: dirty bits of modified pages are set so lazy writer will flush page
  - For write-through: modifications are flushed to disk
- Note: Cache manager copies to from virtual page → relies on memory manager to map page from file

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## Cache Support Routines

- Copy data to and from Cache to user space buffers
  - Two read version for cached and non-cached read provided by file system driver
- Access (meta-)data directly in the cache (for file system drivers) – data has to be present in physical memory (has to be pinned  $\equiv$  not flushed)
- Obtain Memory Description List (MDL) for DMA (describes physical address)
- Write Throttling:
  - Restrict number of writes if this would hurt performance
  - First free physical pages if required by flushing dirty pages

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