File Systems

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Lesson Plan

- Introduction to File Systems
- Storage Space Management
- Common File Systems
- Q&A
- Additional Links
- Activity

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Introduction to File Systems

- File System is a method and data structure that the operating system uses to control how files are placed logically for storage and retrieval.
- The task of the file system is to maintain an optimal file structure.
- Without a file system, information stored will be difficult to identify and retrieve.
- There are different file systems in Operating Systems such as Windows, Linux, and MacOS.
- Each system is with unique structure and logic, properties of speed, flexibility, security, size, and more.

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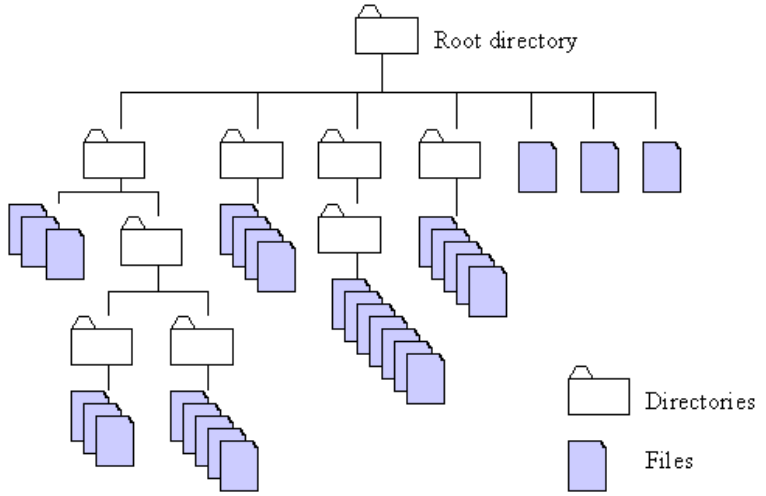
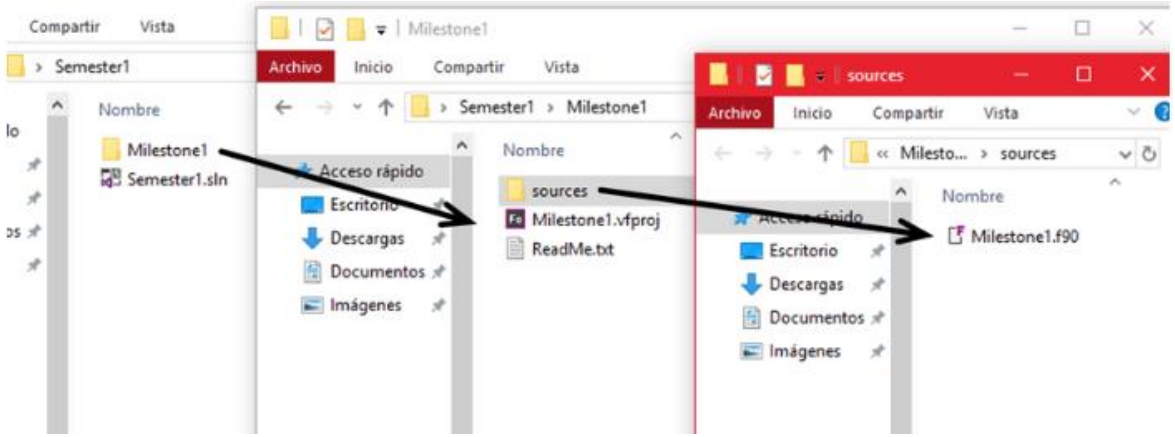
Introduction to File Systems Cont.

- Normally operating systems organise files and folders in a hierarchy.





Introduction to File Systems Cont.

- A **file** is a resource for recording data on a computer storage device, primarily identified by its filename. A file can be a written document, image, video, program, or any other kind of data designed for different purposes. Files can store multiple types of data at once. Users can open, read, edit, save, and close files using computer programs.
- A **directory / folder** is a file system cataloging structure that contains references to other computer files and directories. Files are organised by storing related files in the same directory. In a hierarchical structure, a directory inside another directory is called a **subdirectory**.
- The topmost directory in such a structure, which does not have a parent of its own, is called the **root directory**.

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Introduction to File Systems Cont.

- **File Meta Data**

File **metadata** is information that describes or relates to a file, such as its name, size, type, author, location, date created, date modified, last access date, last backup, access permission, etc.

File metadata can be embedded within the file itself, such as in a PDF or an image, or stored externally by the file system.

In Unix-like operating systems, a structure called **inode** can store metadata unrelated to the content of the file itself. The inode indexes information by number, which can be used to access the location of the file and then the file itself.

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Introduction to File Systems Cont.

- File Systems…
  - Provides I/O support for a variety of storage device types.
  - Provides interface to users to handle file activities and supports multiple users in a multiuser systems environment.
  - Minimises the chances of lost or destroyed data.
  - Recovers free space to reallocate new files after deleting existing files.
  - Assigns disk space to files using various disk scheduling algorithms.
  - Keeps track of all the data locations of a file.

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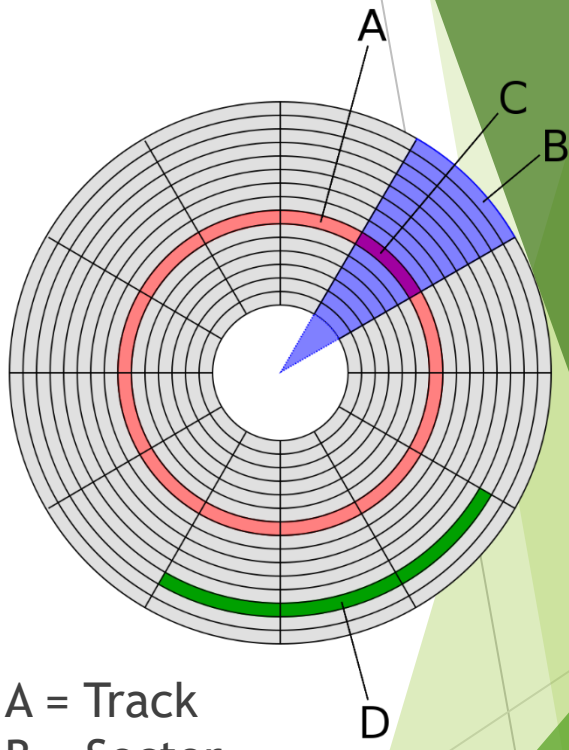
Storage Space Management

- The **surface area** of a storage disk, where it stores data, is divided up into circular tracks which are then pie-sliced into sectors. Each sector has the same size and has a unique address or disk block number.
- A **cluster** or **allocation unit** is a unit of file storage management on a hard drive in an operating system and can consist of one or more physical sectors. Clusters are a logical concept used by operating systems, not a physical characteristic of a hard drive. A cluster need not be physically contiguous on the disk, it may span more than one track.



A = Track
B = Sector
C = Sector of a Track
D = Cluster

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Storage Space Management Cont.

Block Allocation

- File systems keep track of blocks belonging to each file and blocks which are available for use.
- When a new file is created, the file system finds an available block and allocates it. (clusters are created in block allocation)
- When a file is deleted, the file system makes its blocks available for re-allocation.

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Storage Space Management Cont.

Block Allocation Cont.

- The goals of the block allocation system are…
  - Increasing speed of allocating and freeing blocks.
  - Minimising space overhead. The data structures used by the allocator should be small while leaving as much space as possible for data.
  - Minimising fragmentation.
  - Maximising contiguity. Data that is likely to be used at the same time should be physically contiguous, if possible, to improve performance.

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Storage Space Management Cont.

Disk Fragmentation

- Fragmentation is a natural occurrence happen because files are constantly being written, deleted, and resized.
- The saved modifications for a file are usually stored at a disk drive location that is different from that of the original file.
- Disk fragmentation occurs when a file is broken up into pieces to fit on the disk.
- When a file is spread out over several locations, it takes longer to read and write resulting in slow computer performance.

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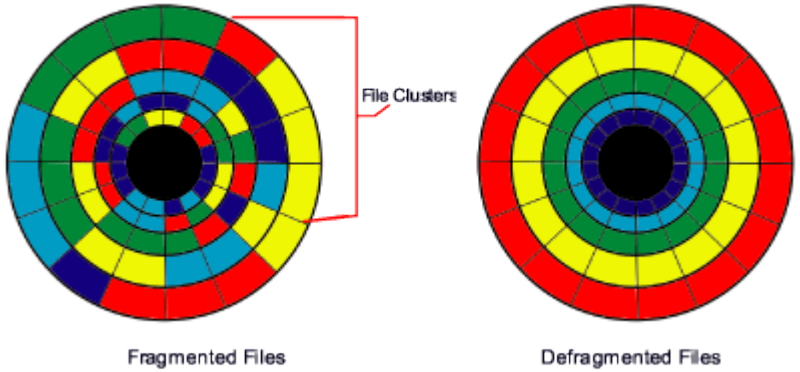
Storage Space Management Cont.

Disk Defragmentation



- The process of defragmentation moves the data blocks on the hard drive around to bring all the parts of a file together.
- Defragmentation reduces file system fragmentation, increasing the efficiency of data retrieval and thereby improving the overall performance of the computer.
- Also, it cleans the storage and provides additional storage capacity.
- Most modern operating systems have built-in disk defragmentation tools that perform the defragmentation process automatically.

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Storage Space Management Cont.

Disk Formatting

- Disk formatting is a process to configure the data-storage devices before initial usage.
- Disk formatting is usually required when a new operating system is going to be used by the user. It is also done when there is a space issue and requires additional space for the storage of more data in the drives.
- Disk formatting erases existing files within the disk.
- We can perform disk formatting on both magnetic platter-based hard drives and solid-state drives.
- Disk formatting involves **Low-Level Formatting**, **Partitioning**, and **High-Level Formatting**.

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Storage Space Management Cont.

Low-Level Formatting

- Low-level formatting is performed by the hard disk manufactures.
- Low level formatting is a type of physical formatting that involves making cylinders and tracks in the blank hard-disk. Then tracks are divided into sectors.
- It is impossible to recover data after low-level formatting.
- This formatting is not suggested to normal users. Because low-level formatting causes damage to hard disk which shortens its lifetime.

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Storage Space Management Cont.

Partitioning

- Partitioning is the process of dividing the hard disk into one or more regions. The regions are called partitions or volumes.
- It can be performed by the users, and it will affect the disk performance.
- A table called **partition table / partition map** (in DOS, Windows, and Mac OS) is maintained on a disk by the operating system that outlines and describes the partitions on that disk. This table is known as a **disk label** in Unix / Linux systems.

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Storage Space Management Cont.

High-Level Formatting

- High-Level formatting is done by the user.
- First it clears the data on hard disk, then generates boot information, then will setup a new file system to the partition.
- High-Level formatting does not harm the hard disk. It can be done easily with a Disk Management tool.
- This formatting can be used to fix some problems like errors in the file system, corrupted hard-drive and developing bad sectors.

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Storage Space Management Cont.

- First few blocks on the storage device always contain critical data about partitions.
- The system's firmware uses these data structures to boot up the operating system on a partition.
- A firmware is low-level software embedded into electronic devices to operate the device or bootstrap another program to do it. Firmware exists in computers, peripherals, or even electronic home appliances.
- Firmware provides a standard interface for complex software like an operating system to boot up and work with hardware components.

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Storage Space Management Cont.

- Firmware resides on non-volatile memory, like a flash ROM attached to the motherboard.
- Hardware manufacturers make firmware based on two specifications.
  - Basic Input / Output System (BIOS)
  - Unified Extensible Firmware Interface (UEFI)
- There are two main partitioning methods supported by those two firmware.
  - Master Boot Record (MBR) Partitioning
  - GUID Partition Table (GPT) Partitioning

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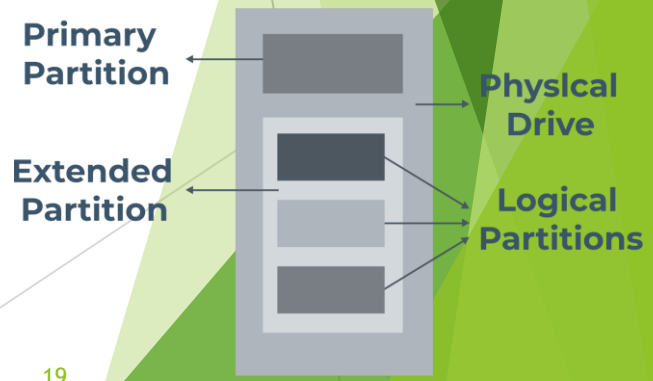
Storage Space Management Cont.

Master Boot Record (MBR) Partitioning - Supports BIOS-based firmware

- In this partitioning method, the first sector on the storage device contains essential data to boot up the system. It is called **MBR**.
- MBR contains the following information:
  - The boot loader, which is a simple program (in machine code) to initiate the first stage of the booting process
  - A partition table, which contains information about your partitions.
- MBR Supports 2 types of partitions.
  - Primary Partition – Bootable partitions which contain OS
  - Extended Partition – Not bootable



Storage Space Management Cont.

Master Boot Record (MBR) Partitioning - Supports BIOS-based firmware Cont.

- MBR is widely used and simple, but it has several limitations.
  - MBR's data structure limits the number of partitions to four (04).
  - Each partition can be a maximum of 2TB.
  - The content of the MBR sector has no backup. If MBR gets corrupted due to an unexpected reason, the hardware device becomes useless.

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Storage Space Management Cont.

GUID Partition Table (GPT) Partitioning - Supports UEFI-based firmware

- The GPT partitioning scheme is more advanced than MBR and doesn't have the limitations of MBR.
- GPT can have as many partitions as the operating system allows.
- Also, there is no limitation to the size of the partition.
- Although MBR is still widely supported, GPT is gradually replacing MBR.

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Common File Systems

FAT (File Allocation Table)

- First introduced in 1977 for hard drives.
- **FAT** file system family is supported by almost all operating systems for PCs, including all versions of Windows and MS-DOS/PC DOS, OS/2.
- So, the FAT file systems are well-suited as a universal exchange format between computers and devices of any type and age.
- Over the years, the file system has been expanded from FAT12 to FAT16 and FAT32.
- Various features have been added to the file system including subdirectories, codepage support, extended attributes, and long filenames.

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Common File Systems

FAT (File Allocation Table) Cont.

- The FAT12 and FAT16 file systems had a limit on the number of entries in the root directory of the file system and had restrictions on the maximum size of FAT-formatted disks or partitions.
- FAT32 addresses the limitations of FAT12 and FAT16, except for the file size limit of close to 4 GB, but it remains limited compared to NTFS.
- FAT12, FAT16, and FAT32 also have a limit of eight characters for the file name, and three characters for the extension (such as .exe). This is commonly referred to as the **8.3 filename limit**.
- VFAT, an optional extension to FAT12, FAT16, and FAT32, introduced in Windows 95 and Windows NT 3.5, allowed long file names to be stored in the FAT file system.

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Common File Systems Cont.

NTFS (New Technology File System)

- This is a journaling file system developed by Microsoft with the introduction of Windows NT 3.1.
- *A journaling file system is a file system that keeps track of changes not yet committed to the file system's main part by recording the goal of such changes in a data structure known as a "**journal**". In the event of a system crash or power failure, such file systems can be brought back online more quickly with a lower likelihood of becoming corrupted.*
- NTFS is the default file system of the Windows NT family. It uses MFT (Master File Table) instead of FAT Table. NTFS is the preferred file system on Windows and is supported in Unix / Linux as well.

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Common File Systems Cont.

NTFS (New Technology File System) Cont.

- Windows can convert FAT32/FAT16/FAT12 into NTFS without the need to rewrite all files.
- NTFS uses several files hidden from the user to store metadata, which can help improve speed and performance when reading data.
- NTFS supports…
  - Access Control Lists (ACLs)
  - File System Encryption
  - Transparent Compression
  - Sparse Files
  - File System Journaling

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Common File Systems Cont.

exFAT (Extensible File Allocation Table)

- Introduced by Microsoft in 2006 and optimised for flash memory such as USB flash drives and SD cards.
- exFAT can be used where NTFS is not a feasible solution, and when a greater file size than the standard FAT32 file system supports.
- Windows 8 and later versions natively support exFAT boot and support the installation of the system in a special way to run in the exFAT volume.

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Common File Systems Cont.

HPFS (High Performance File System)

- Developed by Microsoft in cooperation with IBM and came to the market with OS/2 1.20 in 1989.
- This was a file system for servers that could provide much better performance when compared to FAT.
- HPFS simply allocates any first free cluster on the disk for the file fragment and seeks to arrange files in contiguous blocks, or at least ensure that its fragments are placed maximally close to each other.
- HPFS had significant limitations and eventually became obsolete.
- The native support for it has been removed from Windows starting from NT 4.

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Common File Systems Cont.

ext2, ext3, ext4 (Extended File System)

- The "**ext**" file systems are Linux's primary file systems. This is usually the default option when installing Linux. ext2 is rather primitive and ext3 and ext4 are more advanced.
- ext4 supports volumes up to 1EB and Maximum file size is 16TB.
- ext4 is backwards compatible with ext2 and ext3.
- By default, Windows and Mac OS cannot read ext file systems. There are third-party tools to read ext file systems from Windows, but NTFS support in Linux is better than ext support in Windows.
- Red Hat recommends using XFS (not ext4) for volumes over 100TB.

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Common File Systems Cont.

HFS (Hierarchical File System)

- Developed by Apple for Mac OS X in 1985. It is also referred to as Mac OS Extended. HFS replaced the original MacOS file system.
- HFS+ has the following properties:
  - Maximum volume size is 8EB.
  - Files stored in HFS+ partitions can be as large as the partition.
  - Windows users can read HFS+ but not write.
  - Drivers are available that allow Linux users to read and write to HFS+ volumes.

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Common File Systems Cont.

XFS

- XFS is a high-performance open-source file system that was initially created by Silicon Graphics.
- In 2001, it was merged into the Linux kernel and is now supported by most Linux distributions and is even used as the default file system for some Linux distributions.
- XFS supports large files and large file systems.
- XFS deploys the journaling principle for any updates to its metadata. All changes are written to the Journal first before the actual blocks get modified, which enables its instant recovery in case of any corruption.

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Common File Systems Cont.

ReFS (Resilient File System)

- ReFS is Microsoft's newest file system (codenamed "Protogon"), designed to maximise data availability, scale efficiently to large datasets across diverse workloads, and provide data integrity by means of resiliency to corruption.
- Introduced in 2012 with Windows Server 2012. The technology now is included in Windows 8 & 10.
- ReFS is a fault-tolerant technology that came to replace NTFS. Was designed to eliminate the shortcomings of the predecessor and reduce the amount of information that may be lost during various operations. Supports working with large files.

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Common File Systems Cont.

APFS (Apple File System)

- This is a proprietary file system developed and deployed by Apple Inc. for the new versions of macOS, iOS, and their other OSs.
- It aims to fix the core problems of HFS+.
- APFS features strong encryption, space sharing, snapshots, fast directory sizing, and improved file system fundamentals.

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Common File Systems Cont.

UFS (Unix File System)

- The Unix file system is a hierarchical file system used by Unix-based operating systems to store and organise files and directories.
- It is a tree-like structure that starts with a single directory called the root directory, which is denoted by a forward slash (/) character.
- Unix file system also uses a set of permissions to control access to files and directories.
- Each file and directory have an owner and a group associated with it, and permissions can be set to allow or restrict access to these entities.

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Common File Systems Cont.

Operating System	File Systems Supported
DOS	FAT12, FAT16
Windows	FAT, NTFS, exFAT, ReFS, HPFS
Linux	ext2, ext3, ext4, XFS, Linux Swap(FAT16, FAT32, NTFS)
MacOS	HFS, HFS+, APFS, FAT, exFAT

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Q&A

- Time for your questions and queries ...

Additional Links

- https://www.ufsexplorer.com/articles/file-systems-basics/
- https://www.indeed.com/career-advice/career-development/common-file-systems

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Activity

- Find differences between BIOS and UEFI.
- Explore more about file systems that are not discussed in the lesson.

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Thank you!