NTFS 1

File Systems – Last Extra!

Sistemas Operativos y Distribuidos

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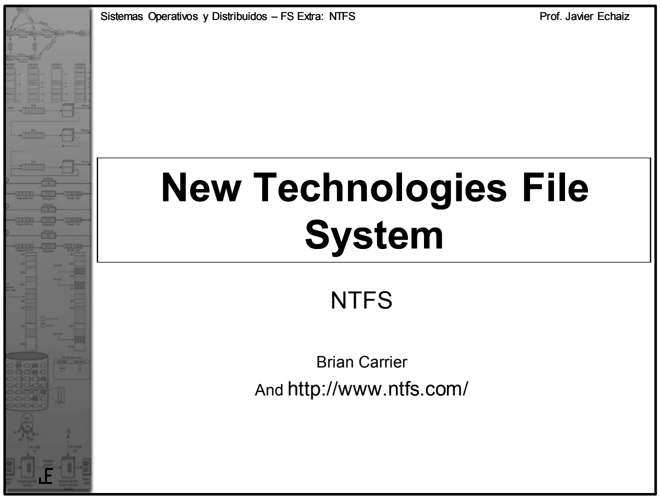
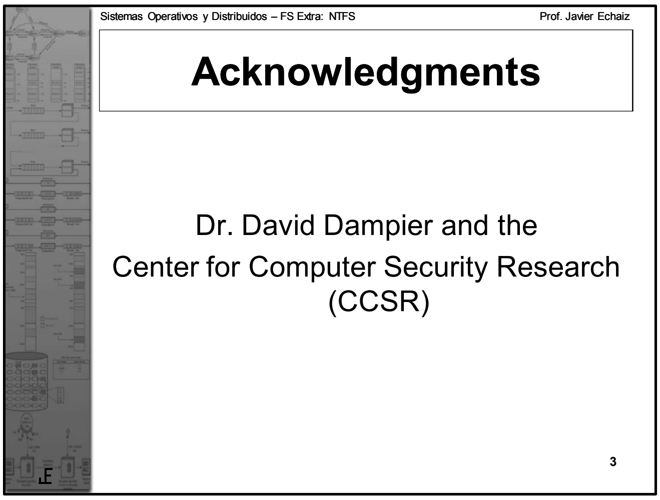


New Technologies File System

NTFS

Brian Carrier
And http://www.ntfs.com/



Acknowledgments

Dr. David Dampier and the
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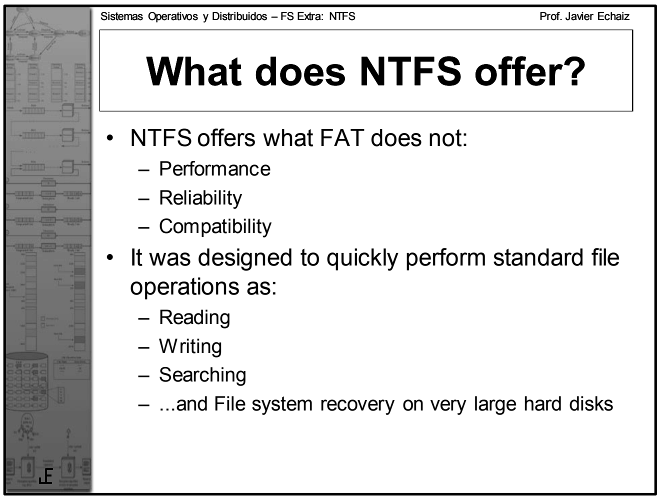
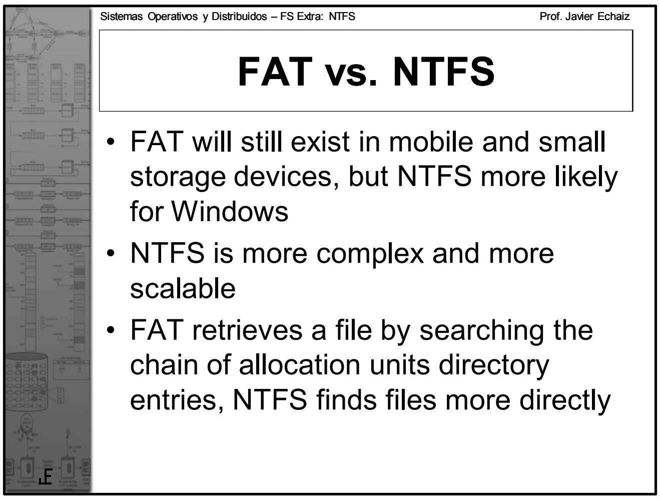
(CCSR)



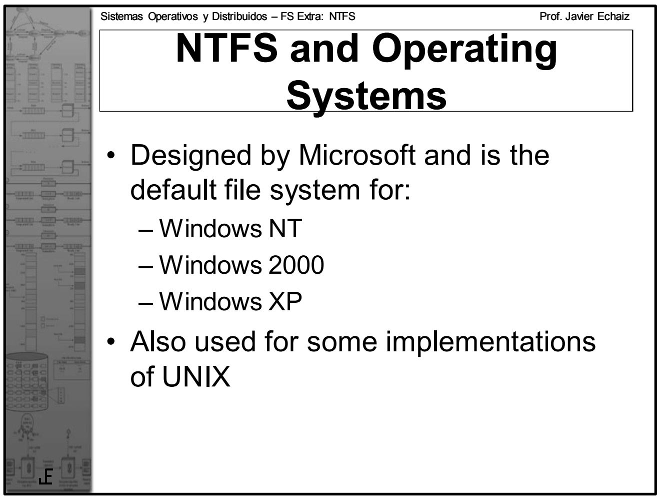
What does NTFS offer?

- NTFS offers what FAT does not:
  - Performance
  - Reliability
  - Compatibility
- It was designed to quickly perform standard file operations as:
  - Reading
  - Writing
  - Searching
  - ...and File system recovery on very large hard disks



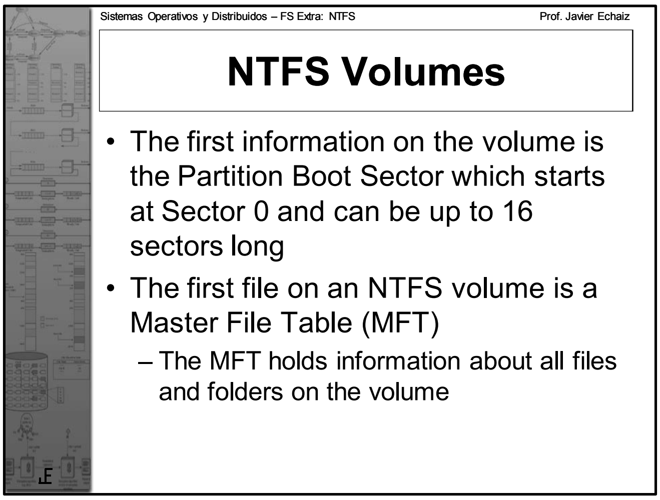
FAT vs. NTFS

- FAT will still exist in mobile and small storage devices, but NTFS more likely for Windows
- NTFS is more complex and more scalable
- FAT retrieves a file by searching the chain of allocation units directory entries, NTFS finds files more directly



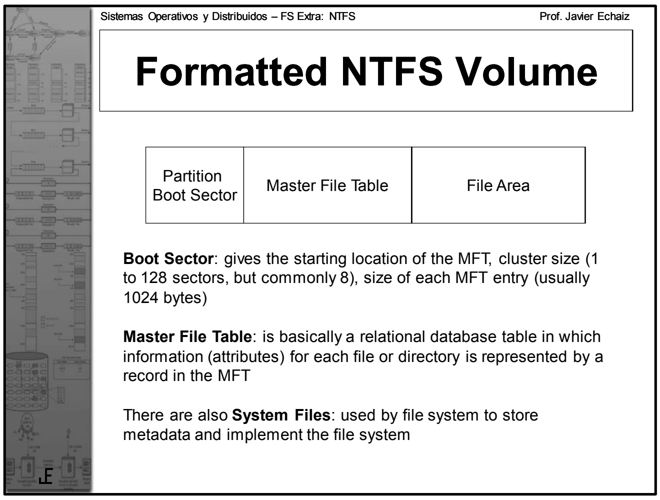
NTFS and Operating Systems

- Designed by Microsoft and is the default file system for:
  - Windows NT
  - Windows 2000
  - Windows XP
- Also used for some implementations of UNIX



NTFS Volumes

- The first information on the volume is the Partition Boot Sector which starts at Sector 0 and can be up to 16 sectors long
- The first file on an NTFS volume is a Master File Table (MFT)
  - The MFT holds information about all files and folders on the volume



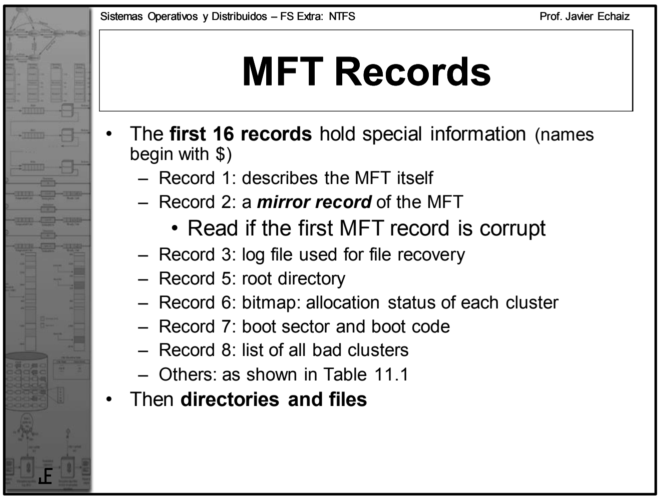
Formatted NTFS Volume

Partition Boot Sector	Master File Table	File Area

Boot Sector: gives the starting location of the MFT, cluster size (1 to 128 sectors, but commonly 8), size of each MFT entry (usually 1024 bytes)

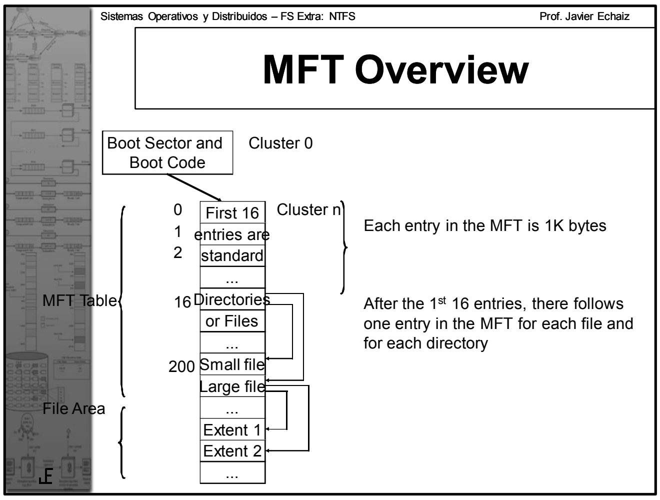
Master File Table: is basically a relational database table in which information (attributes) for each file or directory is represented by a record in the MFT

There are also **System Files**: used by file system to store metadata and implement the file system



MFT Records

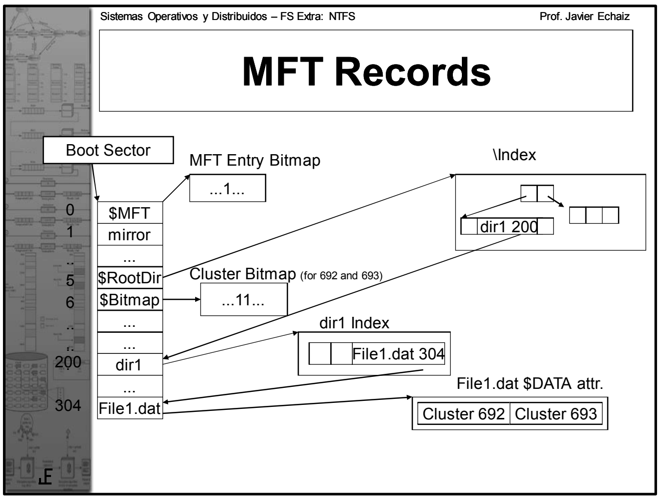
- The **first 16 records** hold special information (names begin with $)
  - Record 1: describes the MFT itself
  - Record 2: a ***mirror record*** of the MFT
    - Read if the first MFT record is corrupt
  - Record 3: log file used for file recovery
  - Record 5: root directory
  - Record 6: bitmap: allocation status of each cluster
  - Record 7: boot sector and boot code
  - Record 8: list of all bad clusters
  - Others: as shown in Table 11.1
- Then **directories and files**



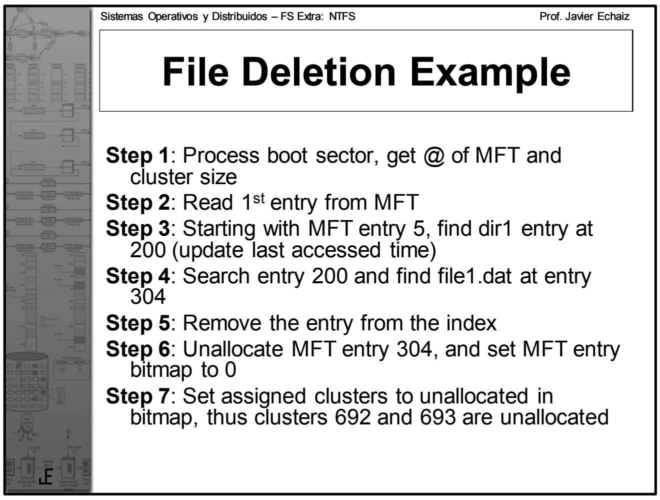
MFT Overview

Each entry in the MFT is 1K bytes

After the 1st 16 entries, there follows one entry in the MFT for each file and for each directory

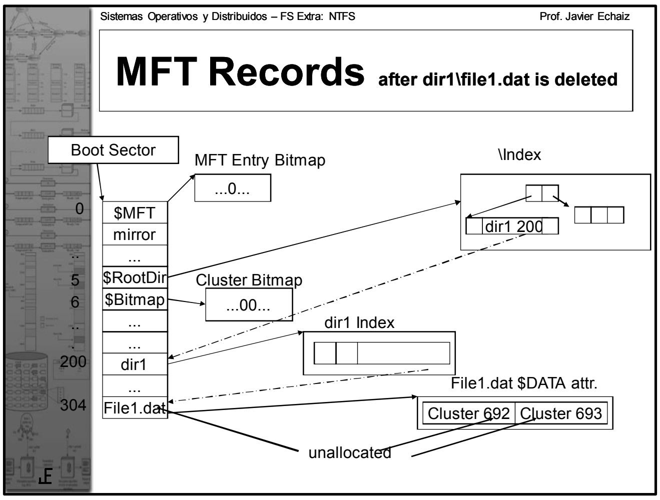


MFT Records

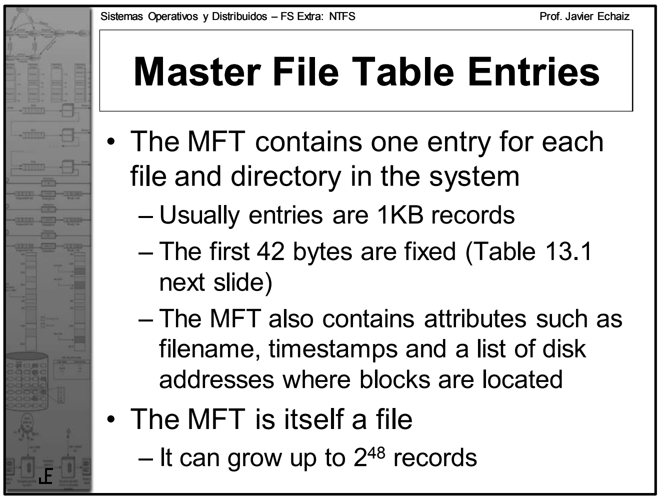


File Deletion Example

Step 1: Process boot sector, get @ of MFT and cluster size
Step 2: Read 1st entry from MFT
Step 3: Starting with MFT entry 5, find dir1 entry at 200 (update last accessed time)
Step 4: Search entry 200 and find file1.dat at entry 304
Step 5: Remove the entry from the index
Step 6: Unallocate MFT entry 304, and set MFT entry bitmap to 0
Step 7: Set assigned clusters to unallocated in bitmap, thus clusters 692 and 693 are unallocated

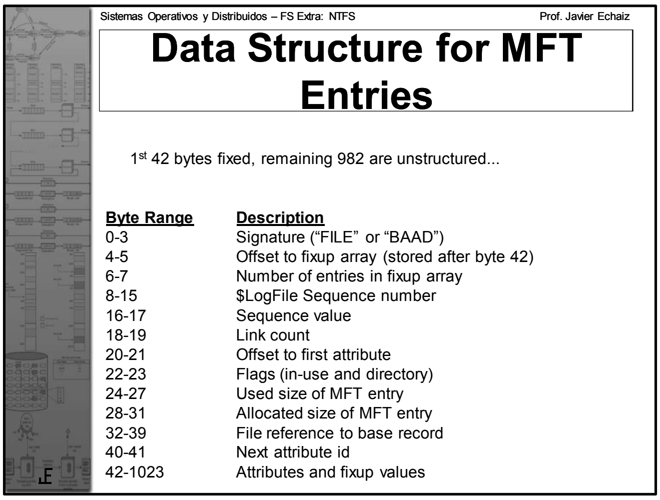


MFT Records after dir1\file1.dat is deleted



Master File Table Entries

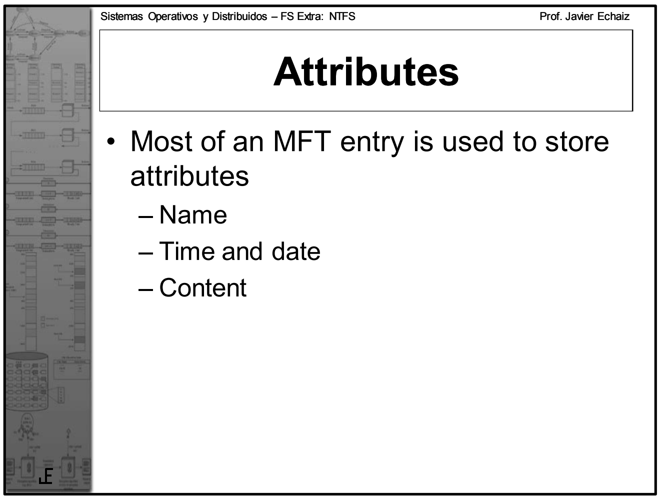
- The MFT contains one entry for each file and directory in the system
  - Usually entries are 1KB records
  - The first 42 bytes are fixed (Table 13.1 next slide)
  - The MFT also contains attributes such as filename, timestamps and a list of disk addresses where blocks are located
- The MFT is itself a file
  - It can grow up to 2^{48} records



Data Structure for MFT Entries

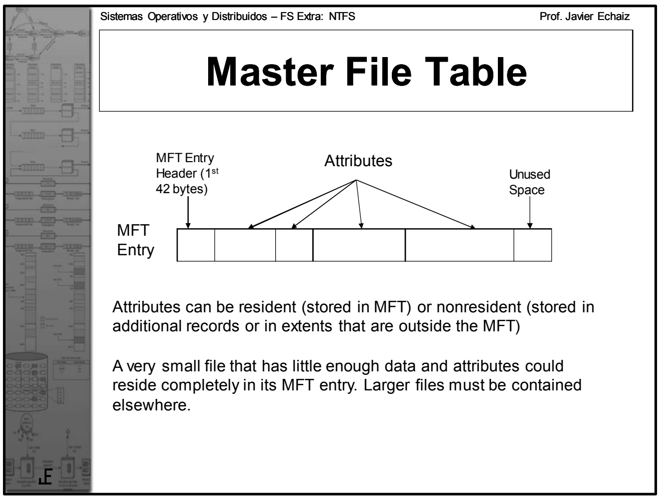
1st 42 bytes fixed, remaining 982 are unstructured...

Byte Range	Description
0-3	Signature (“FILE” or “BAAD”)
4-5	Offset to fixup array (stored after byte 42)
6-7	Number of entries in fixup array
8-15	$LogFile Sequence number
16-17	Sequence value
18-19	Link count
20-21	Offset to first attribute
22-23	Flags (in-use and directory)
24-27	Used size of MFT entry
28-31	Allocated size of MFT entry
32-39	File reference to base record
40-41	Next attribute id
42-1023	Attributes and fixup values



Attributes

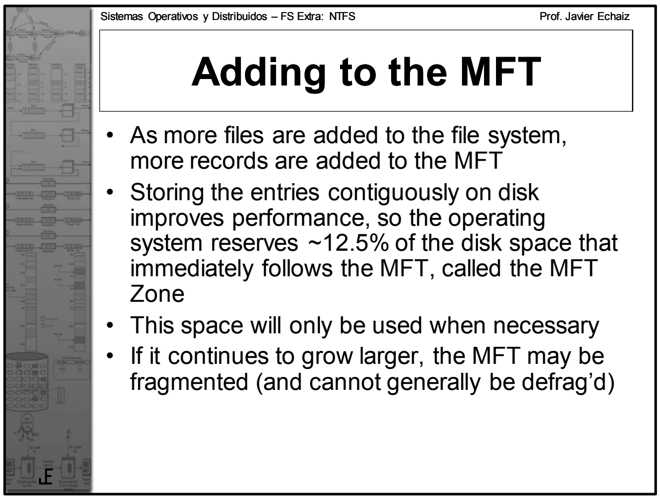
- Most of an MFT entry is used to store attributes
  - Name
  - Time and date
  - Content



Master File Table

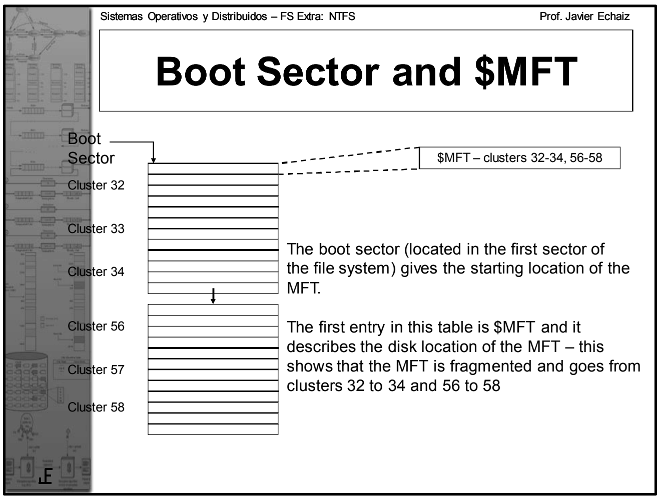
Attributes can be resident (stored in MFT) or nonresident (stored in additional records or in extents that are outside the MFT)

A very small file that has little enough data and attributes could reside completely in its MFT entry. Larger files must be contained elsewhere.



Adding to the MFT

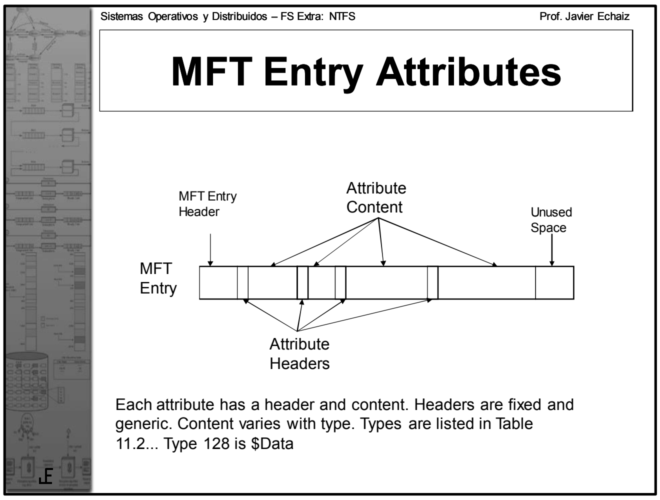
- As more files are added to the file system, more records are added to the MFT
- Storing the entries contiguously on disk improves performance, so the operating system reserves ~12.5% of the disk space that immediately follows the MFT, called the MFT Zone
- This space will only be used when necessary
- If it continues to grow larger, the MFT may be fragmented (and cannot generally be defrag’d)



Boot Sector and $MFT

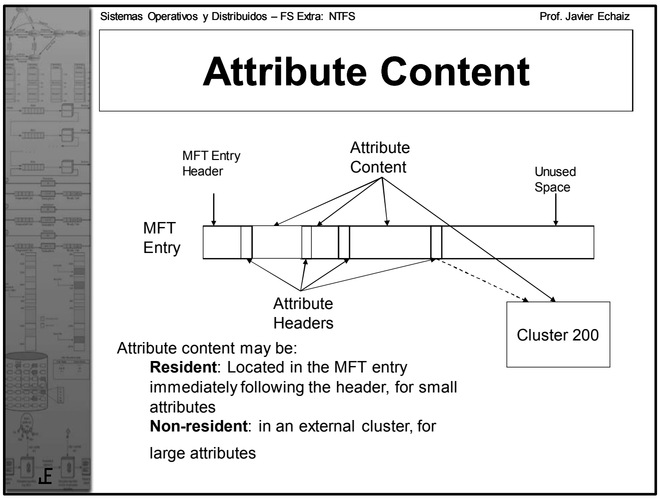
The boot sector (located in the first sector of the file system) gives the starting location of the MFT.

The first entry in this table is $MFT and it describes the disk location of the MFT – this shows that the MFT is fragmented and goes from clusters 32 to 34 and 56 to 58



MFT Entry Attributes

Each attribute has a header and content. Headers are fixed and generic. Content varies with type. Types are listed in Table 11.2... Type 128 is $Data

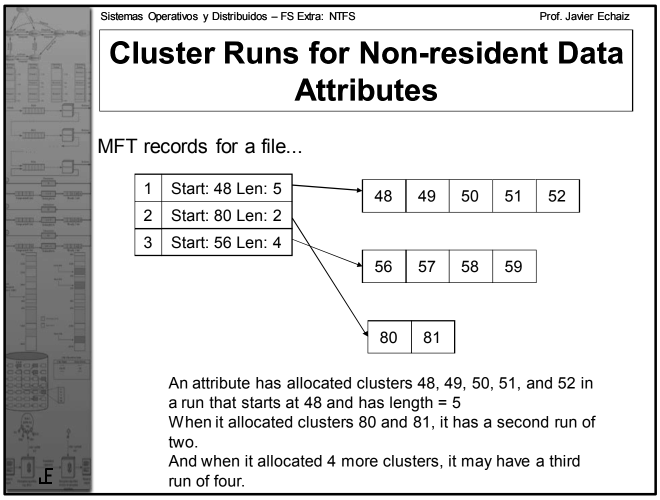


Attribute Content

Attribute content may be:

Resident: Located in the MFT entry immediately following the header, for small attributes

Non-resident: in an external cluster, for large attributes



Cluster Runs for Non-resident Data Attributes

MFT records for a file...

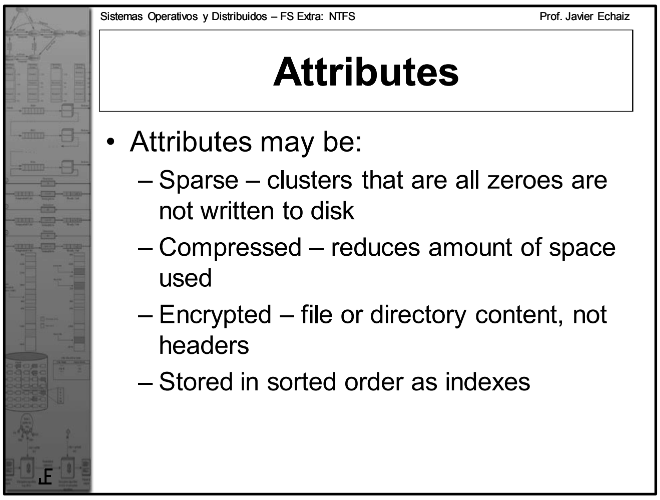
1	Start: 48 Len: 5
2	Start: 80 Len: 2
3	Start: 56 Len: 4

48	49	50	51	52

56	57	58	59

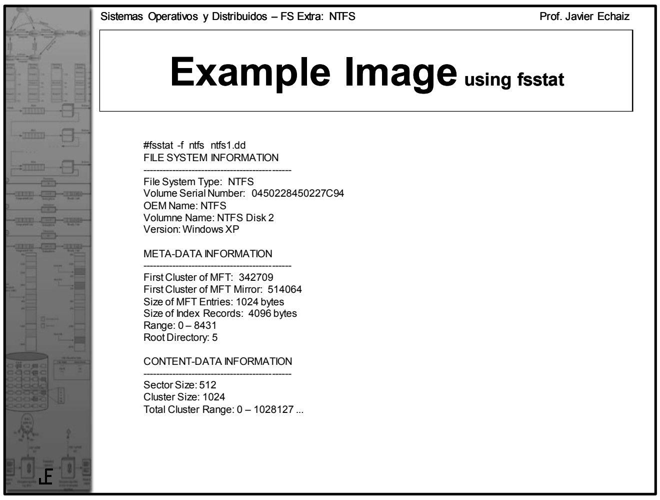
80	81

An attribute has allocated clusters 48, 49, 50, 51, and 52 in a run that starts at 48 and has length = 5
When it allocated clusters 80 and 81, it has a second run of two.
And when it allocated 4 more clusters, it may have a third run of four.



Attributes

- Attributes may be:
  - – Sparse – clusters that are all zeroes are not written to disk
  - – Compressed – reduces amount of space used
  - – Encrypted – file or directory content, not headers
  - – Stored in sorted order as indexes

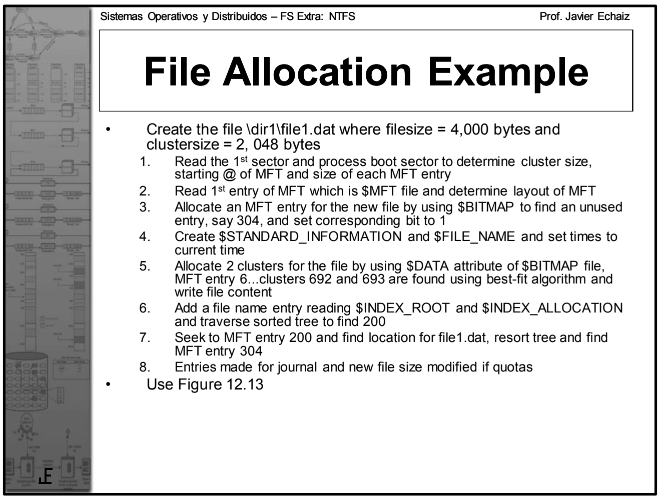


Example Image using fsstat

```
#fsstat -f ntfs ntfs1.dd
FILE SYSTEM INFORMATION
--------------------------------------------
File System Type: NTFS
Volume Serial Number: 0450228450227C94
OEM Name: NTFS
Volumne Name: NTFS Disk 2
Version: Windows XP

META-DATA INFORMATION
--------------------------------------------
First Cluster of MFT: 342709
First Cluster of MFT Mirror: 514064
Size of MFT Entries: 1024 bytes
Size of Index Records: 4096 bytes
Range: 0 – 8431
Root Directory: 5

CONTENT-DATA INFORMATION
--------------------------------------------
Sector Size: 512
Cluster Size: 1024
Total Cluster Range: 0 – 1028127 ...
```



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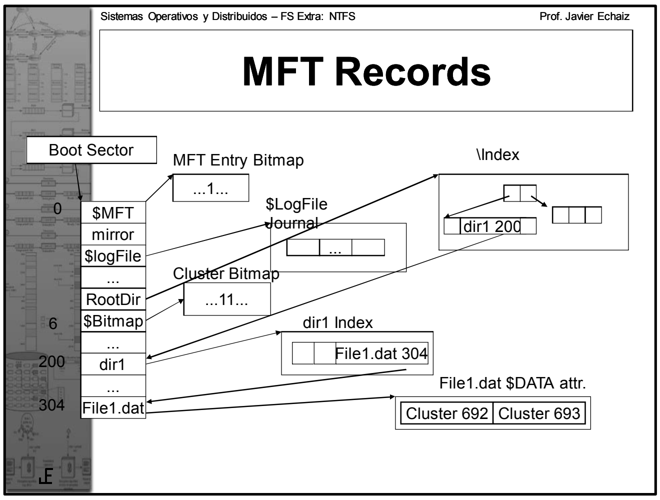
File Allocation Example

- Create the file \dir1\file1.dat where filesize = 4,000 bytes and clustersize = 2, 048 bytes
  1. Read the 1st sector and process boot sector to determine cluster size, starting @ of MFT and size of each MFT entry
  2. Read 1st entry of MFT which is $MFT file and determine layout of MFT
  3. Allocate an MFT entry for the new file by using $BITMAP to find an unused entry, say 304, and set corresponding bit to 1
  4. Create $STANDARD_INFORMATION and $FILE_NAME and set times to current time
  5. Allocate 2 clusters for the file by using $DATA attribute of $BITMAP file, MFT entry 6...clusters 692 and 693 are found using best-fit algorithm and write file content
  6. Add a file name entry reading $INDEX_ROOT and $INDEX_ALLOCATION and traverse sorted tree to find 200
  7. Seek to MFT entry 200 and find location for file1.dat, resort tree and find MFT entry 304
  8. Entries made for journal and new file size modified if quotas
- Use Figure 12.13



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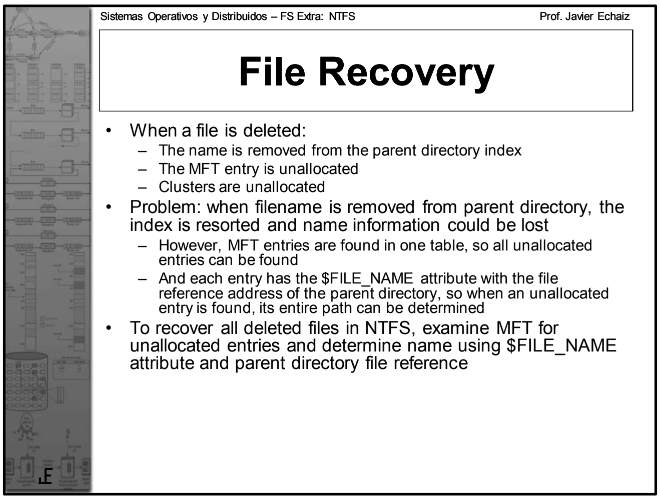
MFT Records



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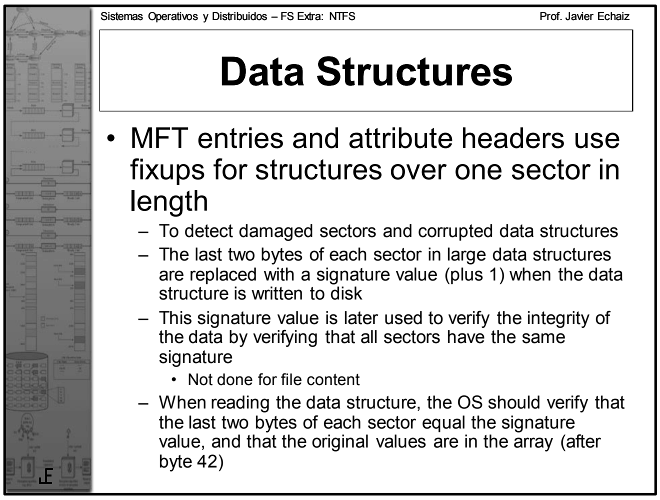
File Recovery

- When a file is deleted:
  - The name is removed from the parent directory index
  - The MFT entry is unallocated
  - Clusters are unallocated
- Problem: when filename is removed from parent directory, the index is resorted and name information could be lost
  - However, MFT entries are found in one table, so all unallocated entries can be found
  - And each entry has the $FILE_NAME attribute with the file reference address of the parent directory, so when an unallocated entry is found, its entire path can be determined
- To recover all deleted files in NTFS, examine MFT for unallocated entries and determine name using $FILE_NAME attribute and parent directory file reference



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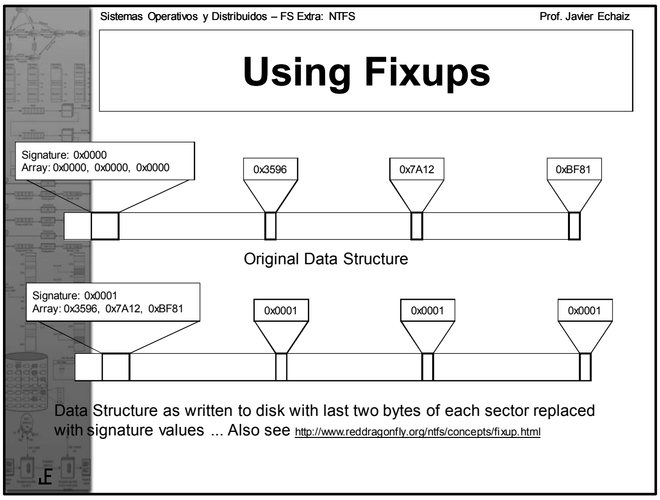
Data Structures

- MFT entries and attribute headers use fixups for structures over one sector in length
  - To detect damaged sectors and corrupted data structures
  - The last two bytes of each sector in large data structures are replaced with a signature value (plus 1) when the data structure is written to disk
  - This signature value is later used to verify the integrity of the data by verifying that all sectors have the same signature
    - Not done for file content
  - When reading the data structure, the OS should verify that the last two bytes of each sector equal the signature value, and that the original values are in the array (after byte 42)



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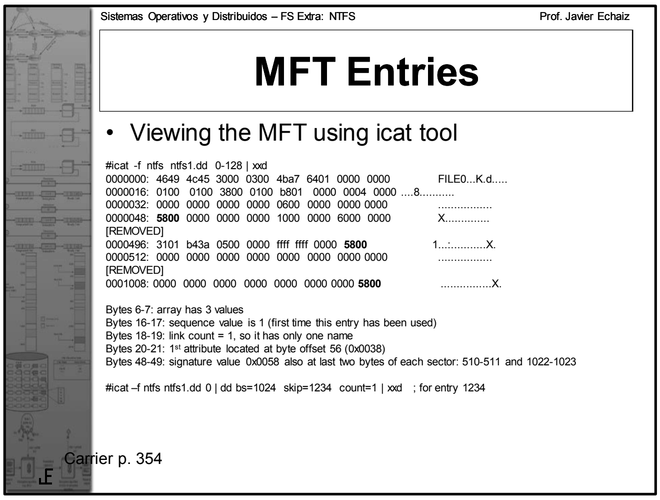
Using Fixups

Original Data Structure

Data Structure as written to disk with last two bytes of each sector replaced with signature values ... Also see http://www.reddragonfly.org/ntfs/concepts/fixup.html



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MFT Entries

- Viewing the MFT using icat tool

```
#icat -f ntfs ntfs1.dd 0-128 | xxd
0000000: 4649 4c45 3000 0300 4ba7 6401 0000 0000       FILE0...K.d.....
0000016: 0100 0100 3800 0100 b801 0000 0004 0000 ....8...........
0000032: 0000 0000 0000 0000 0600 0000 0000 0000       ................
0000048: 5800 0000 0000 0000 1000 0000 6000 0000       X...............
[REMOVED]
0000496: 3101 b43a 0500 0000 ffff ffff 0000 5800      1...:...........X.
0000512: 0000 0000 0000 0000 0000 0000 0000 0000       ................
[REMOVED]
0001008: 0000 0000 0000 0000 0000 0000 0000 5800       ...............X.
```

Bytes 6-7: array has 3 values
Bytes 16-17: sequence value is 1 (first time this entry has been used)
Bytes 18-19: link count = 1, so it has only one name
Bytes 20-21: 1st attribute located at byte offset 56 (0x0038)
Bytes 48-49: signature value 0x0058 also at last two bytes of each sector: 510-511 and 1022-1023

```
#icat –f ntfs ntfs1.dd 0 | dd bs=1024 skip=1234 count=1 | xxd ; for entry 1234
```

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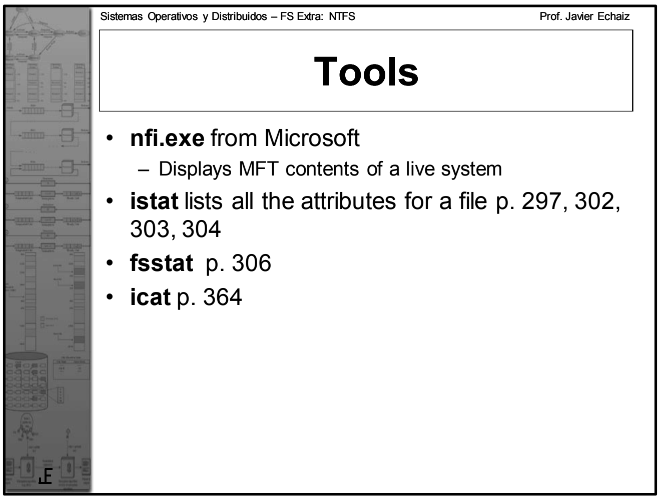
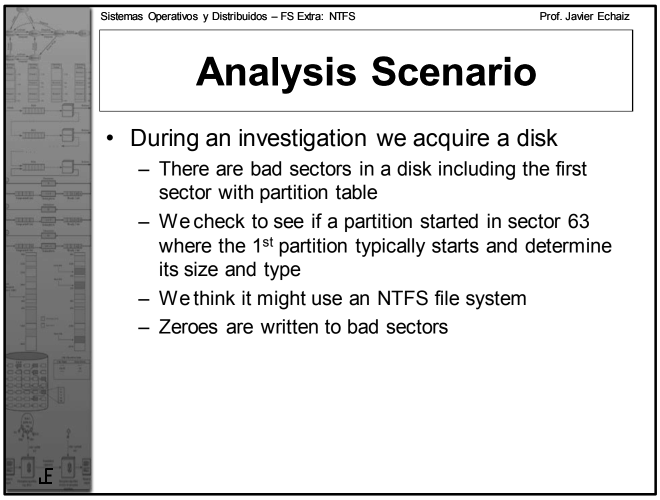


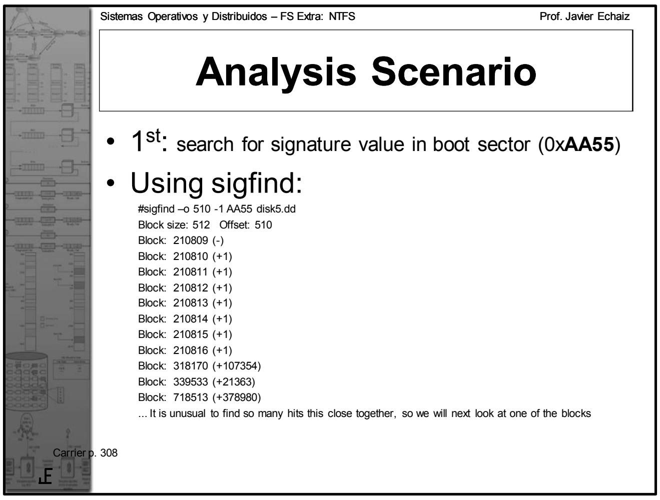
Tools

- **nfi.exe** from Microsoft
  - Displays MFT contents of a live system
- **istat** lists all the attributes for a file p. 297, 302, 303, 304
- **fsstat** p. 306
- **icat** p. 364



Analysis Scenario

- During an investigation we acquire a disk
  - There are bad sectors in a disk including the first sector with partition table
  - We check to see if a partition started in sector 63 where the 1st partition typically starts and determine its size and type
  - We think it might use an NTFS file system
  - Zeroes are written to bad sectors



Analysis Scenario

- 1st: search for signature value in boot sector (0x**AA55**)
- Using sigfind:

```
#sigfind –o 510 -1 AA55 disk5.dd
Block size: 512   Offset: 510
Block:  210809 (-)
Block:  210810 (+1)
Block:  210811 (+1)
Block:  210812 (+1)
Block:  210813 (+1)
Block:  210814 (+1)
Block:  210815 (+1)
Block:  210816 (+1)
Block:  318170 (+107354)
Block:  339533 (+21363)
Block:  718513 (+378980)
```

... It is unusual to find so many hits this close together, so we will next look at one of the blocks

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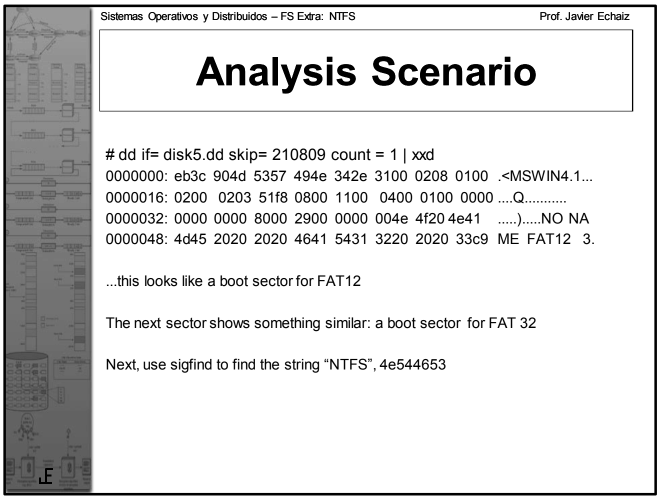


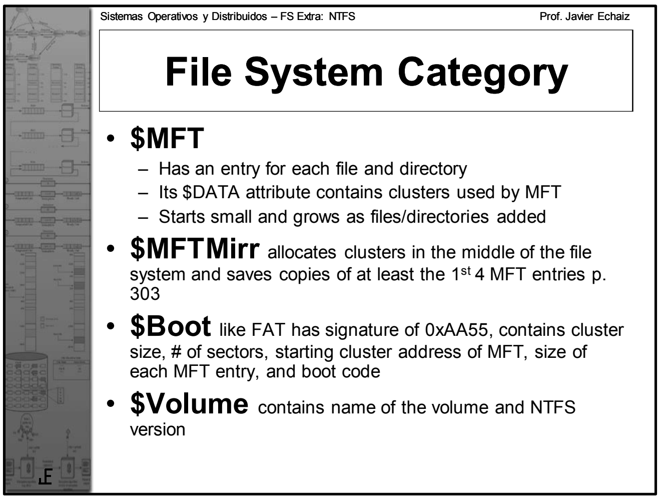
Analysis Scenario

```
# dd if= disk5.dd skip= 210809 count = 1 | xxd
0000000: eb3c 904d 5357 494e 342e 3100 0208 0100  .<MSWIN4.1...
0000016: 0200  0203 51f8 0800 1100  0400 0100 0000 ....Q..........
0000032: 0000 0000 8000 2900 0000 004e 4f20 4e41   .....).....NO NA
0000048: 4d45 2020 2020 4641 5431 3220 2020 33c9  ME  FAT12   3.
```

...this looks like a boot sector for FAT12

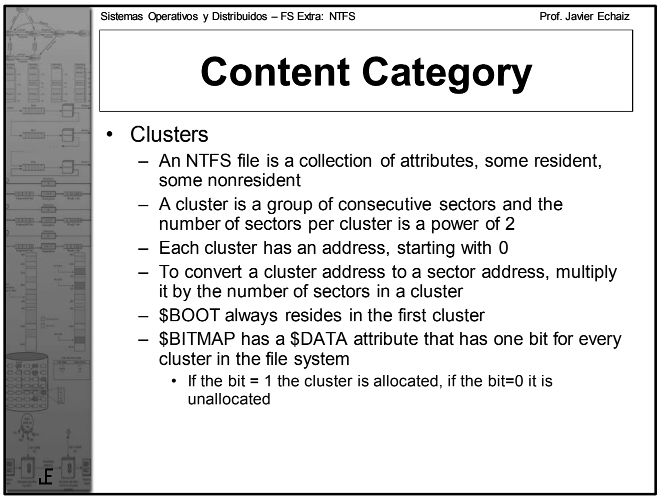
The next sector shows something similar: a boot sector for FAT 32

Next, use sigfind to find the string “NTFS”, 4e544653



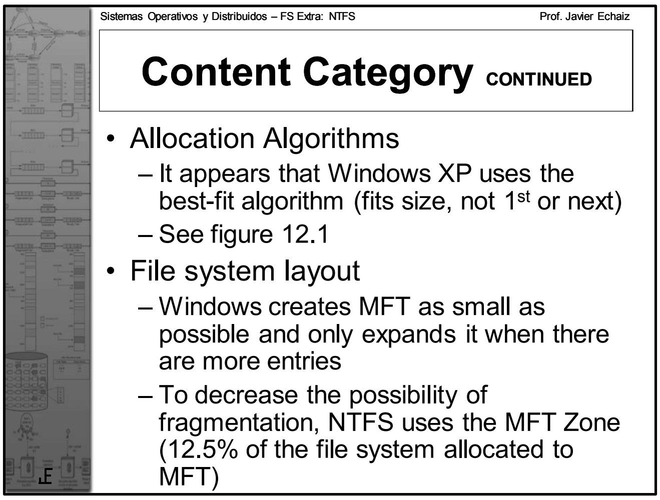
File System Category

- **$MFT**
  - Has an entry for each file and directory
  - Its $DATA attribute contains clusters used by MFT
  - Starts small and grows as files/directories added
- **$MFTMirr** allocates clusters in the middle of the file system and saves copies of at least the 1st 4 MFT entries p. 303
- **$Boot** like FAT has signature of 0xAA55, contains cluster size, # of sectors, starting cluster address of MFT, size of each MFT entry, and boot code
- **$Volume** contains name of the volume and NTFS version



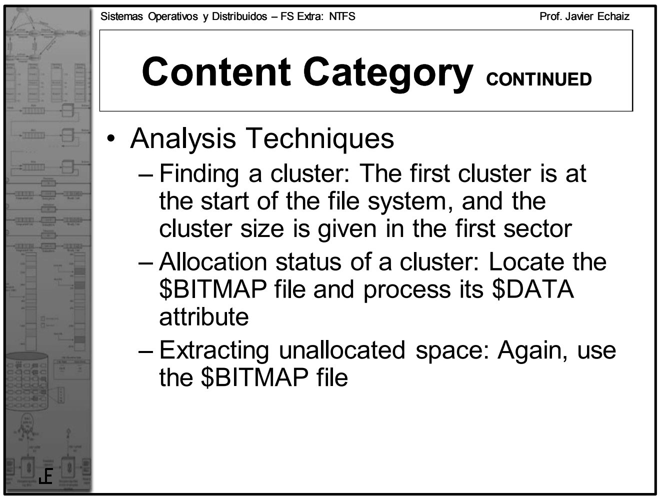
Content Category

- Clusters
  - An NTFS file is a collection of attributes, some resident, some nonresident
  - A cluster is a group of consecutive sectors and the number of sectors per cluster is a power of 2
  - Each cluster has an address, starting with 0
  - To convert a cluster address to a sector address, multiply it by the number of sectors in a cluster
  - $BOOT always resides in the first cluster
  - $BITMAP has a $DATA attribute that has one bit for every cluster in the file system
    - If the bit = 1 the cluster is allocated, if the bit=0 it is unallocated



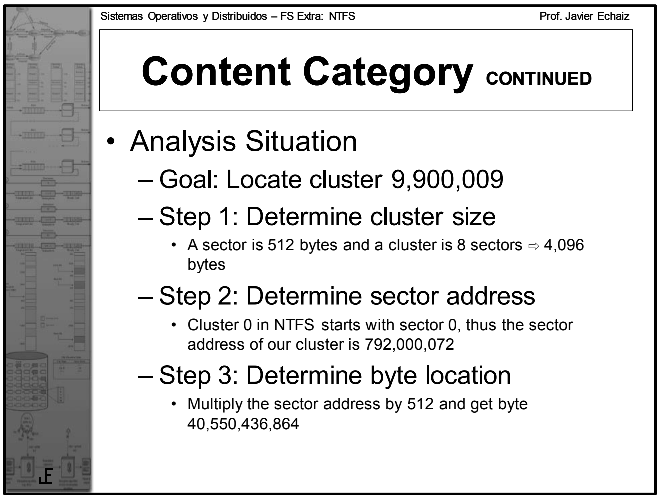
Content Category CONTINUED

- Allocation Algorithms
  - It appears that Windows XP uses the best-fit algorithm (fits size, not 1st or next)
  - See figure 12.1
- File system layout
  - Windows creates MFT as small as possible and only expands it when there are more entries
  - To decrease the possibility of fragmentation, NTFS uses the MFT Zone (12.5% of the file system allocated to MFT)



Content Category CONTINUED

- Analysis Techniques
  - Finding a cluster: The first cluster is at the start of the file system, and the cluster size is given in the first sector
  - Allocation status of a cluster: Locate the $BITMAP file and process its $DATA attribute
  - Extracting unallocated space: Again, use the $BITMAP file



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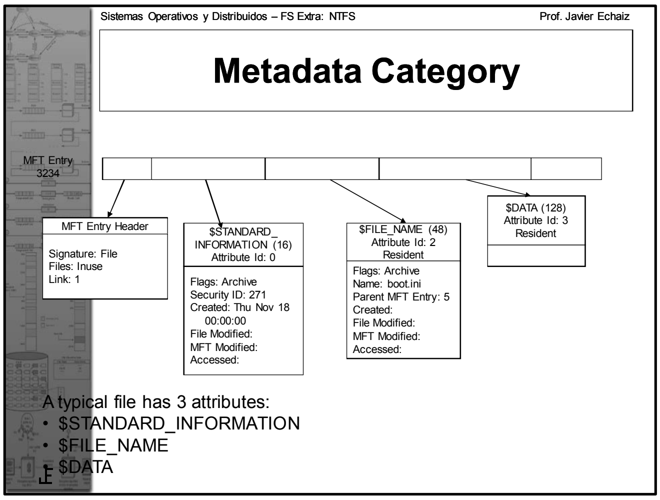
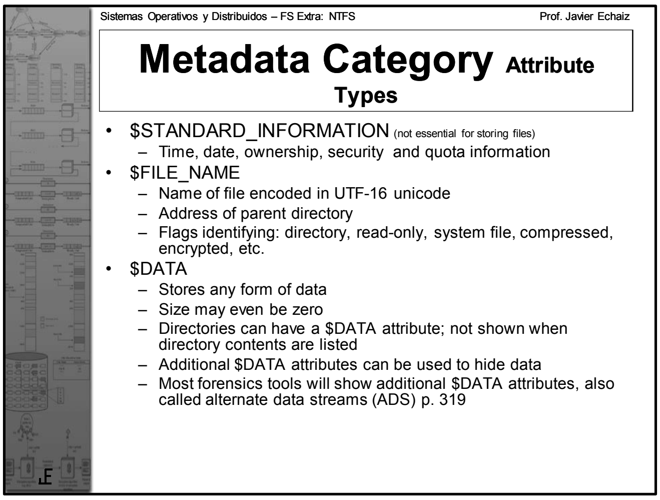
- Analysis Situation
  - Goal: Locate cluster 9,900,009
  - Step 1: Determine cluster size
    - A sector is 512 bytes and a cluster is 8 sectors ⇨ 4,096 bytes
  - Step 2: Determine sector address
    - Cluster 0 in NTFS starts with sector 0, thus the sector address of our cluster is 792,000,072
  - Step 3: Determine byte location
    - Multiply the sector address by 512 and get byte 40,550,436,864



Metadata Category

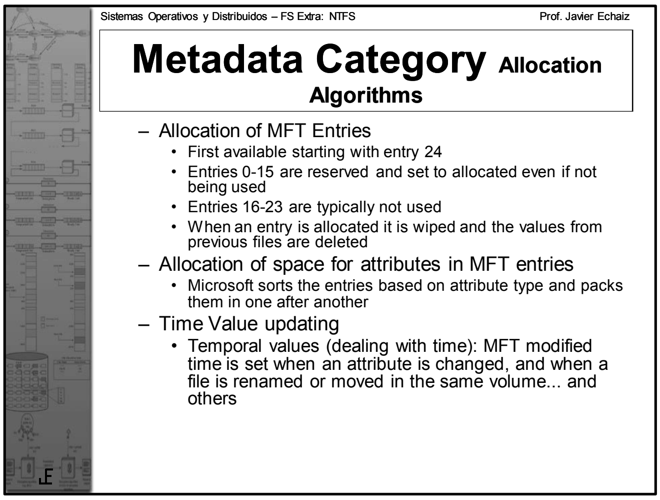
A typical file has 3 attributes:

- $STANDARD_INFORMATION
- $FILE_NAME
- $DATA



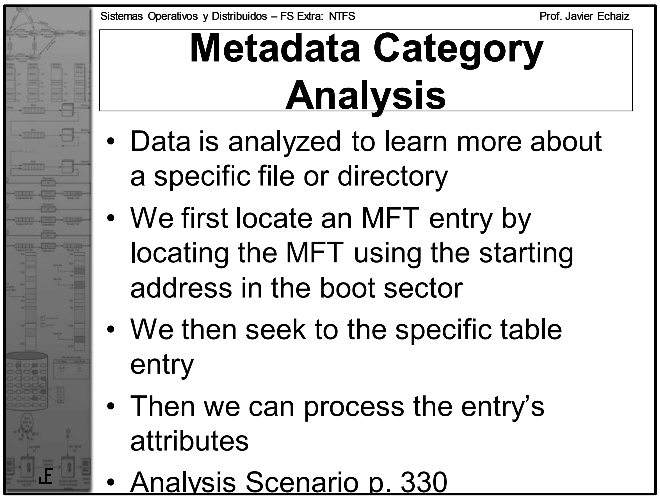
Metadata Category Attribute Types

- $STANDARD_INFORMATION (not essential for storing files)
  - Time, date, ownership, security and quota information
- $FILE_NAME
  - Name of file encoded in UTF-16 unicode
  - Address of parent directory
  - Flags identifying: directory, read-only, system file, compressed, encrypted, etc.
- $DATA
  - Stores any form of data
  - Size may even be zero
  - Directories can have a $DATA attribute; not shown when directory contents are listed
  - Additional $DATA attributes can be used to hide data
  - Most forensics tools will show additional $DATA attributes, also called alternate data streams (ADS) p. 319



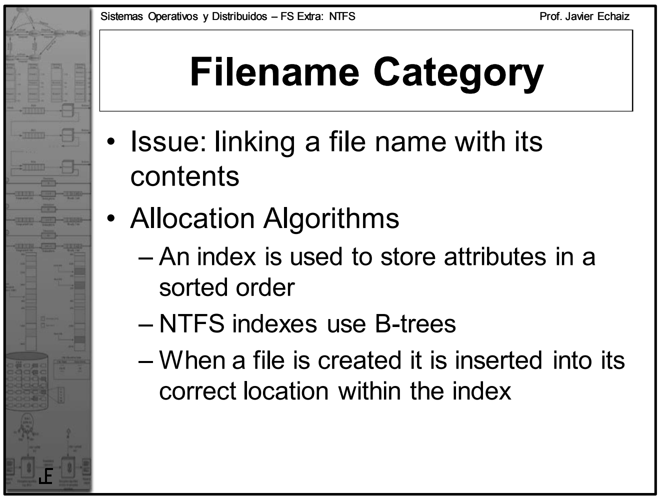
Metadata Category Allocation Algorithms

- Allocation of MFT Entries
  - First available starting with entry 24
  - Entries 0-15 are reserved and set to allocated even if not being used
  - Entries 16-23 are typically not used
  - When an entry is allocated it is wiped and the values from previous files are deleted
- Allocation of space for attributes in MFT entries
  - Microsoft sorts the entries based on attribute type and packs them in one after another
- Time Value updating
  - Temporal values (dealing with time): MFT modified time is set when an attribute is changed, and when a file is renamed or moved in the same volume... and others



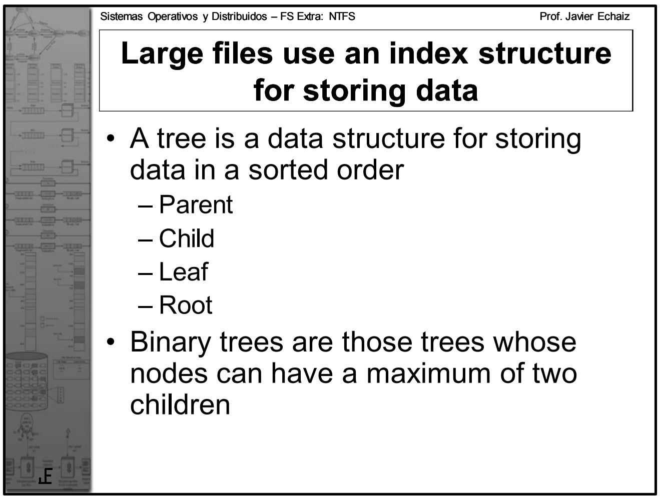
Metadata Category Analysis

- Data is analyzed to learn more about a specific file or directory
- We first locate an MFT entry by locating the MFT using the starting address in the boot sector
- We then seek to the specific table entry
- Then we can process the entry’s attributes
- Analysis Scenario p. 330



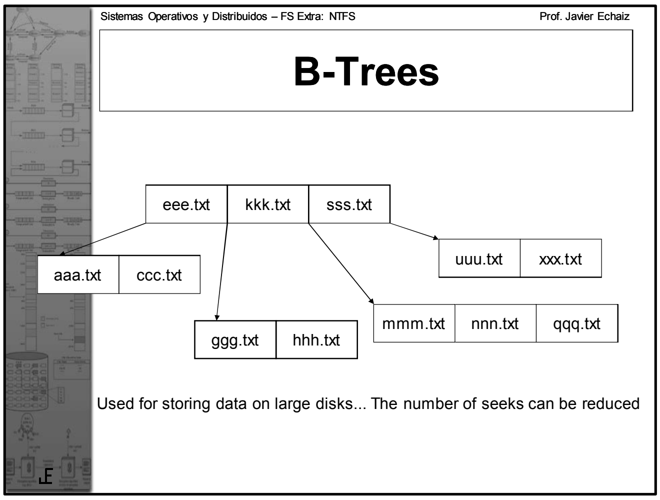
Filename Category

- Issue: linking a file name with its contents
- Allocation Algorithms
  - An index is used to store attributes in a sorted order
  - NTFS indexes use B-trees
  - When a file is created it is inserted into its correct location within the index



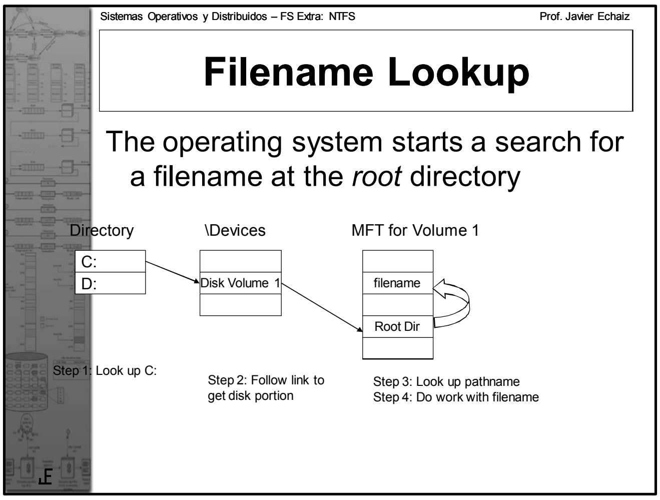
Large files use an index structure for storing data

- A tree is a data structure for storing data in a sorted order
  - Parent
  - Child
  - Leaf
  - Root
- Binary trees are those trees whose nodes can have a maximum of two children



B-Trees

Used for storing data on large disks... The number of seeks can be reduced



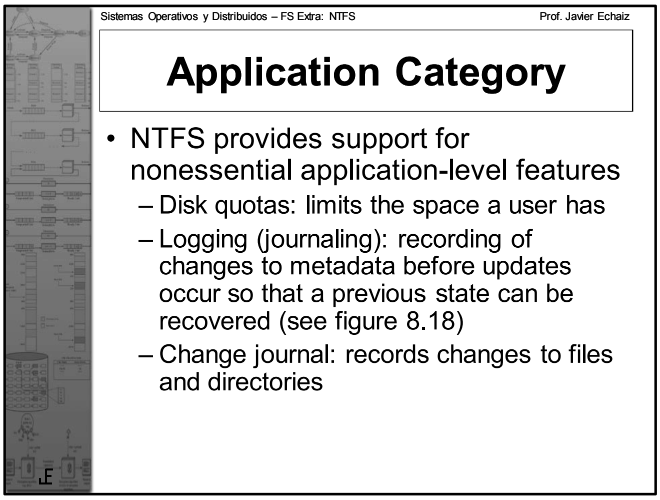
Filename Lookup

The operating system starts a search for a filename at the *root* directory

Step 1: Look up C:

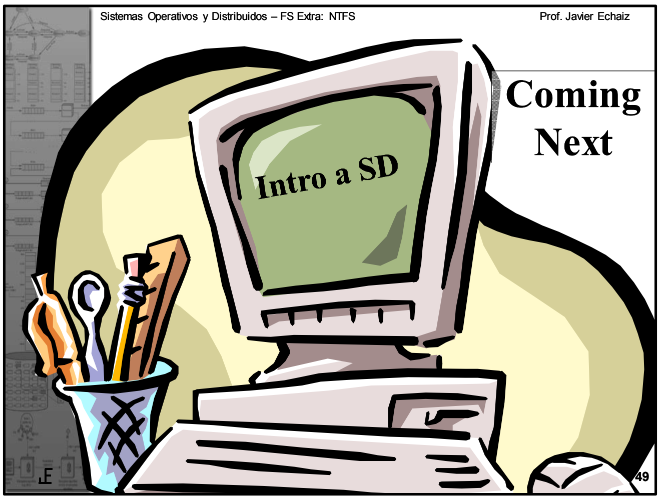
Step 2: Follow link to get disk portion

Step 3: Look up pathname
Step 4: Do work with filename



Application Category

- NTFS provides support for nonessential application-level features
  - Disk quotas: limits the space a user has
  - Logging (journaling): recording of changes to metadata before updates occur so that a previous state can be recovered (see figure 8.18)
  - Change journal: records changes to files and directories



Sistemas Operativos y Distribuidos – FS Extra: NTFS

Prof. Javier Echaiz

Coming Next

Intro a SD

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