Windows NT File System

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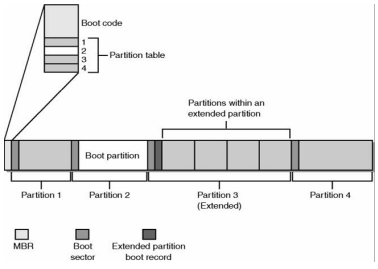
Outline

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

Disk Partitioning



Boot Process

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

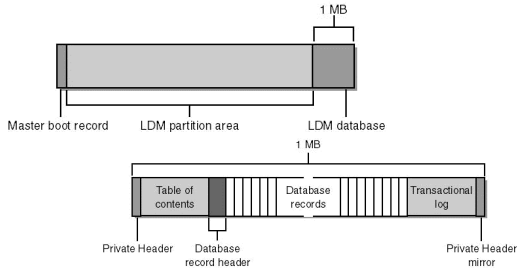
Partition Table

- 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“

„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

„Dynamic Partitioning“ (2)



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

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

Sample Output

```
---------- Dynamic Disk Information ----------
DiskGroup: Btsdelln2Dg0
Group-ID: e81df72b-f373-41d2-9a5a-351fbc4928ca

 Subdisk  Rel Sec   Tot Sec  Tot Size    Plex       Vol Type  Col/Ord  DevName    State
 ========  =======   =======  ========    ====       ========  =======  =========  ======
 LDM-DATA  0         0

 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

 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
```


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)

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, Ntdetect.com)
- *Boot volume:* contains Win2K operating system files (%Systemroot%)

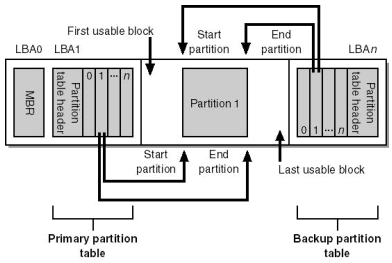
Sample Output (2)

```
---------- LDM Volume Information ----------

Volume   Volume  Mnt  Subdisk   Plex        Physical   Size      Total    Col  Rel      Vol
Name     Type    Nme  Name      Name        Disk       Sectors   Size     Ord  Sectors  State
======   ======  ===  =======   ==========  =========  =======   =======  ===  =======  ======
Stripe1  Stripe  E    Disk1-01  Stripe1-01  Harddisk0  12288000  4096000  1/3  63       ACTIVE
Stripe1  Stripe  E    Disk2-01  Stripe1-01  Harddisk1  12288000  4096000  2/3  63       ACTIVE
Stripe1  Stripe  E    Disk4-01  Stripe1-01  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
```


GUID Partition Table (GPT)

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

GPT



Note: LBA = Logical Block Address

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

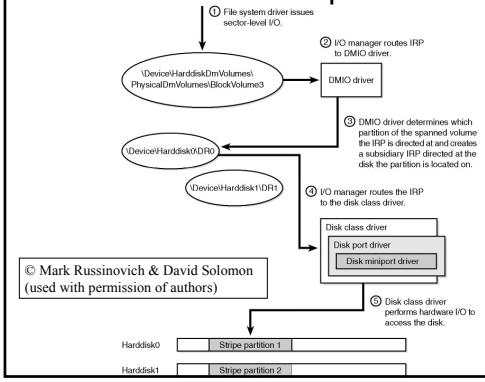
Storage Drivers

- 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)

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)

Volume I/O Operation



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“

Outline

- Storage Management
  - Partitioning
  - Multi-Disk Volumes
- Cache Manager
- NTFS
  - Structure
  - FS drivers
  - MFT
  - Logging

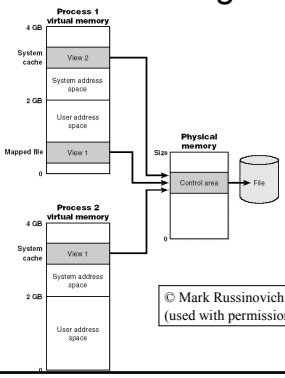
Cache Manager

- 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

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

Coherent Caching Scheme



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

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

Cache Structure

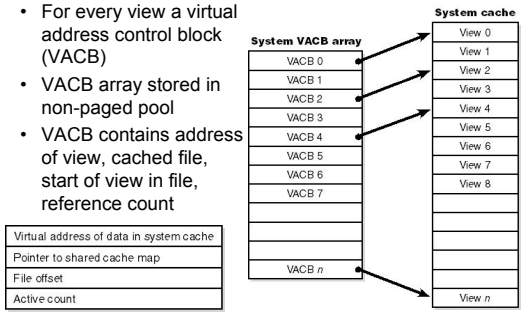
- Cache manager divides system cache memory region in 256KB slots (views)
- At file I/O cache manager maps 256KB aligned and sized region from file into free slot
- Slots are used on round robin basis
- Only „active“ views are mapped into address space
  - View becomes inactive depending on I/O (sequential/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

Cache Size

- Cache Virtual Size
  - < 16MB physical memory: cache = 64 MB
  - > 16MB : 128MB + (phys. – 16MB)/4MB * 64MB = 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“

System Wide Cache Data Structures

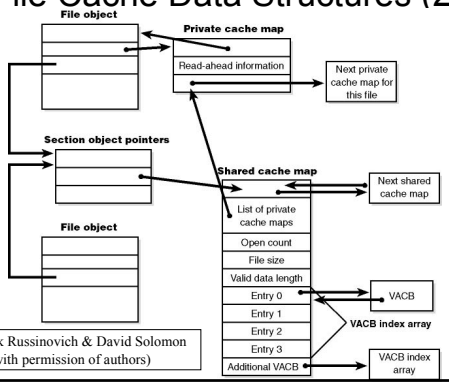
- For every view a virtual address control block (VACB)
- VACB array stored in non-paged pool
- VACB contains address of view, cached file, start of view in file, reference count



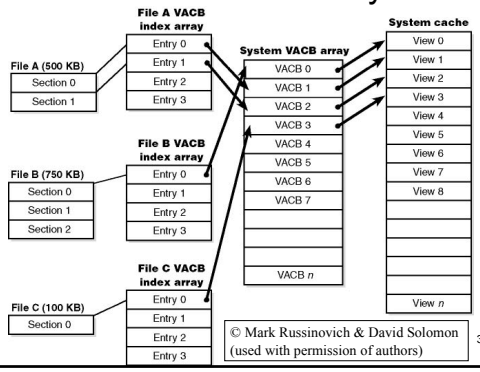
Per-File Cache Data Structures

- 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

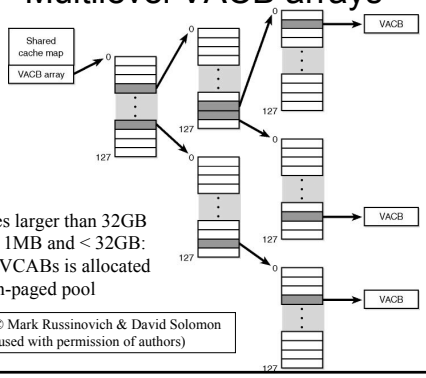
File Cache Data Structures (2)



VACB Index Arrays



Multilevel VACB arrays



• For files larger than 32GB
• Files > 1MB and < 32GB: array of VCABs is allocated from non-paged pool

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

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

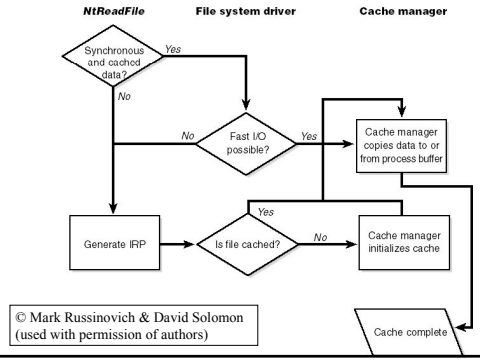
System Threads

- 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

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, ...

Fast I/O



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

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 ≡ 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